Universidad de Oviedo

Departamento de Psicología

Universidad de Oviedo

TESIS DOCTORAL

Programa de Doctorado en Educación y Psicología

SIGNAL DETECTION THEORY ON ASSOCIATIVE LEARNING:

AN EXAMPLE FROM CONTRARY CUE INTERACTION PHENOMENA

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SIGNAL DETECTION THEORY ON ASSOCIATIVE LEARNING: AN EXAMPLE FROM CONTRARY CUE INTERACTION PHENOMENA

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RESUMEN DEL CONTENIDO DE TESIS DOCTORAL

1.- Título de la Tesis	
Español/Otro Idioma: La Teoría de Detección de Señales en el Aprendizaje Asociativo: un ejemplo desde fenómenos de interacción entre claves contrarios	Inglés: Signal Detection Theory on Associative Learning: an example from contrary cue interaction phenomena

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RESUMEN (en español)

La interacción entre claves es un conjunto de fenómenos en los que dos claves se entrenan juntas (AX) y el comportamiento a la clave objetivo (X) es modulado por la clave no objetivo (A). Estos fenómenos son de gran importancia para las actuales teorías del Aprendizaje Asociativo. La interacción puede ser positiva, si la respuesta a X está relacionada positivamente con A, o negativa, si la respuesta a X está relacionada negativamente con A. Ambas interacciones pueden surgir del mismo diseño, y la tesis se centra en dos de ellos: A+/AX+, que da lugar a aumentación o bloqueo, y A+/AX-, que da lugar a condicionamiento de segundo orden (CSO) o inhibición condicionada (IC). La TDS distingue entre lo que se percibe (sensibilidad) y la predisposición a responder de una cierta manera (criterio de respuesta). Esta distinción permitiría explicar estos fenómenos contrarios como cambios en el criterio de respuesta. Los presentes experimentos estudiaron cómo modificar parámetros que producen cambios en el criterio de respuesta modularon la interacción entre claves en los diseños anteriormente mencionados.

Los dos diseños solo se diferencian en la contingencia de reforzamiento de AX, que es equivalente a uno de los principales factores que afectan al criterio de respuesta, la matriz de pagos. Los Experimentos 1-3 estudian este factor. En el Experimento 1, se entrenaron cuatro grupos de ratas en un procedimiento de entrada al comedero con diferentes contingencias de reforzamiento de AX (1, 0.66, 0.33 y 0). Los resultados mostraron un incremento en la respuesta a X en las primeras sesiones que desapareció a medida que las sesiones avanzaron, estando la magnitud de respuesta directamente relacionada con la magnitud de la contingencia de reforzamiento. Este incremento inicial fue consistente con aumentación en el Grupo 1 y CSO en el Grupo 0, y la ausencia de respuesta al final, con bloqueo en el Grupo 1 e IC en el Grupo 0. El Experimento 2 replicó estos grupos, incluyendo pruebas de sumación y retraso al final del experimento, confirmando que solo el Grupo 0 desarrolló propiedades inhibitorias. Además, el Experimento 3 replicó el Grupo 1 con un control, confirmando la aparición de aumentación y bloqueo en distintos momentos del entrenamiento.

Los Experimentos 4-9 se centraron en el diseño A+/AX- y el efecto de variar las probabilidades de presentación de A y AX en la interacción entre claves. En el Experimento 4, las ratas fueron entrenadas con 14 ensayos A y 2 AX en cada sesión. Los sujetos mostraron un incremento consistente con CSO en las primeras sesiones, pero la IC se descartó en una prueba de retraso posterior. En el Experimento 5, se usaron 11 A y 5 AX en cada sesión, encontrando un incremento en las primeras sesiones del experimento que podría indicar CSO, y una tendencia a la IC en la prueba de retraso. En el Experimento 6, con 8 ensayos A y 8 AX, los sujetos mostraron CSO en la primera mitad del experimento, e IC en la prueba de retraso. En el Experimento 7, donde se usaron 5 ensayos A y 11 AX, no fue evidente un incremento en la respuesta, pero se confirmó IC en la prueba de retraso. En el Experimento 8, con 2 ensayos A y 14 AX, no se encontró ni CSO ni IC. Finalmente, el Experimento 9 comparó todos los grupos experimentales de los cinco experimentos previos, encontrado que la magnitud de respuesta en las primeras sesiones del condicionamiento y en la prueba de retraso estaba directamente relacionada con la proporción de ensayos A/AX.

Los resultados de los experimentos indican que tres variables modulan la interacción entre

claves: el número de sesiones, la contingencia de reforzamiento de AX, y la proporción de ensayos A/AX. Además, los resultados presentados suponen un desafío para la mayoría de modelos contemporáneos de Aprendizaje Asociativo, pero pueden entenderse desde la TDS como cambios tanto en la sensibilidad (número de sesiones) como en el criterio de respuesta (contingencia de reforzamiento de AX y proporción de ensayos).

RESUMEN (en Inglés)

Cue interactions are a set of phenomena in which two cues are trained together (AX) and the behaviour to the target cue (X) is modulated by the non-target cue (A). These phenomena are of central importance for current Associative Learning theories. The interaction can be positive, when responding to X is positively related to A, or negative, when responding to X is negatively related to A. Both interactions might arise from the same design, and the thesis focuses on two of these designs: A+/AX+, that leads to augmentation or blocking, and A+/AX-, that leads to second order conditioning (SOC) or conditioned inhibition (CI). SDT distinguishes between what is perceived (sensitivity) and the willingness to produce a certain response (response criterion). This distinction would allow to explain contrary cue interaction phenomena as changes in response criterion. The present experiments studied how modifying parameters that produce changes in response criterion modulated cue interaction in the aforementioned designs.
The two designs differ only on the contingency of reinforcement of AX, which is equivalent to one of the main factors that affect response criterion, the pay-off matrix. Experiments 1-3 focused in this factor. In Experiment 1, four groups of rats were trained in a magazine procedure with different contingencies of reinforcement for AX (1, 0.66, 0.33 and 0). The results of this experiment showed an increase in responding to X in the first sessions that disappeared as the sessions progressed, being the magnitude of this increase directly related to the magnitude of the contingency of reinforcement. This initial increase was consistent with augmentation in Group 1 and SOC in Group 0, and the absence of responding at the end, with blocking in Group 1 and CI in Group 0. Experiment 2 replicated Groups 1 and 0, including summation and retardation tests at the end of the experiment, confirming that inhibitory properties were only developed for Group 0. Furthermore, Experiment 3 replicated Group 1 with a control, confirming that augmentation and blocking appeared in different moments of the training.
Experiments 4-9 focused on the A+/AX- design and what effect varying the probabilities of presentation of A and AX trials had on cue interactions. In Experiment 4, rats were trained with 14 A and 2 AX trials per session. Subjects showed an increase consistent with SOC in the first sessions, but CI was discarded in a subsequent retardation test. In Experiment 5, 11 A and 5 AX per session were used, again finding an increase in the first sessions of the experiment that might indicate SOC, and a tendency towards CI in the retardation test. In Experiment 6, with 8 A and 8 AX trials, subjects showed SOC in the first half of the experiment, and then CI in the retardation test. In Experiment 7, where 5 A and 11 AX trials were used, no increase in responding was evident, but CI was confirmed in the retardation test. In Experiment 8, with 2 A and 14 AX trials, nor SOC neither CI were evident. Finally, Experiment 9 compared all the experimental groups from the previous five experiments, finding that the magnitude of responding both in the first sessions of the conditioning and in the retardation test was directly related to the proportion of A/AX trials.
The results of the experiments point to three variables that modulate cue interactions: the number of sessions, the contingency of reinforcement of AX, and the proportion of A/AX trials. Also, the results reported are challenging for most contemporary Associative Learning models, but can be understood within SDT as changes in both sensitivity (number of sessions) and response criterion (contingency of reinforcement of AX and proportion of A/AX trials).

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You know what a learning experience is?

A learning experience is one of those things that says,

"You know that thing you just did? Don't do that."

(Douglas Adams)

Agradecimientos

Gracias todos aquellos con los que he compartido laboratorio o seminarios, que me han guiado, discutido y acompañado: Nacho, Joaquín, Félix, Susi, Bea, Judit, Gonzalo, Jose(s) y Tichu.

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Resumen

La interacción entre claves es un conjunto de fenómenos en los que dos claves se entrenan juntas (AX) y el comportamiento a la clave objetivo (X) es modulado por la clave no objetivo (A). Estos fenómenos son de gran importancia para las actuales teorías del Aprendizaje Asociativo. La interacción puede ser positiva, si la respuesta a X está relacionada positivamente con A, o negativa, si la respuesta a X está relacionada negativamente con A. Ambas interacciones pueden surgir del mismo diseño, y la tesis se centra en dos de ellos: A+/AX+, que da lugar a aumentación o bloqueo, y A+/AX-, que da lugar a condicionamiento de segundo orden (CSO) o inhibición condicionada (IC). La TDS distingue entre lo que se percibe (sensibilidad) y la predisposición a responder de una cierta manera (criterio de respuesta). Esta distinción permitiría explicar estos fenómenos contrarios como cambios en el criterio de respuesta. Los presentes experimentos estudiaron cómo modificar parámetros que producen cambios en el criterio de respuesta modularon la interacción entre claves en los diseños anteriormente mencionados.

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Abstract

Cue interactions are a set of phenomena in which two cues are trained together (AX) and the behaviour to the target cue (X) is modulated by the non-target cue (A). These phenomena are of central importance for current Associative Learning theories. The interaction can be positive, when responding to X is positively related to A, or negative, when responding to X is negatively related to A. Both interactions might arise from the same design, and the thesis focuses on two of these designs: A+/AX+, that leads to augmentation or blocking, and A+/AX-, that leads to second order conditioning (SOC) or conditioned inhibition (CI). SDT distinguishes between what is perceived (sensitivity) and the willingness to produce a certain response (response criterion). This distinction would allow to explain contrary cue interaction phenomena as changes in response criterion. The present experiments studied how modifying parameters that produce changes in response criterion modulated cue interaction in the aforementioned designs.

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The results of the experiments point to three variables that modulate cue interactions: the number of sessions, the contingency of reinforcement of AX, and the proportion of A/AX trials. Also, the results reported are challenging for most contemporary Associative Learning models, but can be understood within SDT as changes in both sensitivity (number of sessions) and response criterion (contingency of reinforcement of AX and proportion of A/AX trials).

CHAPTER 1: Introduction

One central way to acquire knowledge is by establishing cause-effect relationships between events in the world. In fact, for the survival of the organisms, it is of great importance to be able to detect which events predict other significant events of life, such as food, water or dangers. This knowledge can be acquired by means of Associative Learning. One of the most important forms of Associative Learning is Pavlovian Conditioning, a phenomenon in which the repeated conjoint presentation of two stimuli leads to one of them, the conditioned stimulus or CS, to produce the same response, conditioned response or CR, that, initially, was only produced by the other stimulus, the unconditioned stimulus or US (Mackintosh, 1983).

Current theories of Associative Learning propose that this knowledge is acquired by the formation of associations between representations of the events of the world. This view comes from a long tradition of experimental psychology of learning, focused in describing how organisms copy what is presented in the world. This associacionist perspective has its roots in empiricism, and has dominated the experimental psychology for more than a century, from the formulation of Thorndike's effect law (1898). This idea was reinforced by the discovery of conditioned reflexes by Pavlov (1927/1960) and Twitmyer (1905) and since the 30's of the 20th century, the theory of learning focused on describing how organisms copy what is presented in the environment (Hull, 1943, is a good example of this). It is worth noting that Hume (1748/1956) took to the extreme the idea that the organism was a tabula rasa and all knowledge came from experience, concluding that causal relationships between events cannot be acquired by mere experience, but only the habit that one event has always preceded other event in the past, but there is no guarantee that it will continue to happen in that way in the future.

Introduction

Kant (1787/1929) proposed a new approach, the Copernican swift. This approach rejected the empiricist view in which knowledge copies to the objects in the world, given that objects are not present in the word for the subject to copy them but they are achievements of the subject. For this reason, association cannot be a justification of knowledge. However, it can be a particular case of the subject's activity, for example, the result of a decision making process. So, two events are not associated only by being co-presented, the subject adds something: the decision about the adequacy of associating or not in particular circumstances. This thesis takes into account Kant's approach, as the main interest is to understand under which conditions the subject decide the way cues interact. For this reason, the thesis aims to evaluate if classical conditioning can be understood as a decision making process, considering that responses are decisions made by a subject that perceives complex relationship between stimuli. To fulfil this aim, the research is focused on some of the most important phenomena for the development of Associative Learning theories since the 70's of the 20th century: cue interaction phenomena. This would be addressed in relation with Signal Detection Theory (SDT), a decision theory from the field of psychophysics that distinguishes between what is perceived and the willingness to produce a certain response to that perception.

CUE INTERACTIONS

Cue interactions can be defined as a set of phenomena in which, when two CSs are trained together (AX), the behaviour that is developed in the presence of the target stimulus X is modulated by the non-target stimulus A. Most of the modern Associative Learning theories and research have focused in one particular form of cue interaction, negative mediation. Negative mediation between stimulus occurs when the response to the target cue X is inversely related to the response to target A, that is, if responding to A is high, responding to X will be low, and vice versa.

Some of the most relevant negative mediation phenomena were already described by Pavlov (1927/1960). One of them is overshadowing, in which less responding is observed to the target stimulus X if it was accompanied by another (usually more salient) stimulus A when paired with reinforcement (AX+) than when it was reinforced alone (X+). The other is Conditioned Inhibition (CI), in which X gains inhibitory properties after a training in which the non-target stimulus A is reinforced when presented alone, but non-reinforced when presented with X (A+/AX-). However, the interest in negative mediation phenomena increased drastically in the 70’s, with findings the discover of effects such as blocking (Kamin, 1968), overexpectation (Rescorla, 1970), relative validity (Wagner et al., 1968) and degraded contingency (Rescorla, 1968). Blocking is the decreased responding to X when X is reinforced in the presence of A, a stimulus that was previously reinforced alone (A+ then AX+). Overexpectation is defined as the decreased responding to X that occurs when, in the first phase, X and A are separately reinforced (X+/A+), and in the second phase, X and A are presented together followed by the same reinforcement that received when presented alone (AX+). Similarly, relative validity happens when X is reinforced if presented in the presence of a stimulus A, but not in the presence of a stimulus B

(AX+/BX-). This treatment leads to a lower responding to X when compared with a control condition in which both AX and BX compound are reinforced in the 50% of the presentations. Finally, the degraded contingency effect occurs when responding to X is lowered by introducing presentations of the reinforcer in the absence of X. This latter phenomenon can be understood as negative mediation by the context.

All these findings lead to the formulation of the most influential model in Associative Learning, the Rescorla & Wagner model (1972). This model and posterior developments based on it (Dickinson & Burke, 1996; Mackintosh, 1975a; Pearce, 1987, 1994; Pearce & Hall, 1980; Van Hamme & Wasserman, 1994; Wagner, 1981), as well other statistical models (e.g. Allan, 1980; Cheng, 1997) and the comparator hypothesis (Miller & Matzel, 1988; Denniston et al., 2001) have focused on explaining negative mediation phenomena. Also, this form of cue interaction has received a great deal of investigation, being found across many different preparations such as autoshaping (e.g., Holland et al., 2014; Khallad & Moore, 1996; Leyland & Mackintosh, 1978; Williams, 1984), magazine training (e.g., Bellingham & Gilette, 1981; Lattal & Nakajima, 1998; Murphy et al., 2001; Rescorla, 1999), conditioned suppression (e.g., Carr, 1974, Kamin, 1969; Rescorla, 1970; Wagner et al., 1968, Experiment II), taste-aversion (e.g., Gillan & Domjan, 1977; Lindsey & Best, 1973; Luongo, 1976), spatial learning (e.g., Kosaki et al., 2013; Rodrigo et al., 1997; Spetch, 1995) and human contingency judgments (e.g., Baker et al., 1993; Chapman & Robbins, 1990; Collins & Shanks, 2006; Dickinson et al., 1984; Matute et al, 1996) and across very different species such as snails (Acebes et al., 2012, 2009; Loy et al., 2006; Prados et al., 2013a), planarians (Prados et al., 2013b); honeybees (e.g., Couvillon & Bitterman, 1989; Couvillon et al. 1997; Smith & Cobey, 1994), slugs (Sahley et al., 1981), crickets (Terao & Mizunami, 2017; Terao et al., 2015), fish (Tennant & Bitterman, 1975), toads (e.g. Daneri &

Muzio, 2013; Daneri & Muzio, 2015), pigeons (e.g., Khallad & Moore, 1996; Miles & Jenkins, 1973; vom Saal & Jenkins, 1970; Williams, 1984), rabbits (e.g., Merchant & Moore, 1973; Mis et al., 1972; Kehoe, 1982; Kehoe & White, 2004; Wagner et al., 1968, Experiment III), rats (e.g., Kamin, 1968) and humans (e.g., Chapman & Robbins, 1990; Kimmel & Bevill, 1991; Martin & Levey, 1991).

Despite the theoretical importance and the vast amount of research that negative mediation has received, recent studies have doubted that these phenomena are as widespread as it was believed to be. Take as an example the study by Maes et al. (2016; see also Maes et al., 2018), in which they report 15 failures to find blocking, even when employing procedures that successfully found blocking in the previous literature, thus suggesting that one of the central phenomena in the developing of associative theory is not as robust as literature suggest, and that parameters under which blocking occurs are still not clear.

Furthermore, there are some phenomena in which cue interaction takes the form of positive mediation. Positive mediation phenomena are those in which the response to the target cue X is directly related to the response to target A, that is, if responding to A is high, responding to X will be high, and vice versa. Some examples of these phenomena are potentiation (Rusiniak et al., 1979), augmentation (Batson & Batsell, 2000) and second order conditioning (SOC; Pavlov, 1927/1960). In potentiation, when a weak cue X is trained in compound with a strong cue A, high responding to X is observed. Similarly, augmentation is observed when a stimulus X is reinforced in compound with a stimulus A, that has already been paired with the US. SOC is the finding that responding to X increases after being paired without reinforcement with a stimulus A that has been reinforced. It should be noted that the procedures that lead to positive mediation phenomena are highly similar, if not identical, to procedures that lead to negative mediation (Table 1). Specifically, potentiation and overshadowing are both found in an AX+ design, augmentation and blocking in an A+/AX+ design, and SOC and CI are found in an A+/AX- design. This represents a significant challenge to most Associative Learning theories because, as they were developed to account for negative mediation phenomena, they cannot account for positive mediation phenomena. An exception to this would be those theories that distinguish between acquisition and performance, such as Stout and Miller (2007) and Pineño (2007), that were developed in the light of the possibility of this dual outcome of the procedures.

Table 1

Procedures that lead to positive and negative mediation

Training	Result	Phenomenon
AX+	X↑	Potentiation
	X↓	Overshadowing
A+/AX+	X↑	Augmentation
	X↓	Blocking
A+/AX-	X↑	Second Order Conditioning
	X↓	Conditioned Inhibition

Note. X↑ represents an increased responding to X in comparison with an appropriate control, whereas X↓ represents a decreased responding to X in comparison with an appropriate control.

Modulatory variables of cue interactions

Given that the same experimental designs can lead to radically opposite results, it is of great importance to elucidate which variables determine the form that cue interactions will take. Urcelay (2017) proposed that cue interactions can be seen as a continuum from positive to no interaction to negative mediation. This author reviewed some of the variables that determine cue interactions, primarily focusing on studies of potentiation and overshadowing. He concluded that three variables are of great importance: relative stimulus duration, contingency and contiguity. A relatively short duration of the stimuli with respect to the intertrial interval (ITI) lead to overshadowing, whereas relatively long stimuli lead to potentiation. Degrading the contingency (both by presenting the stimuli or the reinforcer alone) in different moments of training lead to an attenuation of overshadowing, that might reverse into potentiation. Finally, the time between the offset of the stimuli and the onset of the US modulates cue interaction in such a way that when there is not a gap between them overshadowing is evident, with intermediate traces no interaction occurs, and with long traces potentiation is developed. The effect of the time between the offset of the stimuli and the onset of the US was assessed by Kehoe et al. (1981) in an A+/AX- design using as a US a shock that produced the closure of the rabbits nictitating response, which was measured as the CR. In Experiment 3B of this study, they trained the subjects with different interval between A and the US. Specifically, 0.1 s, 0.14 s, 0.16 s, 0.32 s and 0.4 s intervals were used. No SOC was found in the 0.1 s interval, but all other interval successfully led to similar levels of SOC.

Also, the contiguity between the stimuli in the compound was already pointed out by Pavlov (1927/1960) as a determinant of the occurrence of SOC or CI. According to Pavlov, the overlapping of the stimuli led to CI, but if the target stimulus X was presented before the stimulus A, with no trace between them, CI was not observed. Also, when the gap between X and A was increased, SOC was found. In fact, Pavlov claimed that, in order to achieve SOC, with increasing intensity of X, the interval between stimuli should be increased. However, later studies found SOC when X and A overlapped (e.g. Maisiak & Frey, 1977; Rescorla, 1982). In Experiment 2 of the already reported study by Kehoe et al. (1981) with the rabbits' nictitating membrane response, the authors found that there was an inverse relationship between the interval between X and A and the magnitude of CR observed to X. Specifically, with an interstimuli interval (ISI) of 0.4 s the higher level of CR was obtained, it declined to an intermediate level at the 0.8 s ISI and a low level was found with a 2.4 s ISI. It is worth noting that, despite different levels of CR depending on the X-A interval, SOC was found in the three conditions when compared with the control condition. Gibbs et al. (1991) found similar results using the same procedure and ISIs of 0.4 s, 1.4 s, 2.4 s, 4.4 s and 8.4 s. Again, in all conditions SOC was found, but the level of responding was a negatively decelerated function to the duration of the ISI, in such a way that a great decrement in the magnitude of the CR was found when the ISI was increased from 0.4 s to 1.4 s, a smaller decrement was found when the ISI was increased to 2.4 s, but no difference in the magnitude of responding was found between 2.4 s, 4.4 s and 8.4 s ISIs.

Concerning studies on augmentation, the effect of this variable has also been examined. Batsell & Batson (1999), in Experiment 1, paired an odour with illness induced by an intraperitoneal injection of LiCl (A+) in a first phase, and then presented either a compound solution of a taste and the odour that was paired 5 min after with LiCl (XA→+) or presented first the taste and 5 minutes later the odour immediately followed by LiCl (X→A+). The results of this experiment showed that responding to the taste (X) was augmented when the compound conditioning was performed simultaneously with the odour (XA→+), but it was not when it was performed sequentially (X→A+). However, in this latter case, blocking was not observed. Experiment 3 by Batsell et al. (2001) found similar results, but in this case the stimulus conditioned in Phase 1 was the taste and the target stimulus trained with it in Phase 2 was the odour. Again, simultaneous, but not sequential, presentations lead to augmentation of the responding to the odour, and sequential presentations did not lead to the development of blocking. Further, they found parallel results in the absence of Phase 1 taste conditioning, founding potentiation with simultaneous but no sequential AX+ pairings. It is worth noting that in the Experiment 5 of this study, this same procedure, but with unreinforced simultaneous AX presentations in Phase 2, did not lead to the development of SOC, but CI cannot be confirmed as inhibitory test were not performed.

In these experiments, the effects of spatial and temporal contiguity were confounded, as in simultaneous presentations the odour and the taste were presented in the same bottle, whereas in sequential presentations they were presented in different bottles. In Experiment 1 by Jensen et al. (2018), one group received the odour and the taste mixed in the same bottle, other group received both stimuli at the same time, but in different bottles, and a third group received the odour 4 minutes after the taste was removed. Augmentation was found both when the stimuli were presented in the same bottle and when they were presented in separate bottles, but just when they were presented at the same time. Further, in Experiments 2-4, they showed that some degree of temporal overlap was necessary to produce augmentation, but augmentation was still evident when there was partial overlap of 2 min of the 4 min of stimulus exposure. However, the results by Dickinson et al. (1983) suggest otherwise. In Experiment 1, using a conditioned lick suppression procedure, a light was paired with a shock in Phase 1 (A+), and then, in Phase 2, groups received one trial training in which either the light was presented simultaneously with a click and the compound was immediately followed by a shock (AX→+) or the light was presented after the termination of the click and the shock was presented after the termination of the light (X→A→+). Both conditions lead to augmentation of responding to click, contrary to previous results found in aversion learning. In Experiment 2, when a trace interval of 7.5 s was inserted between the offset of the click and the onset of the light, augmentation was abolished, although blocking was not observed.

Taken together, the results from these studies did not unequivocally confirm an effect of the contiguity of the stimuli. Both SOC and augmentation have been found with simultaneous and sequential AX presentations. Further, none of these studies found neither CI nor blocking when a delay between X and A was included. In fact, it is worth noting that blocking has been found using simultaneous AX parings (e.g., Mackintosh et al., 1980; Pierce & Heth, 2010).

Other variable that might modulate the transition from positive to negative mediation is the number of trials. Good et al. (2015) studied the effect of this variable on augmentation in a taste aversion procedure, in which illness was induced by rotation. In the first experiment, they presented either 1, 2 or 4 A+ trials in Phase 1, and 1 AX+ trial in Phase 2. The results of this experiment indicated that augmentation was developed with 2 and 4 A+ trials, but not with 1 A+ trial. Although aversion was higher with 4 than with 2 A+ trials, no significant differences between them were found. In the second experiment, they used 2 A+ trials in Phase 1, and 1 or 3 AX+ trials in Phase 2. There was strong aversion to X in both conditions, and aversion was stronger with 3 AX+ trials than with 1. It should be noted that, Azorlosa and Cicala (1986) used a conditioned lick suppression procedure, and a two phase blocking design, in which in a first phase a noise was paired with shock (A+), and in the second phase, simultaneous presentations of the noise and a light paired with the shock (AX+). In Experiment 1, 10 AX+ trials were used, and in Experiment 2, 1 AX+ trial was employed. Both experiments successfully found blocking. However, no direct comparison of the number of AX+ trials was performed. In a subsequent study (Azorlosa & Cicala, 1988) they compared the blocking effect with 1, 10 or 30 AX+ trials. In Experiment 1, they found that blocking was stronger in the group trained with 1 AX+ trials than in the groups that were trained with 10 or 30 AX+ trials, that did not differ between them. It is worth noting that other studies have failed to achieve blocking with 1 AX+ training trial. One such example is the study by Mackintosh (1975b), that also used a conditioned lick suppression paradigm and trained subjects with 8 A+ trials in a first phase and either 8 or 1 AX+ trials in the second phase. In Experiment 1, in which both Phase 1 and Phase 2 training was performed in one session each, blocking was found with 8 but not with 1 AX+ trials. In Experiment 2, Phase 1 training proceeded in two sessions of 4 A+ trials each, and, in Phase 2, groups received either two sessions of 4 AX+ trials, eight sessions of 1 AX+ trial, or one session of 1 AX+ trial. Only the groups that were trained with two sessions of 4 AX+ trials showed blocking. The absence of blocking in the group that received eight sessions of 1 AX+ trial was probably due to the change in the massing of trials from Phase 1 to Phase 2, as in Experiment 3, with Phase 1 consisting in eight sessions of 1 A+ trial, blocking was found with 8 sessions of AX+ trials, but not with 1 session of 1 trial.

The effect of this variable has also been studied in SOC and CI. Herendeen and Anderson (1968), using a Sidman avoidance task, trained two groups of subjects with a different amount of AX pairings across ten sessions: one group received 10 A+ presentations per session and 20 AX- presentations per session, the other also received 10 A+ presentations, 18 A- presentations and 2 AX- presentations per session. Results indicated that when subjects were trained with 2 AX-, SOC was evident, but not when 20 AX- presentations were included. In the already reported Experiment 2 of the study by Kehoe et al. (1981), responding to the second order stimulus X across sessions followed an inverted U shape, increasing in the first sessions and decreasing in the latter, which was confirmed by a significant quadratic trend. This was explicitly assessed in the Experiment 2 of the already reported study of Gibbs et al. (1991) with the rabbits' nictitating membrane response. All groups received 30 A+ trials per session, and differed in the number of AX- trials per session: 5, 15, 25, and 50 trials. Results indicated that all groups developed SOC, and the magnitude of responding followed an inverted U shape function of the number of trials, with responding being higher in groups that received 15 and 25 AX- trials, intermediate with 5 AX- trials, and lower with 50 AX- trials.

None of these studies assessed if CI was developed, given that the inhibitory properties of stimulus X were not tested. Rescorla (1972), using a conditioning bar press suppression procedure, on a first phase trained subjects during two sessions in which rats were presented with 4 trials of a light paired with a shock (A+) per session, and during the fifteen sessions of the second phase, subjects were trained with 1 A+ trial, and 3 trials of a tone paired with the light (AX-). A summation test was performed at the end of training, in which the light alone and the tone-light compound were presented. In the first trials, SOC was evident, but as trials progressed, suppression was attenuated. In the summation test, significant attenuation of suppression in the tone-light compound was found when compared with responding to light alone, which was interpreted as evidence of CI. Similarly, Holland and Rescorla (1975), in Experiment 3, using a magazine training procedure, trained in a first phase 8 trials of a light paired with the delivery of 2 food pellets (A+) per session. This phase continued for twelve and a half sessions. In the second phase, that lasted thirty-seven and a half sessions, subjects received 6 presentations of a click followed by the light (AX+) and 2 A+ trial refreshers per session. After this training, a summation test in which 4 AX- trials and 4 A- trials per session, during three sessions. Responding to X first increased, thus showing SOC, and decreasing gradually after session three. It is worth noting that SOC was evident throughout training as responding was higher than in an unpaired control group. On the summation test, there was a significant reduction of responding to AX when compared to A, thus indicating CI.

Other studies have investigated the effect of number of trials in interaction with other variables. Yin et al. (1994), using a conditioned lick suppression procedure and auditory stimuli, trained subjects in an A+/AX- design. For some groups, all A+ trials were presented in four sessions before other four sessions of AX- training. For other groups, all trials were intermixed in one phase consisting in eight sessions. In the phasic condition, all groups received 24 A+ trials per session in Phase 1, and in the intermixed condition, 12 A+ trials per session were presented. These groups differed in the number of AX- trials employed. In the phasic condition, subjects received either 1 or 12 AX- trials per session. In the intermixed condition, subjects received either 0.5 or 6 AX- trials per session (0.5 indicates that AX- trials were presented every other session). Thus, all subjects received a total of 96 A+ presentations, subjects that received few AX- trials received a total of 4 presentations, and subjects that received many AX- trials received a total of 48 presentations. In Experiment 1, SOC was found when few AX- trials were used, no matter if training proceeded in two phases or in one phase. In Experiment 2, a summation test with an independently trained transfer excitor was performed and found that CI was developed only many AX- trials and when A+/AX- training was intermixed. These results were further confirmed in Experiment 3 with a retardation test. With many AX- trials and two phase training, a non-significant tendency towards CI was observed. Stout et al. (2004) with the same procedure, trained subjects with A+ and AX- trials intermixed in one phase, consisting of eight sessions, in which 6 A+ trials were presented per session. For some groups, the AX- compound was presented simultaneously, with complete overlap of the stimuli, and for other groups, the AX- compound was presented serially, with A presented immediately following the offset of X. AX- trial number was manipulated, in such a way that some subjects received few trials, i.e., 0.5 presentations per session (0.5 indicates that AX- trials were presented every other session), others received an intermediate number, i.e., 2.5 presentations per session (2.5 indicates that 3 AX- trials were presented in half of the sessions and 2 AX- trials in the other half), and the rest received many AX- trials, i.e., 12.5 presentations per session (12.5 indicates that 13 AX- trials were presented in half of the sessions and 12 AX- trials in the other half). So, all subjects received a total of 48 A+ trials, those in the few condition received a total of 4 AX- trials, those in the intermediate condition received a total of 20 AX- trials, and those in the many condition received a total of 100 AX- trials. In Experiment 1, a summation test with an independently trained transfer excitor and an excitation test were performed after this training. The summation test revealed that subjects that were trained with few AX- trials did not showed CI, no matter if the trials were presented serially or simultaneously, the subject that were trained with an intermediate number of AX- trials showed CI only when the compound was presented simultaneously, and those that were trained with both serial and simultaneous many AX- trials showed CI. In the excitation test, results on SOC were symmetrical to those found on the summation test, in such a way that the subjects that received few trials showed SOC, as subjects that received an intermediate number of AX- with a serial arrangement, and subjects that received an intermediate number of AX- trials in a simultaneous arrangement and all subjects that received many AX- trials did not show SOC. These results were further confirmed in the Experiment 2 with a retardation test, that again showed that CI was only developed with an intermediate number of AX- trials if they were simultaneously presented, and with many AX- trials. It is worth noting that, in these studies, the ITI was different for the different AX- trial number condition, which can constitute a confounding variable, especially taking into account that the relative stimulus duration to the ITI was one of the variables that Urcelay (2017) pointed out as a determinant of cue interactions.

Also, it should be mentioned that the number of trials has been varied differently in the studies reported here. Most of the studies have varied the number of AX trials per session (Azorlosa & Cicala, 1986, 1988; Gibbs et al., 1991; Good et al., 2015; Herendeen & Anderson, 1968; Stout et al., 2004; Yin et al., 1994; Good et al., 2015, also varied the number of A+ presentations). On one hand, the studies with the A+/AX+ design did not reach clear results as, to date, augmentation and blocking have not been found within the same study. The only study that assessed the number of trials in augmentation (Good et al., 2015) found that more AX+ trials produced a stronger augmentation, however results on blocking are conflicting. Azorlosa and Cicala (1988) found stronger blocking with 1 AX+ training than with 10 or 30 trials, whereas Mackintosh (1975b) found no blocking with 1 trial. On the other hand, studies on the A+/AX- design have consistently found that SOC appears after few AX- training trials, and CI after many AX- trials. The trial number has also been studied taking into account the number of training sessions (Kehoe et al., 1981; Rescorla, 1972; Holland & Rescorla, 1975), finding that SOC is stronger in the first sessions of training, and that CI was evident at the end of training. Nevertheless, this has not been studied with the A+/AX+ design.

It is important to consider results from human contingency judgments tasks. Evidence that suggest that positive mediation emerges with little time to think is reviewed hereafter. In Experiment 1, Karazinov and Boakes (2007) trained subjects with an A+/AX- design, using an allergy task in which participants had to predict in each trial how likely was that foods were producing migraine in a patient. All participants experienced all 8 A+ trials prior to 4 AX+ trials, however, a group of participants had 3 s to respond in each trial, and another group had no time restriction. In a test with no time restriction, participants that had 3 s to respond in training showed SOC, but participants with no time restriction in training did not. However, in a summation test with an independently trained transfer excitor, neither group showed CI. In Experiment 2, 8 A+ and 8 AX- trials were presented intermixed in training, finding again SOC in the group that was trained with 3 s to respond, and finding a tendency towards CI in the summation test, although statistically non-significant. Lee and Livesey (2012) extended the previous results in an experiment with a similar task in which the participants had to predict what symptom, if any, a drug would produce. Again, two groups of participants were used. In one group, participants were instructed to be as accurate as possible, and received a buzzer and the word ‘INCORRECT’ in capital letters in the screen if they predicted wrong, and the word ‘correct’ in a smaller font if they predicted right. The other group were instructed to be as fast as possible and had a time restriction to respond of 1.5 s. If this time limit was exceeded, a buzzer and the word ‘FASTER’ appeared in the screen. No specific feedback of right or wrong responses was given to this group, although for both groups, after responding, the correct outcome was displayed in the screen. A+ and AX- trials were both presented 16 times intermixed in one phase. In the rating test, in which participant were asked to rate the likelihood of a symptom in the presence of different drugs, the group instructed to be fast showed SOC and the group instructed to be accurate showed CI. In a subsequent test that proceeded like the one before, but after participants were shown that A lead to a particular symptom and AX lead to none, both groups showed CI. Similar manipulations also affected subjects' performance in an A+/AX+ design. Vadillo and Matute (2010) used a web-based task in which participants had to rescue war refugees by placing them in a truck. The road that the truck had to travel could be mined or not, and colour lights in a spy radio acted as cues that predicted if the road had mines. So, CR of the participants to a cue was measured as the number of refugees placed in a truck in a given trial, a response that participants can only emit when the colour lights were present. In the first phase, participants were exposed to 16 A+ trials, and in the second phase, participants were exposed to 4 AX+ trials. The time to respond was 3 s for a group of participants, and 6 s for the other group. In test, participants that had 3 s time restriction showed augmentation, whereas participants that had 6 s did not show neither augmentation nor blocking. The finding of augmentation in the 3 s condition was replicated in a subsequent study in which the task was delivered either on-site or through the web (Vadillo & Matute, 2011).

Other variables in human studies have influence in these phenomena. Mitchell et al. (2005b) used an allergist task, in which cue compounds were formed of foods that are usually presented together (e.g., fish and chips), that could produce different fictitious allergic reactions. 24 A+ and 8 AX+ trials were presented intermixed in one phase. In test, participants were asked both what allergy followed each food and to which degree they thought that food caused the allergic reaction. Participants showed augmentation in the recalling of which allergy followed which food, whereas blocking was developed when asked to rate how likely food caused the allergy. Similar results were found by Mitchell et al. (2007) with an A+/AX- design, again using an allergist task in which A were different foods and X different herbal remedies. In Experiment 1, 16 A+ trials were trained in the first phase, and then other 24 A+ and 48 AX- trials were trained in the second phase. In a subsequent summation test, in which participants were asked which compound of cues were most likely to produce a specific allergy, CI was evident. However, when participants were asked to categorise individual stimuli (foods, herbal remedies and allergies) in two groups, they were more accurate when X and + belonged to the same group than when they belonged to different groups. In Experiment 2, the same training was employed, but three groups were included to test the role of the order A+ and AX- presentations. One group had an order of presentation identical to Experiment 1, in other, all A+ trials were presented before AX- trials, and in the remaining group, all AX- trials were presented before A+ trials. In summation test, the group with intermixed and forward A+/AX- presentations showed CI, whereas the group with backward presentations did not show any effect. On the categorization test, only the group that received intermixed presentations showed a higher accuracy when X and + belonged to the same group.

Finally, Beesley and Shanks (2012) examined learning in an A+/AX+ design using an implicit learning task with humans, in which the contingencies are masked with a cover task and not explicitly asked about. The task chosen was a contextual cuing task, in which a visual search task of a target stimulus in a matrix of distractors is performed. Some configurations of target and distractors are repeated, so participants learn that a configuration of distractors signals a target location, performing faster when these configurations are present. However, this learning is not strictly necessary to complete the task. In Experiment 1, participants were trained in four sessions in which 64 A+ and 64 AX+ trials were presented per session. No blocking was found in this experiment. Experiment 2 replicated the first experiment with two modifications: in A+ trials, random distractors were included in order to equate the number of distractors in all trials, and in the first two sessions of the experiment, 192 A+ trials were presented per session, whereas in the final two sessions, 16 A+ trials per session were presented at the start of the session before the 64 AX- trials per session. In this experiment, no blocking, but augmentation was found.

Taken together, all these results suggest that both positive and negative mediation are possible in cue interactions. Most of the variables reviewed here lead to conflicting results. Regarding stimulus contiguity, both SOC and augmentation are possible under both simultaneous and sequential presentations. Furthermore, the study by Stout et al. (2004) showed that this variable interacts with the number of AX trials in the A+/AX- design. The number of AX- trials is other of the most important variables that has been demonstrated to have an important effect in the appearance of SOC or CI. However, the studies that evaluated the number of AX+ trials in the A+/AX+ design lead to conflicting results. The number of sessions is another important variable in determining SOC or CI, but its effect has not been examined in the A+/AX+ design. The main findings in studies with human subjects suggest that time pressure favours positive mediation, and that causal questions showed results consistent with negative mediation, but subjects showed positive mediation when the frequency of the Cs and the US was assessed. In order to account for Associative Learning, further research in the conditions under which form of interaction would be observed is needed, and models that aim to account for Associative Learning need to be able to incorporate all the variety of modulatory variables that influence it.

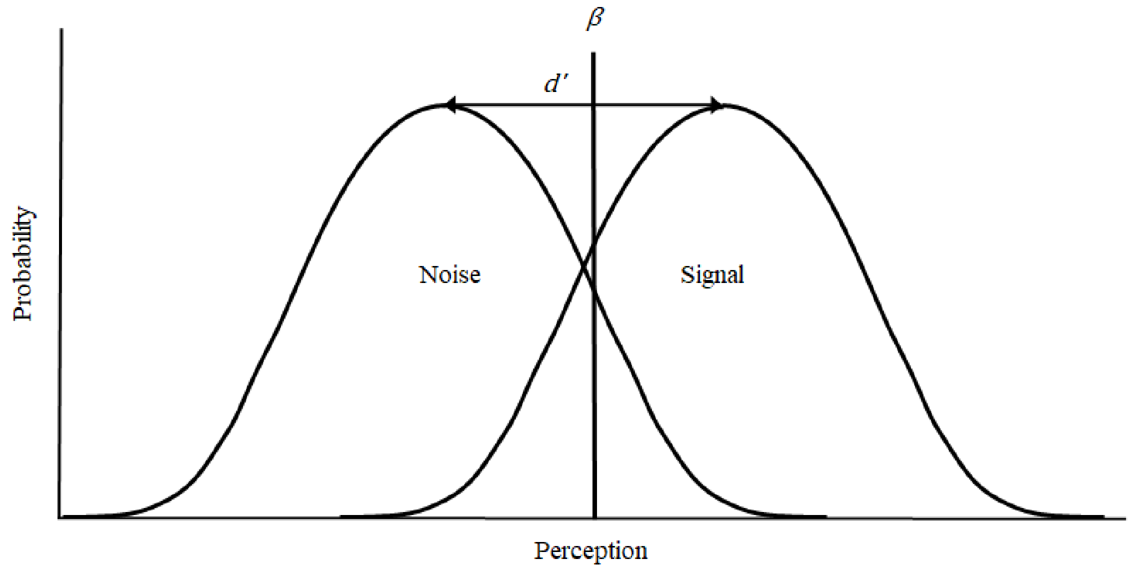
SIGNAL DETECTION THEORY

The theory

Signal Detection Theory (SDT; Green & Swets, 1966) is a theory that comes from the field of psychophysics. This theory describes how decisions are made in uncertain situations, assuming that the subject has an active role on their perception, making decisions in order to maximize the expected value of a particular response to what is perceived. This theory makes the assumption that a certain stimulus is not always perceived in the same way, due to variations in both the instruments or sources that produce the stimulus and the perceptive system of the subject. Thus, the perception of the stimulus varies in a continuum, following a normal distribution. Also, this stimulus is usually presented in a noisy background, that also leads to variable perceptions normally distributed. The main feature of this theory is that it differentiates between two main components of the decision: sensitivity and response criterion (also called decision bias). Sensitivity refers to perceptive components as the physical properties of the stimuli and the ability of the subject to detect them, which is dependent on the overlap of the internal perceptive functions. Response criterion refers to the willingness to produce a particular response, and is independent of sensitivity. Response criterion is affected by a range of variables, such as the number of trials, the instructions, the value of making a particular response, or motivational factors, and is represented as the point in the internal stimulation perceived above which a particular response is produced. A schematic of the model is depicted in Figure 1.

Figure 1

Schematic of SDT



Note. Graphic representation of SDT, in which the probability distributions of internal sensation of the signal and the background of noise are depicted. d' represents a measure of sensitivity as the distance between the mean of the noise and signal distributions. β represents the response criterion, in such a way that response is produced to all values to the right of it.

The most basic SDT procedure is the Yes/No task, in which in some trials the signal is presented on the background of noise and in other trials only the background of noise is presented. Two responses are possible in this task, one that indicates that the subject detected the signal and one that indicates that the subject did not detect the signal. Thus, each trial has four possible outcomes, as is depicted in Table 2. When the signal is present and the subject indicates so, the outcome is a Hit (H); when the signal is present but the subject indicates that is not, the outcome is an Omission (O); when the signal is absent but the subject indicates that is present, the outcome is a False Alarm (FA); and when the signal is absent and the subject indicates so, the outcome is a Correct Rejection (CR).

Table 2

The Yes/No task and its four outcomes

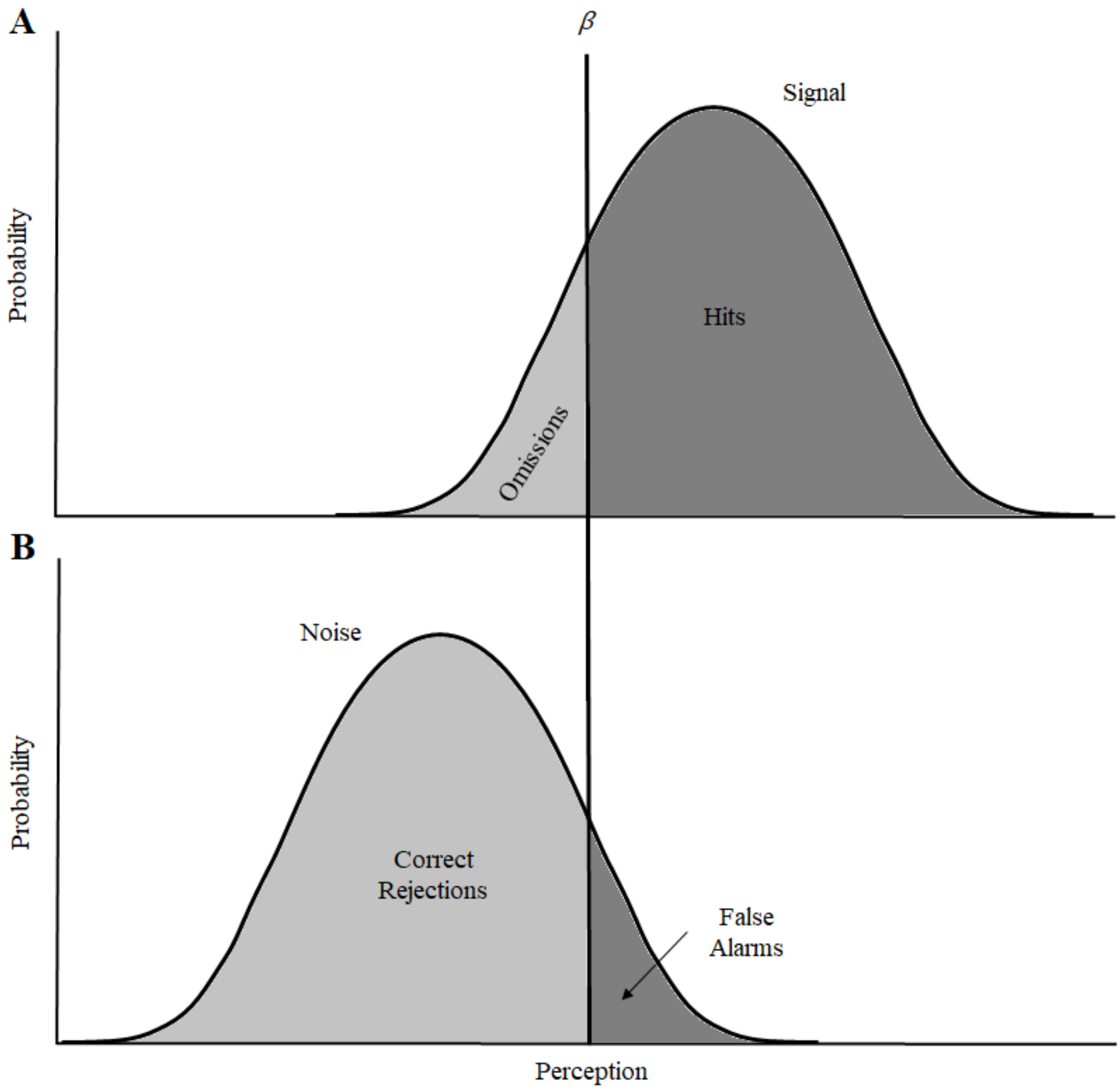
	Signal + Noise	Noise
Detect	Hit	False Alarm
No detect	Omission	Correct Rejection

As can be seen in Figure 2A, the probability of Hits is the area under the signal distribution function that is at the right of the criterion, whereas the probability of Omissions is the area under the signal distribution function that is at the left of the criterion. Similarly, as can be seen in Figure 2B, the probability of False Alarms is the area under the noise distribution that is at the right of the criterion, whereas the probability of Correct Rejections is the area under the noise distribution function that is at the left of the criterion. The probabilities of Hits and Omissions are independent from the probabilities of False Alarms and Correct Rejections, as they belong to different distributions, Signal and Noise respectively.

It can be concluded from Figure 2 that, if sensitivity increases (that is, the distributions overlap less), the same criterion placement would lead to more Hits and Correct Rejections, and less Omissions and False Alarms. Regarding the response criterion, a more liberal one (that is, a criterion placed to the left) would promote more Hits and False Alarms, but less Omissions and Correct Rejections, whereas a more conservative criterion (that is, a criterion placed to the right) would lead to less Hits and False Alarms, but more Omissions and Correct Rejections.

Figure 2

The four outcomes of the Yes/No task in the schematic of SDT



Note. Panel A depicts the distribution function of the signal. Panel B depicts the distribution function of the noise. β represents the response criterion. In panel A, the area under the curve in dark grey represents the probability of Hits, and the area in light grey represents the probability of Omissions. In panel B, area under the curve in dark grey represents the probability of False Alarms, and the area in light grey represents the probability of Correct Rejections.

Applications of SDT to the psychology of learning

Decision making can be considered an essential psychological process, that cannot be explained by simpler processes and that is able to account for all the psychological activity (Gigerenzer & Murray, 1987, Loy et al., 2009). The inference revolution, according to Gigerenzer and Murray (1987), consisted in the standardization in psychology of the statistical concept of hypothesis testing and its reinterpretation from cognitive psychology as a theory to explain psychological processes. This transformed the understanding of psychophysics, perception, memory and thinking as processes of decision making. However, the experimental psychology of learning seemed to be an exception to this revolution, given the central importance of the concept of association in this field.

SDT has been applied to learning mainly as a tool, specially to the understanding of discrimination. The differentiation between sensitivity and response criterion makes SDT a useful tool to get more accurate data, allowing to calculate sensitivity indexes, and also to examine which variables affect response criterion. For example, Hack (1963) applied SDT methodology to instrumental discrimination learning on rats, in which sensitivity indexes were calculated to different stimulus intensities, showing that sensitivity increased with increasing intensity of the auditory stimulus employed. Similar results on the relationship between stimulus intensity and sensitivity has been assessed in other discrimination studies: differences in the length of reinforcement schedules in pigeons (Rilling & McDiarmid, 1965; Hobson, 1975), concentrations of four difference substances (sodium chloride, sucrose, tartaric acid and quinine sulphate) in rats (Morrison & Norrison, 1966), light intensities in pigeons (Blough, 1967; Hodos & Bonbright, 1972), colour wavelengths in pigeons (Wright, 1972), and duration of visual stimuli in pigeons (McCarthy & Davison, 1980). McCarthy et al. (1982) found that sensitivity lowered as function of the delay between stimulus presentation and the availability of the response device in a light intensity discrimination in pigeons.

Boneau et al. (1965) and Nevin (1965) showed that pigeons pecked most often to an auditory stimulus that predicted non-reward in trials following reinforcement than in trials following non-reinforcement, an effect that was not due to changes in sensitivity but in response criterion. Suboski and Spevack (1968) found that, in the discrimination of stimulus auditory frequency, rats showed a more liberal criterion with higher levels of deprivation. Also, increasing the number of extinction and spontaneous recovery trials produced a more conservative criterion. Clopton (1972) analysed the discrimination of increments in background noise in monkeys, finding that changes in both lowering the intensity of the background noise and bigger increments of noise intensity improved sensitivity, whereas increases in the probability of occurrence of an increment increased response criterion. Grice (1972) reviewed experiments with human eyelid conditioning in which the effect of CS intensity was assessed, presenting results in which modifying the verbal instructions given to participants lead to changes in criterion, and relating SDT with Hull's theory (1943). Wright and Nevin (1974) examined the effect of reinforcement of correct responses and punishment of incorrect responses in pigeons, finding that the ratio of reinforcement needed to counteract the biasing effect of shock punishment increased with shock intensity. Hobson (1978) investigated the effect of different pay-off matrixes in the discrimination of fixed ratio schedules, finding that pay-off matrix affected the response criterion but not sensitivity.

The reinforcement rate has been shown to produce changes in response criterion, while not affecting sensitivity in numerous studies (Boldero et al., 1985; McCarthy & Davison, 1979, 1980, 1981; Stubbs, 1976; Wright, 1972). Also, Boldero et al. (1985) and Alsop and Porritt (2006) found that reinforcer magnitude affected response criterion while leaving sensitivity unaffected. Nevin et al. (1982) found that reinforcement affect both sensitivity and response criterion, but in different ways: the difference in reinforcement of correct responses (Hits and Correct Rejections) and errors (False Alarms and Misses) affected sensitivity, whereas response criterion is affected by the ratio of reinforcement of the two possible responses. The volume of taste stimuli also affects both sensitivity and response criterion in rats, with sensitivity being positively related with stimulus volume and response criterion being inversely related to stimulus volume, in such a way that as volume increase, criterion gets more conservative (Brosvic et al, 1991). Herremans et al. (1995) examined the effect of reinforcement in a delayed conditional discrimination in rats, finding that the higher the reinforcement ratio was for the signal, the more liberal was the response criterion, being this effect stronger after long delays. Sensitivity decreased as delay increased, and decreased with more extreme values of reinforcement ratio. It is important to note the work of Schmajuk (1987), who proposed that classical conditioning can be understood in terms of SDT as a decision process in which the subject has to decide to emit a CR in the presence of a CS, which is considered to be a signal that is presented in a background of noise. Following Hollis' hypothesis (1982), which proposed that the CR was a preparatory response in order for the organism to optimize the interaction with the US, the decision process in classical conditioning would be driven to maximize the trade-off between the benefits and the costs of emitting a CR. This approach has high ecological validity, as links classical conditioning with evolution, as those behavioural strategies that promote maximum fitness should be selected.

Mason et al. (2003) examined results from rabbits' nictitating response experiments in which a feature positive discrimination was trained, such that a noise was reinforced in trials in which was presented in compound with a tone, but non-reinforced when presented alone (AX+/A-). The intensity of the tone was systematically varied, finding that the more intense the tone was, more responding to the compound, and that a low but consistent probability of responding to the noise was retained, in such a way that the more intense the tone was, lower probability of responding to the noise. The authors described how neither Rescorla and Wagner model (1972) nor Pearce model (1987) could predict these results. However, these results were easily accounted for in terms of SDT, as increases in sensitivity increase Hits (that is, responding in the presence of AX+) and decreases False Alarms (that is, responding in the presence of A-). It should be noted that this work had very little impact on subsequent research, receiving only two cites (retrieved from Scopus on the 27th of May, 2021).

According to Siegel et al. (2009) classical conditioning has great similarities with human contingency judgments, given that the way in which a human judges the relationship between a cue and an outcome is analogous to the way a non-human animal learns the relationship between a CS and a US. Thus, research with classical conditioning preparations in non-human animals can be connected to the research with contingency judgments preparations in humans. The authors illustrated these similarities by comparing two 2x2 matrixes that depict the presentation of events in both classical conditioning and contingency judgment tasks (see Table 3).

Table 3

Comparison between classical conditioning and contingency judgments

Classical Conditioning			Contingency Judgments		
	US	noUS		O	noO
CS	*a*	*b*	C	*a*	*b*
noCS	*c*	*d*	noC	*c*	*d*

Note. On the left, 2x2 matrix for the presentation of events in classical conditioning. CS means that a CS is presented in a trial, noCS means that a CS was not presented in a trial, US means that a US was presented in a trials, and noUS means that a US was not presented in a trial. On the right, 2x2 matrix for the presentation of events in contingency judgments. C means that a cue was presented in a trial, noC means that a cue was not presented in a trial, O means that an outcome was presented in a trial and noO means that an outcome was not presented in a trial. For both matrixes, *a*, *b*, *c* and *d* represent the frequencies of each trial type.

As can be seen in Table 3, in classical conditioning preparations, on a given trial the CS might be present (CS) or absent (noCS) and the US might be present (US) or absent (noUS). Trials in which both the CS and US occur with a frequency *a*, trials in which the CS is presented and the US is absent occur with a frequency *b*, trials in which the CS is absent and the US is presented occur with a frequency *c*, and trials in which both CS and US are not presented occur with a frequency *d*. Similarly, in contingency judgments preparations, on a given trial the cue might be presented (C) or not (noC) and the outcome might happen (O) or not (noO). Again, trials in which the cue and the outcome are present occur with a frequency *a*, trials in which the cue is present and the outcome is absent occur with a frequency *b*, trials in which the cue is absent and the outcome is present occur with a frequency *c*, and trials in which both the cue and the outcome are absent occur with a frequency d. These similarities lead to various authors to claim that similar associative processes underlie both tasks and claim that associative models developed in the light of Pavlovian Conditioning, such the one by Rescorla and Wagner (1972), can account for the results in contingency judgment tasks (Dickinson et al, 1984; Shanks & Dickinson, 1987; Wasserman et al., 1993, Wasserman et al., 1996). However, more recent research has found some limitations of these models and turned to SDT, based on the similarities that contingency judgment tasks have with SDT tasks. In both tasks, a cue (or signal) may be present or absent, the outcome might follow the cue or not (similar to feedback indicating if the signal was present) and subjects may say that cue predicts the outcome or not (similar to saying that the signal was present or absent). The contingency between the cue and the outcome (or the CS and the US) can be calculated as Δp, following Equation 1:

$$\Delta p = P(O|C) - P(O|noC) = \frac{a}{a+b} + \frac{c}{c+d} \quad (1)$$

in which $P(O|C)$ is the conditional probability of the outcome given the cue (or of the US given the CS), that is calculated dividing the frequency *a* by the sum of the *a* and *b* frequencies, and $P(O|noC)$ is conditional probability of the outcome given the absence of the cue (or the US in the absence of the CS), that is calculated dividing the frequency *c* by the sum of *c* and *d* frequencies.

Allan et al. (2005) examined the outcome-density effect, in which, under the same cue-outcome contingencies, higher cue-outcome contingency judgments are found with increasing probabilities of the outcome. In this experiment, subjects had to judge the effect of a chemical in a bacterial strain. Δp was 0 for half of the subjects and 0.467 for the other half, and the probability of the outcome was varied within-subjects in three levels (low, medium and high). Two type of responses were recorded. Prediction responses were measured every trial, such that after presentation of the chemical the subject had to predict if the bacteria would survive or not. After the prediction response, subjects were shown if bacteria survived and if their prediction was correct or incorrect. Also, every 20 trials of the total 60 trials, rating responses were measured, using a rating scale ranging from -100 to +100, negative values indicating that the chemical had a negative effect on bacteria's survival and positive values indicating that the chemical had a positive effect on bacteria's survival. Ratings were higher for subjects that received a 0.467 contingency than a 0 contingency, and for both contingencies, ratings increased with increasing outcome density. Based on prediction responses, contingency of outcome prediction to the cue was computed as the probability of predicting the presence of the outcome if the cue was present (P(Y|C)) minus the probability of predicting the presence of the outcome if the cue was absent (P(Y|noC)). The contingency of outcome prediction was affected by Δp, but not by the probability of the outcome. However, both P(Y|C) and P(Y|noC) had a direct relation with the probability of the outcome. Thus, as the probability of the outcome increased, so did the probability of predicting the outcome both when the cue was present and absent. In the SDT analysis, P(Y|C) is the probability of Hits and P(Y|noC) is the probability of False Alarms. These probabilities were used to calculate sensitivity and response criterion indexes, finding that the outcome probability did not affect sensitivity, but did affect the response criterion, in such a way that the higher was this probability, the more liberal was the criterion, similar to what is reflected in ratings. This was consistent with manipulations in SDT tasks in which feedback about the presentation of the signal was manipulated, in such a way that in some trials in which the signal was not presented subjects were told that the signal was present, finding that this manipulation promoted a more liberal criterion (Kinchla & Atkinson, 1964).

Perales et al. (2005) used a similar methodology to study the effects of cue density (Experiment 1) and manipulations of the pay-off matrix (Experiments 2 and 3). In Experiment 1, the task employed required the participants to predict if the presence of a minefield would lead to an enemy tank to explode. Prediction responses and ratings were recorded in a similar way to Allan et al.'s (2005) study. This task had two different phases, one with a low cue density and one with high cue density. Participants were divided in two groups with different Δp, one with a positive Δp and other with a null Δp. The results indicated that ratings were higher in the positive Δp than in the null Δp condition, and also higher in the high cue density than in the low cue density condition. Sensitivity and response criterion indexes were calculated from prediction responses, finding that sensitivity was only affected by the contingency in such a way that higher sensitivity was found under positive contingency, whereas response criterion was affected by both the contingency and the cue density, in such a way that a higher cue density promoted a more liberal criterion, and that this effect was larger in the positive contingency than in the null contingency condition, a result similar to the one found in rating responses. In Experiment 2, participants were trained in a task in which they were asked about the covariation between a symptom and a disease. This task had four phases with different pay-off matrixes that were instructed at the beginning of each phase. One of these pay-off matrix should promote a liberal criterion, other should promote a conservative criterion, and the remaining two was unrelated to the frequency of a positive or negative prediction response, so they should promote neutral criteria. One group of participants was trained with a positive Δp, a second group with a negative Δp, a third group with a null Δp and a low cue density and a fourth group with a null Δp with a high cue density. Ratings were higher for the positive Δp group than for the rest of groups, that did not differ between them, so cue density effect was not evident in this experiment. Also, ratings were higher in for the pay-off matrix that promoted the liberal criterion than to the pay-off matrix that promoted a conservative criterion, but no other significant differences were found. Again, sensitivity varied only as function of the Δp, being high in the positive Δp group, intermediate in the negative Δp group, and low in the null Δp group. Response criterion was affected only by the pay-off matrix in the way expected. Experiment 3 aimed to replicate the effect of the pay-off matrix in a causal task in which participants were asked to predict if a radiation produced mutations in a fish. The task had two phases, one with the pay-off matrix that promoted a liberal criterion and one with the pay-off matrix that promoted a conservative criterion. For one group, causal ratings were asked for in each trial, and for the other, they were asked for every 8 trials block. Half of the participants in each group were trained with a positive Δp and the other half with a negative Δp. The frequency of causal judgments had no effect on the ratings, but the positive Δp group showed higher ratings than the negative Δp group (being more accurate in the former than in the latter), and the ratings were higher in the pay-off matrix condition that promoted the liberal criterion than in the pay-off matrix condition that promoted a conservative criterion. Sensitivity was higher in the positive Δp group than in the negative Δp group, being this effect reduced in the groups that were asked to judge the causal relationship with a high frequency. Response criterion was only affected by the pay-off matrix, in the way that was expected.

In order to unify the methods of SDT and contingency judgments tasks, Allan et al. (2006) proposed a method for the study of contingency judgments that significantly reduced the time of the trials and so allowed to get much more information from a single participant. In this procedure, known as the streamed-trial procedure, trials involve the presentation of geometric figures as cues and outcomes and presentations last 100 msec. With this method, the authors replicated both the effect of the outcome density and the pay-off matrix in the response criterion found in the experiments previously reported. In the study by Crump et al. (2007), the streamed trial procedure was validated with a within-subjects design using two levels of Δp (0 and 0.467), two levels of outcome density (low and high) and two different judgments, a rating of the cue-outcome contingency and an estimation of the occurrence of the four types of trials (*a*, *b*, *c* and *d* in Table 3). Results of the contingency ratings indicated that those rating were higher in the $\Delta p = 0.467$ condition than in the $\Delta p = 0$ condition and in the high outcome density condition than in the low density condition, and that the outcome density effect was larger in the $\Delta p = 0$ condition than in the $\Delta p = 0.467$ condition. The frequency estimations were transformed by applying $\Delta p = \frac{a}{a+b} - \frac{c}{c+d}$. For these results, there was only an effect of contingency, being higher in the 0.467 than in the 0 condition.

Allan et al. (2008) used the streamed-trial procedure combined with the method of the constant stimuli and categorical responses in which the cue-outcome contingency was classified as either weak or strong in order to apply SDT to contingency judgments. In Experiment 1A, eleven Δp values were presented in different streamed-trials, and the categorization response was asked after each of it. Based on these responses, psychometric curves were constructed for each participant, from which sensitivity and response criterion indexes could be estimated. Experiment 1B extended the applicability of the procedure by employing emoticons instead of the geometric forms used in Experiment 1A. Experiment 1C demonstrated that this method was also suitable to construct psychometric functions for the averaged data of a group of participants. In Experiment 2, this method was employed in order to investigate the asymmetry that is usually found in the literature between positive and negative contingencies, being the ratings more accurate with positive than with negative contingencies (e.g., Wasserman et al., 1993; Maldonado et al., 1999). 11 positive and negative Δp values were used, finding that sensitivity was constant for positive and negative contingencies, but response criterion was smaller for positive than for negative contingencies, thus indicating that the asymmetry is due to changes in the response criterion. Experiment 3 replicated the results by Allan et al. (2005), finding that changes in response criterion were responsible for the outcome density effect. Finally, Experiment 4 replicated the findings by Perales et al. (2005) in which the pay-off matrix had an effect in response criterion, but no effect in sensitivity.

Hannah et al. (2009) extended the applicability of the method to the study of blocking. In Experiment 1, using geometric forms as stimuli and a one-phase training, four target and non-target cue combinations were possible: the non-target and the target are both present, the non-target is present but the target is absent, the non-target is absent but the target is present, and both are absent. For these four types, the outcome might be present or absent, resulting in 8 types of trials. The contingency between the target cue and the outcome was always 0.5, whereas the contingency between the non-target cue and the outcome was either 0 or 1. After each streamed-trial, participants had to rate the relationship of one of the cues with the outcome. Blocking was evident in this experiment given that ratings for the target cue were higher when the contingency of the non-target cue and the outcome was 0 than when it was 1. This result was replicated in Experiment 2 using stimuli from a typical contingency judgment task, images of foods as cues and allergies as outcomes. Experiment 3 further replicated the applicability of the streamed-trial procedure to a two-phase blocking procedure. There was single-cue phase in which the non-target cue always presented and the target cue was never presented, and with different contingencies between the non-target cue and the outcome (0.75, 0.50 and 0.25). There was also a compound-cue phase, in which both cues were presented with the outcome with a probability of 0.75, the non-target cue was presented with the outcome with a probability of 0.25, and the contingency of the target cue and the outcome was 0.5. Forward and backward order of these phases were also included. Also, control conditions were included in which the food used as a non-target cue was different for each phase, both for forward and backward presentations. Results showed that ratings to the target cue were generally lower for the backward condition than for the forward condition, but both showed that a lower rating was found in the experimental condition. Also, the difference between control and experimental treatment was higher for higher contingencies between the non-target cue and the outcome, independently of the order of the phases.

Siegel et al. (2009) reported a one-phase blocking experiment similar to Experiment 1 by Hannah et al. (2009). In this case, the contingency between the target cue and the outcome was varied across four conditions, the contingency of the non-target cue and the outcome was either 0 or 1, and the response was measured in a categorical way as in Allan et al. (2008). With this procedure, two psychometric functions were constructed for the contingencies of the non-target cue and the outcome 0 and 1, finding that responding was higher for contingency 0 than for contingency 1, that is, blocking was found. Sensitivity indexes were similar for both contingencies, but response criterion varied, in such a way that the blocking effect depends on the criterion placement.

Laux et al. (2010) applied the streamed-trial procedure to another cue interaction phenomenon: causal discounting. Causal discounting occurs when a target cue with an intermediate contingency with the outcome is judged to be less effective when trained in the presence of a non-target cue with a high contingency with the outcome. In Experiment 1 the cues were cans of liquid and the outcome was the blooming of a flower. One group of participants were trained with a non-target cue contingency of 0.33 and the other were trained with a contingency of 0. For both groups, there were two conditions regarding the contingency of the target cue: 0.22 and 0. After each stream, participants responded two questions about the increase in the probability of the outcome due to the non-target and target cue respectively. The results indicated that causal discounting occurred, as participants in which the non-target cue was trained with a contingency of 0 judged that the target cue increased the probability of the outcome more often than participants in which the non-target cue was trained with a contingency of 0.33, no matter if the target was trained with 0 or 0.22 contingencies. There was no effect of the contingency of the non-target cue on sensitivity, and the effect on response criterion, although close, failed to reach significance. Experiment 2 was a replica of the previous experiment, but employing pills as cues and the recovery of a patient as an outcome. The causal discounting effect was replicated and the contingency of the non-target cue had no effect on sensitivity. However, in this experiment there was a significant effect of the contingency of the non-target cue on response criterion, with participants that were trained with a non-target cue contingency of 0 showing a conservative criterion and participants that were trained with a non-target cue contingency of 0.33 showing a liberal criterion.

Maia et al. (2018) tested three hypothesis regarding contingency judgments using the streamed-trial procedure with geometric forms as stimuli. Two of these hypothesis come from the SDT application of the group of Allan described above (Allan et al., 2005, 2008; Siegel, 2009): (1) the subjective contingency follows a normal distribution with a mean μ and a standard deviation σ and (2) σ is constant. The third hypothesis comes from the model by Rescorla and Wagner (1972): (3) μ is a linear function of Δp. In Experiment 1, three pretraining phases and two testing phases were used. In the first pretraining phase, a stream of 10 AX+ and 10 A- trials were presented, in such a way that the Δp of X was 1. In the second training phase, a stream 10 AX- and 10 A+ trials were presented, in such a way that the Δp of X was -1. The third pretraining phase was composed of two streams, one with Δp 1 and other with Δp -1. The two testing phases had streams with different Δp, that could be -0.8, -0.4, 0, 0.4 or 0.8. In all phases, after each stream participants were asked if the outcome was more likely to appear after cue X, and how sure they were of their response (not sure, sure or very sure). Results from this experiment indicated that the SDT model (that is, the subjective contingency follows a normal distribution with a mean μ and a standard deviation σ) adequately fitted the results. However, σ was not constant, but slightly increased with higher positive and negative contingencies. Also, μ was not a linear function of Δp, as subjects showed higher sensitivity to changes in positive than in negative contingencies. As the higher sensitivity to positive contingencies could be due to the question asking if the outcome was more likely after the cue X, Experiment 2 replicated this experiment, but the question asked was if the outcome was less likely to appear after the cue X. Results of this experiment replicated the previous one, so the hypothesis of normal distribution was confirmed, but σ is higher with higher contingencies (although this variation was slight) and sensitivity changes are higher for positive than for negative contingencies.

Following this study, Jozefowiez (2021) did a SDT analysis of the performance of four participants in a contingency judgments task over a long period of time. As in Maia et al. (2018), four type of trials were possible within a stream: AX+, AX-, A+ and A-. Different streams had different X Δp: -0.4, 0, and 0.4. Participants were asked if the contingency between the cue X and the outcome was either negative, null or positive, and then how sure they were of the answer. For a minimum of fifteen sessions participants did not received feedback, when a stable responding was achieved they transitioned to a feedback condition in which a s a screen that said “Correct!” was included after a correct response was made for at least other fifteen sessions, and again transitioned to a no feedback condition when responding was stable. Results from this experiment indicated that sensitivity changed only in two of the four participants, one improving and the other worsening, and response criterion was quite stable over time for all participants. For one participant, the introduction of feedback substantially increased the sensitivity and made response criterion change in such a way that less trials were categorized as null, increased the sensitivity of other participant, and had no impact in the remaining participants. The discontinuation of the feedback had no effect on the sensitivity of the first participant but the second participant’s sensitivity for negative contingencies returned to the level displayed in the previous no feedback sessions. For both, discontinuation of the feedback had an effect on response criterion, in such a way that the first participant was more unsure about their categorizations and the second participant showed a more conservative criterion overall.

Another application of a psychophysical theory to contingency learning, in this case studied in a magazine procedure with rats, can be found in Moris et al. (2012). In Experiment 1a, a $\Delta p = 0.1$ produced excitatory conditioning when $P(O|C)$ = 0.1 and $P(O|noC)$ = 0, but in Experiment 1b Δp = 0.1 was not sufficient to find excitatory conditioning when $P(O|C)$ = 0.9 and $P(O|noC)$ = 0.8. In Experiment 2, excitatory conditioning was found only with a Δp = 0.3 for $P(O|C)$ = 0.9, but no with Δp = 0.15 nor Δp = 0.2. In Experiment 3, with a $P(O|C)$ = 0.5, Δp = 0.2, but not Δp = 0.1, produced excitatory conditioning. Results from Experiment 4 replicated Experiments 1a and 1b within a single experiment. Carnero (2011) extended these results to negative values of Δp. In Experiment 5, a Δp = -0.1 produced inhibitory conditioning when

$P(O|C)$ = 0 and $P(O|noC)$ = 0.1, but not when $P(O|C)$ = 0.8 and $P(O|noC)$ = 0.9. In Experiment 6, Δp values of -0.1, -0.2 and -0.3 did not produced inhibitory conditioning with $P(O|noC)$ = 0.9. In Experiment 7, with a $P(O|noC)$ = 0.5, Δp values of -0.3 and -0.2 produced inhibitory conditioning, whereas Δp = -0.1 did not produce it. These results replicated the asymmetry of positive and negative contingencies found some of the experiments previously reported, and also showed that the absolute Δp value needed to produce conditioning depended on the magnitude of $P(O|C)$ and $P(O|noC)$, a result that, if conditioning is understood as a discrimination between $P(O|C)$ and $P(O|noC)$, was consistent with the psychophysical Weber-Fechner law (Fechner, 1860/1966) which states that the perceived stimulation is a logarithmic function of the intensity of the stimulation.

The asymmetry between inhibitory and excitatory learning was further assessed by Harris et al. (2016), using magazine training procedure with variable CS durations ranging from 2 to 18 s (M =10 s). In Experiments 1 and 3, two groups were trained with a Δp = 3 were used, one of them with $P(O|C)$ = 0.4 and $P(O|noC)$ = 0.1 and the other with $P(O|C)$ = 0.9 and $P(O|noC)$ = 0.6. The results from these experiments showed that both groups developed excitatory conditioning, with no differences between them. Experiment 2 and 4 used a similar design, but for inhibitory conditioning, so two groups were trained a Δp = -3. These results indicated that the group that was trained with $P(O|C)$ = 0.1 and $P(O|noC)$ = 0.4 showed significantly more inhibition than the group trained with $P(O|C)$ = 0.6 and $P(O|noC)$ = 0.9. Furthermore, Experiment 5 compared two groups with different Δp's but the same ration between $P(O|C)$ and $P(O|noC)$, so one group was trained with $P(O|C)$ = 0.1 and $P(O|noC)$ = 0.3 and the other group was trained with $(O|C)$ = 0.3 and $P(O|noC)$ = 0.9. The results showed that both groups developed similar inhibitory properties. So, this study suggested that excitatory conditioning depended on Δp, whereas inhibitory conditioning depended on the ratio between $P(O|C)$ and $P(O|noC)$.

These studies suggest that psychophysical theories, especially SDT, successfully account for how subjects respond to contingencies, and most of the effects reviewed (cue and outcome density, pay-off matrix and blocking) depend on changes in the response criterion. This suggest that changes in responding are not dependent on the strength of CS-US associations, but depend on the sensitivity to the CS-US relationship and the response criterion employed to decide which response to produce. Siegel et al. (2009) suggested that this approach is common for both contingency judgments and classical condition tasks.

OBJECTIVES

Given the importance of cue interaction effects in the development of the theories of Associative Learning, the main objective of the thesis is to evaluate the suitability of SDT by studying cue interactions under this perspective. As SDT distinguishes between sensitivity and response criterion, it could explain that different forms of cue interaction arise from the same design as changes in the response criterion. So, the experimental set presented hereafter focus on modifying those parameters that, according to SDT, produce changes in response criterion and examine the effect that they have in cue interactions. The experiments focus in two cue interaction designs in which positive and negative mediation have been previously reported in the literature: A+/AX+, in which positive mediation is named augmentation and the negative mediation is named blocking; and A+/AX-, in which positive mediation is named second order conditioning (SOC) and negative mediation is named conditioned inhibition (CI). Under the SDT logic, these designs can be understood as a discrimination between A and AX trials, and parallels with the Yes/No task can be established. X can be considered the signal and A can be considered the noise. So, in some trials X is presented in the background of noise (AX) and in some trials only the background of noise is presented (A). Based on the optimization of the trade-off between benefits and costs proposed by Schmajuk (1987), not producing a CR to X would be the most optimal strategy, as X does not predict the appearance of a US for which the subject needs to be prepared and producing the CS is costly. For this reason, if the subject detects X it should not respond to it. This parallel can be observed in Table 4.

Table 4

The parallelism between the Yes/No task and present designs

	Signal + Noise = AX	Noise = A
Detect = noCR	Hit	False Alarm
No detect = CR	Omission	Correct Rejection

The number of sessions was a variable studied in all the experiments reported hereafter, as conditioning training proceeded always in 20 sessions, expecting to find positive mediation in the first sessions and negative mediation at the end of training, based on the results by Rescorla (1972) and Holland and Rescorla (1975). This would be consistent with SDT, given that under conditions of uncertainty as the first sessions of a training with novel stimuli, sensitivity is lower and more extreme response criteria are adopted, thus producing positive mediation (Lynn & Barrett, 2014).

Chapter 2 focused on exploring the effect that the contingency of reinforcement of AX has on cue interactions. It should be noted that the designs employed in the experiments (A+/AX+ and A+/AX-) vary only in the contingency of reinforcement of AX. This is a change the pay-off matrix, one of the main variables that modulate the response criterion in SDT, an effect that has been demonstrated in contingency judgments tasks (Allan et al., 2006, 2008; Perales et al., 2005). In Experiment 1, four groups were trained with different contingencies of reinforcement, in such a way that the probabilities of reinforcing AX were 1, 0.66, 0.33 or 0. Higher responding to X is expected in higher reinforcement contingencies. In Experiment 2, groups in which AX is always and never reinforced, respectively, were replicated including tests for the inhibitory properties, in order to confirm that blocking was present in the first and CI in the second. Finally, in Experiment 3, the group that was trained with AX always reinforced was replicated with an adequate control in order to confirm augmentation and blocking.

Chapter 3 aimed to explore the effect of different A+ and AX- trial number. The a priori probabilities of signal and noise trials is the other main variable that modulates the response criterion in SDT. Many A+ in relation to AX- trials should promote SOC, whereas few A+ trials in relation to AX- trials should promote CI. This is consistent with previous literature (Stout et al., 2004; Yin et al., 1994) in which the number of A+ was constant, finding that few AX- trials promoted SOC and many AX- trials promoted CI. As noted earlier, in these experiments the ITI was varied, which can be a confounding variable. In the set of experiments described in Chapter 3, varying both the number of A+ and AX- trials allowed to maintain the ITI constant. Experiments 4 to 8 employed per session, respectively, 14 A+ and 2 AX- trials, 11 A+ and 5 AX- trials, 8 A+ and 8 AX- trials, 5 A+ and 11 AX-; and 2 A+ and 14 AX- trials. All these experiments included control groups and retardation tests to confirm SOC and CI. In Experiment 9, the experimental groups in Experiments 4 to 8 were replicated in order to compare the level of responding to X developed under the 5 A+/AX- trials combinations.

Finally, in Chapter 4, the implications of the results of the experiments are discussed, contrasting them with different models and explanatory hypothesis of Associative Learning, with special interest in the models that distinguish between learning and performance, propositional theories, and SDT.

CHAPTER 2: The effect of the contingency of reinforcement of AX

In this section, three experiments are reported. These experiments aimed to explore the effect that the number of training sessions have on the transition from positive to negative mediation and the effect of the contingency of reinforcement in the magnitude of responding. The designs of these experiments included a stimulus A that was always reinforced and an AX compound under different contingencies of reinforcement that ranged from 1 (always reinforced) to 0 (never reinforced).

EXPERIMENT 1: Effect of AX reinforcement contingency

The designs of the two pair of contrary phenomena that were reviewed in the introduction vary only in the contingency of reinforcement that AX received, being this contingency 1 in the case of augmentation/blocking and 0 in the case of SOC/CI. This experiment aimed to find the transition from positive to negative mediation with the same training along sessions, and also to examine what happens when the contingency of reinforcement for the compound is intermediate. To fulfil this aim, four groups received a training in which A was always reinforced and AX received different contingencies of reinforcement depending on the group: 1, 0.66, 0.33 and 0. All groups were trained along 20 sessions, expecting to find positive mediation phenomena (an increase in responding) in the first sessions, and a transition to negative mediation phenomena (absence of responding) in the last sessions of the experiment.

Method

Subjects

The subjects were 32 experimentally naive male Wistar rats that were 120 days old and had an average ad libitum weight of 401 g (range, 343–474 g). All procedures related to the maintenance and use of animals were in accordance with the European Law of Animal Welfare and were approved by the Animal Welfare Committee of the University of Oviedo. They were housed in cages, each of which contained four rats that received the same training during the experiment. The weight of the animals was gradually reduced by controlled feeding to 85% of their individual free-feeding weights and was kept at that level throughout the experiment. Each day, in the housing room, there was 12 h of light, beginning at 8 a.m. The experiment was run during this light phase.

Apparatus

Eight identical conditioning chambers (24 × 29 × 38 cm: height × width ×depth; Med Associates) were placed in a sound and light-attenuating shell that incorporated a ventilation fan, which maintained the background noise at 62 dB(A). Background light was turned off for the experiment. The front and back walls were constructed from aluminium, the side walls and the ceiling were of clear methacrylate, and the floor was formed from 0.4 cm stainless steel rods, spaced 1 cm apart. A recessed food well (6 × 6 × 3.5 cm) was placed at the centre of the front wall, 0.5 cm above the floor. Food pellets (45 mg, Test Diet-MLab Rodent Tablet) were delivered to the food well and played the role of the US. The food well was equipped with photocells that allowed the presence of the rat in the well to be automatically recorded, playing the role of the CR. A speaker that produced a 600Hz and 76 dB(A) tone was mounted on the front wall, 8 cm over the food magazine. Above this speaker, there was another speaker that generated a second auditory stimulus: a 3,000 Hz and 82- dB(A) intermittent click. A 2 W and 24 V light was situated just above the food magazine. The tone, click and light all lasted 10 s and were used as stimuli as described in the procedure section below.

Procedure

Subjects were randomly assigned to four groups of eight subjects each. The groups received 4 days of magazine training and then 20 conditioning sessions. The groups were labelled Group 1, Group 0.66, Group 0.33 and Group 0. The experimental design for Experiment 1 is depicted in Table 5.

Magazine training

On days 1–4, the subjects received a 20 min session of magazine training. In each session, food pellets were delivered according to a variable time 120 s schedule. Four pellets were placed in the magazine before the beginning of these sessions.

Conditioning

The effect of the contingency of reinforcement of AX

Conditioning began on day 5 and continued throughout day 24 (a total of 20 sessions). Each conditioning session lasted 77 min. In each session, 18 tones (A), 18 lights (F), 6 tone-click compounds (AX) and 3 clicks (X) were presented in each session. Stimuli were presented in a random order within the session. The ITI had a mean duration of 80 s (range, 50-110 s). The first and last 100 s of each session had no event scheduled. For all groups, the tone was always followed by a food pellet (A+), and the light and the click were non-reinforced (F- and X-, respectively). The only difference between groups was the number of trials per session in which the tone-click compound was reinforced: for Group 1, the six tone-click compound trials were reinforced (6AX+), for Group 0.66, four out of the six tone-click compound trials were reinforced (4AX+ / 2AX-), for Group 0.33, two out of the six tone-click compound trials were reinforced (2AX+ / 4AX-), and for Group 0, the six tone-click compound trials were non-reinforced (6AX-). Thus, the probability of the appearance of the pellet after the presentation was 1 for Group 1, 0.66 for Group 0.66, 0.33 for Group 0.33 and 0 for Group 0.

Table 5

Experimental design for Experiment 1

Group	Conditioning				
1	18 A+	6 AX+	(0 AX-)	18 F-	3X-
0.66	18 A+	4 AX+	(2 AX-)	18 F-	3X-
0.33	18 A+	2 AX+	(4 AX-)	18 F-	3X-
0	18 A+	0 AX+	(6 AX-)	18 F-	3X-

Note. A represents tone presentation, F represents light presentation, AX represents tone-click compound presentation and X represents click presentation. The numbers before the letters indicate the number of trials in which the stimuli were presented in each session. The + symbol indicates that the stimuli were followed by a food pellet and the – symbol indicates that the stimuli were not followed by a food pellet.

Data analysis

Food well entries were registered during the 10 s that preceded the presentation of the CS and during the 10 s of the presentation of the CS itself. The CR controlled by the CS was computed as a difference in responding during the CS and the pre-CS periods, which was averaged for each session. The rationale for choosing this measure was that it allows to control for the general activity differences that can be seen between subjects. All the analyses reported here were performed on the mean differences per session. SPSS 24 (IBM Corp., 2016) was used to analyse the data. The analyses were mixed-model ANOVAs. The level of significance used was $\alpha = 0.05$. The effect sizes for ANOVAs are reported as partial Eta-square (η_p^2). When needed, degrees of freedom were adjusted using the Greenhouse-Geisser correction.

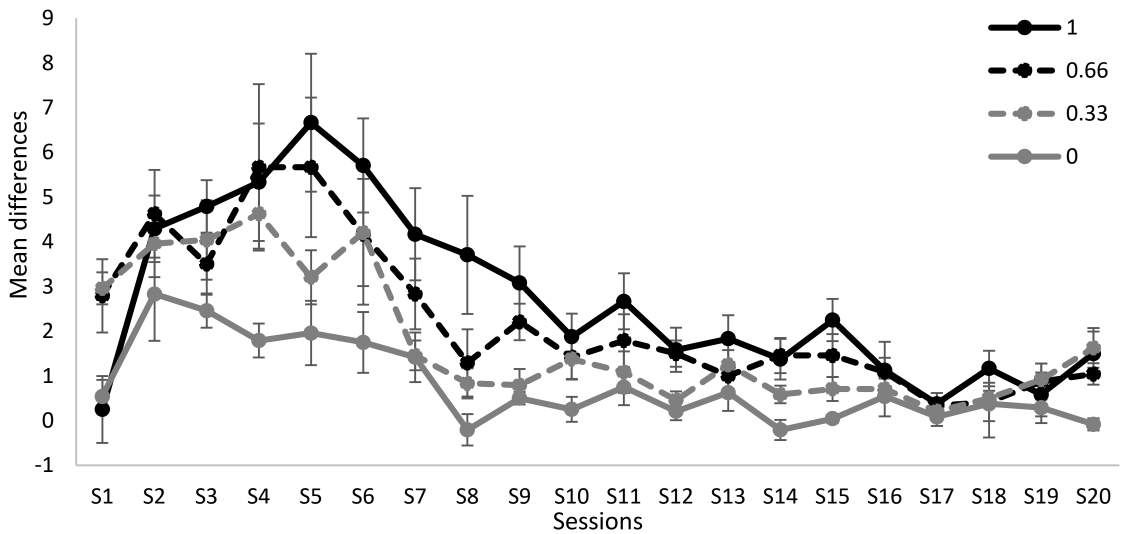
Results

As can be seen in Figure 3, responses to X increased in the first sessions in all groups, all equating around session 10. However, this increase proceeded different for each group. Although in the first session the responses in Groups 0.66 and 0.33 was higher, Group 1 showed the highest overall responding. Group 0.66 was the second that showed most responding, Group 0.33 was the third, and Group 0 showed the lowest increase. At the end of the sessions, responding in all groups equated around 0.

A mixed model ANOVA with the within-subject factor Session and the between-groups factor Group was carried. The ANOVA found a significant effect of the Session [$F(4.432, 124.096) = 22.087$, $p < .001$, $\eta_p^2 = .441$] and of the Group [$F(3, 28) = 5.376$, $p = .005$, $\eta_p^2 = .365$]. Although close, the Session×Group interaction failed to reach significance [$F(13.296, 124.096) = 1.68$, $p = .072$, $\eta_p^2 = .153$]. A simple contrast taking as reference the last session found significant differences in sessions 2 to 7, 9, and 17 ($p < .05$). Sessions 2 to 7 and 9 showed a higher responding than the last session, and session 17 had a lower responding. Post-hoc Tukey comparisons found differences between Group 1 and Group 0 [*MD* = 1.921, *SE* = .501, $p = .003$] and Group 0.66 and Group 0 [*MD* = 1.46, *SE* = .501, $p = .033$]. These analyses indicated that all groups showed an increase in responding in the first sessions (2 to 7 and 9), and that Groups differed in the level of responding, being higher in Group 1 and 0.66, intermediate in Group 0.33, and lower in Group 0.

Figure 3

Conditioning phase in Experiment 1



Note. PreX-X differences (±SEM) averaged for the three X- presentations per session in conditioning are displayed. The black continuous line represents Group 1, which was trained with 18 A+, 6 AX+, 18 F- and 3 X- presentations per session in conditioning. The black discontinuous line represents Group 0.66, which was trained with 18 A+, 4 AX+, 2 AX-, 18 F- and 3 X- presentations per session in conditioning. The grey discontinuous line represents Group 0.33, which was trained with 18 A+, 2 AX+, 4 AX, 18 F- and 3 X- presentations per session in conditioning. The grey continuous line represents Group 0, which was trained with 18 A+, 6 AX-, 18 F- and 3 X- presentations per session in conditioning.

Given the Group differences, a repeated measures ANOVA was carried for each group. For Group 1, there was a significant effect of the Session [$F(19, 133) = 8.551$, $p < .001$, $\eta_p^2 = .55$]. A simple contrast taking as reference the last session found significant differences with sessions 2 to 7 and 9 ($p < .05$). In all these sessions, responding was higher than in the last session. For Group 0.66, the effect of the Session was also significant [$F(19, 133) = 5.56$, $p < .001$, $\eta_p^2 = .443$]. The simple contrast found significant differences ($p < .05$) with the last session in sessions 2 to 5, 7, 9, 12 and 17, being responding higher in sessions 2 to 5, 7, 9 and 12, and lower in session 17. For Group 0.33, there also was a significant effect of the Session [$F(19, 133) = 8.807$, $p < .001$, $\eta_p^2 = .557$]. A simple contrast found significant differences ($p < .05$) in sessions 2 to 5, 14, 15 and 17 with the last session. Responding was higher in sessions 2 to 5, and lower in sessions 14, 15 and 17. Finally, for Group 0, there was also a significant effect of the Session [$F(19, 133) = 3.826$, $p < .001$, $\eta_p^2 = .353$]. The simple contrast found significant differences ($p < .05$) with the last session in sessions 2 to 6 and 9, with responding being higher in all these sessions. These analyses further confirmed that there was a significant increase in the first sessions in all groups when compared with their respective last session.

The significant responding in the first sessions is consistent with X developing excitatory properties. These excitatory properties decreased until they were no longer evident around the middle of the treatment. In Group 1, the increase in responding would be consistent with the phenomenon of augmentation, and the latter lower responding can be consistent with blocking. Similarly, in Group 0, the increase in responding in the first sessions is consistent with SOC, and the latter lower responding might indicate a transition to CI. However, to confirm inhibitory conditioning specific test must be performed (summation and retardation). Groups 2 and 3 also showed this transition from an increase in responding in the first sessions to a lower level of responding in the last sessions. Also, these conclusions relied on within-subjects comparisons along sessions, so proper control groups are needed to confirm these effects. It is worth noting that the magnitude of responding was directly related to the contingency of reinforcement of the compound, that is, the higher was the contingency of reinforcement, the higher was responding in that group throughout the experiment. So, Group 1 showed the higher responding, Group 0.66 was the second that responded the most, Group 0.33 was the third that responded the most and Group 0 showed the lowest responding. However, these differences were only significant between Group 1 and Group 0, and Group 0.66 and Group 0.

EXPERIMENT 2: A+/AX+ and A+/AX- with inhibitory tests

As noted in Experiment 1, inhibitory properties tests are needed to asses if CI has been developed. The aim of Experiment 2 was to replicate the positive to negative mediation transition found in Experiment 1 with the A+/AX+ and A+/AX- design, and to include the summation and retardation tests to assess the inhibitory properties of X at the end of the experiment. When the design employed is A+/AX+, blocking is expected at the end of training, so X should not acquire inhibitory properties, whereas when the design employed is A+/AX-, CI is expected at the end of training, so X should acquire inhibitory properties.

Method

Subjects

Subjects were 32 experimentally naive male Wistar rats that were about 190 days old and that had an average ad libitum weight of 526 g (range, 637–452 g.). All other details regarding animal maintenance were identical to Experiment 1.

Apparatus

The apparatus was identical to the one employed in the previous experiment except that the presence of a lever was also used as a stimulus. The lever was a retractable piece of stainless steel (4.8 × 0.55 × 1.9 cm) and was located 3 cm to the left of the food well. The depression of the lever was not recorded as a response nor had any scheduled consequence.

Procedure

Rats were randomly assigned to two groups of 16 subjects each and then received 4 days of magazine training and 20 sessions of conditioning. After that, half of the subjects of each group received 2 sessions of light conditioning and 1 session of the summation test and the other half received 3 sessions of the retardation test. The Groups were labeled Group Aug/Block and Group SOC/CI. Experimental design is depicted in Table 6. Magazine training proceeded as in the previous experiment, in days 1 to 4.

Conditioning

Conditioning began on day 5 and continued until day 24. In each session 18 tones (A), 18 levers (F), 6 tone-click compounds (AX), and 3 clicks were presented (X). For all groups, every tone presentation was followed by a food pellet, acting as US (A+). The 18 levers and 3 clicks were not reinforced (F- and X- respectively). The only difference between the groups was the if a food pellet was presented after the presentation of the tone-click compound. For Group Aug/Block, the 6 tone-click compound trials were followed by a food pellet (AX+), and for Group SOC/CI none of the tone-click compound trials were reinforced (AX-). All other details of the conditioning phase were as in the conditioning phase in Experiment 1.

Inhibitory Tests

On days 25 and 26, half of the subjects of Groups Aug/Block and SOC/CI received a 20 min transfer excitor conditioning session. Ten lights followed by a food pellet (T+) were presented in each session. On day 27, this half of the subjects from each group received a 20 min summation test session. Eight lights followed by a food pellet (T+) and 2 unreinforced light-click compounds (TX-) were presented in two cycles of 4 lights and 1 light-click compound. On days 25 to 27, the other half of the subjects of Groups Aug/Block and SOC/CI, group received a 20 min retardation session, in which 10 click (X) followed by a food pellet were presented. The mean ITI was 80 s (range, 50–110 s).

Table 6

Experimental design for Experiment 2

Group	Training				Inhibitory Tests		
Aug/Block	18 A+	6 AX+	18 F-	3 X-	10 T+	8 T+	2 TX-
						10 X+	
SOC/CI	18 A+	6 AX-	18 F-	3 X-	10 T+	8 T+	2 TX-
						10 X+	

Note. A means tone presentation, F means lever presentation, AX means tone-click compound presentation, X means click presentation and T means light presentation. The numbers before the letters represent the number or trials of that stimulus that was presented in each session. The symbol + means that the stimulus was followed by a food pellet and the symbol – means that the stimulus was not followed by a food pellet.

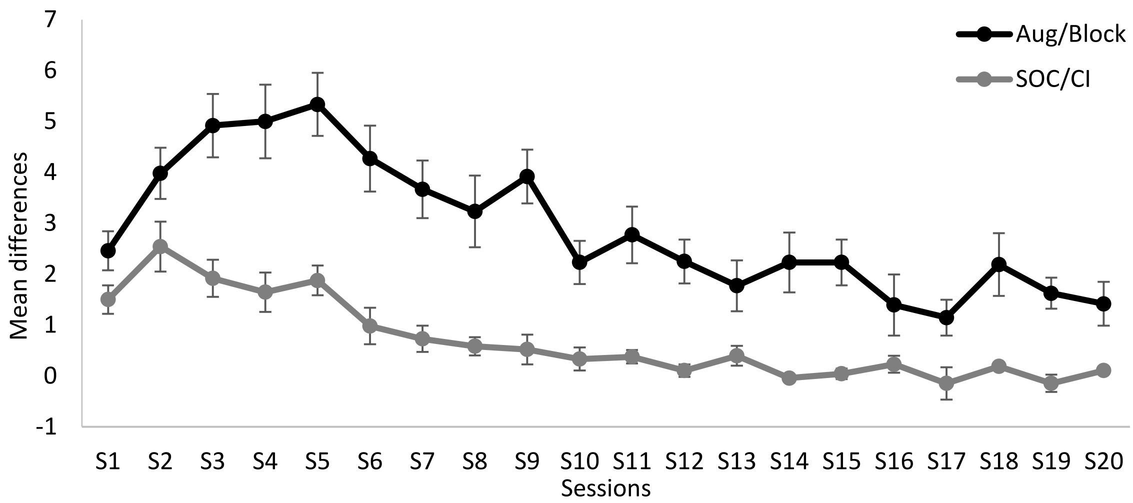
Results

Conditioning

As it can be seen in Figure 4, both groups had a similar response shape to click, that increases in the first sessions and decreases after. For Group SOC/CI, the group in which the compound was not reinforced, response level is lower than for Group Aug/Block, in which the compound was reinforced, throughout the experiment.

Figure 4

Conditioning phase in Experiment 2



Note. PreX-X differences (±SEM) averaged for the three X- presentations per session in conditioning are displayed. The black line represents Group Aug/Bloc, which was trained with 18 A+, 6 AX+, 18 F- and 3 X- presentations per session in conditioning. The grey line represents Group 0, which was trained with 18 A+, 6 AX-, 18 F- and 3 X- presentations per session in conditioning.

A mixed model ANOVA with the within-subjects factor Session and between-groups factor Group showed significant effects for Session [F(6.639, 199.169) = 13.112, p < .001, η_p^2 = .304], Group [F(1, 30) = 70.692, p < .001, η_p^2 = .702] and the interaction Session×Group [F(6.639, 199.169) = 2.227, p = .036, η_p^2 = .069]. Bonferroni corrected pairwise comparisons showed that the groups differed in all sessions (p < .05) except for session 1 and 16. Given that groups showed significant differences, a repeated measures ANOVA was carried for each group. In the group that received AX+, Aug/Block, there was a significant effect for Sessions [F(19, 285) = 6.964, p < .001, η_p^2 = .317]. A simple contrast was carried and sessions from 2 to 9 and session 11 showed significant differences with the last session (p <.05). In the group that received the compound unreinforced, SOC/IC, a significant effect of Session was also found [F(19, 285) = 10.572, p < .001, η_p^2 = .413]. For this group, a simple contrast revealed significant differences (p <.05) with the last session in sessions 1 to 8, all disappeared in the following sessions.

These results indicated that both groups showed an increase in responding in the first part of the experiment, that disappeared in the second part. The initial increase indicated excitatory conditioning in that sessions, that depending on the group can be interpreted as augmentation in the group that received reinforced AX compound, and as SOC in the group that received unreinforced AX compound. Consequently, the decrease in response level on the second part of the experiment could be interpreted as blocking in the reinforced compound group, and as CI in the unreinforced group. To assess if X had acquired inhibitory properties at the end of the experiment, the summation and retardation tests were carried, and their results are presented below.

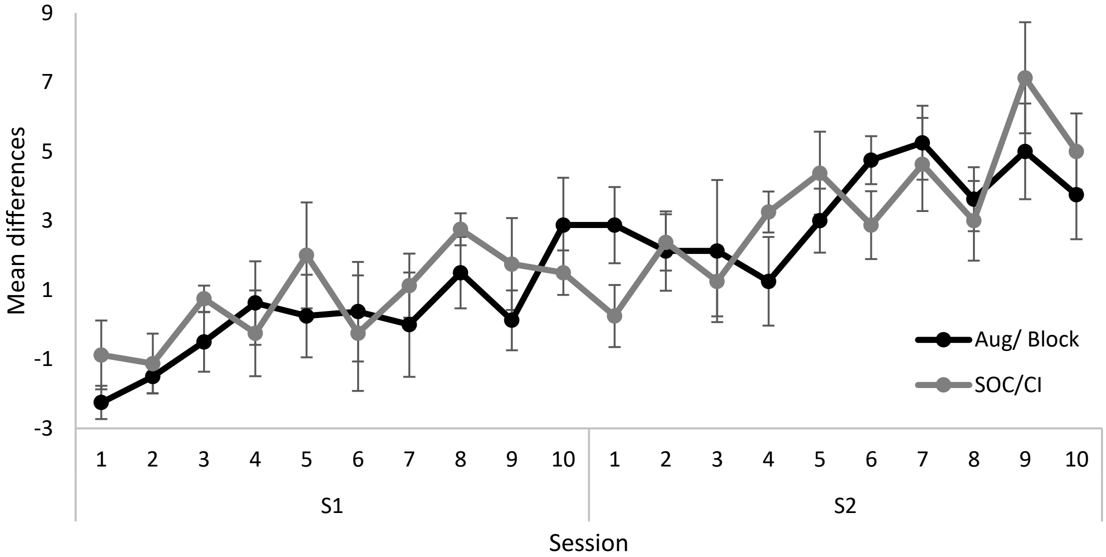
Inhibitory tests

As can be seen in Figure 5, conditioning of the transfer excitor (T+) followed a similar ascending pace for both groups in days 26 and 27.

A mixed-model ANOVA with the within-subjects factor Session and between-groups factor Group showed only a significant effect of factor Session [F(19, 266) = 6.775, p < .001, η_p^2 = .326]. Simple contrast showed that all light presentations after the 8^{th} (included) are significantly different to the first one, thus showing that excitatory conditioning was successfully trained for T.

Figure 5

Transfer excitor conditioning in Experiment 2

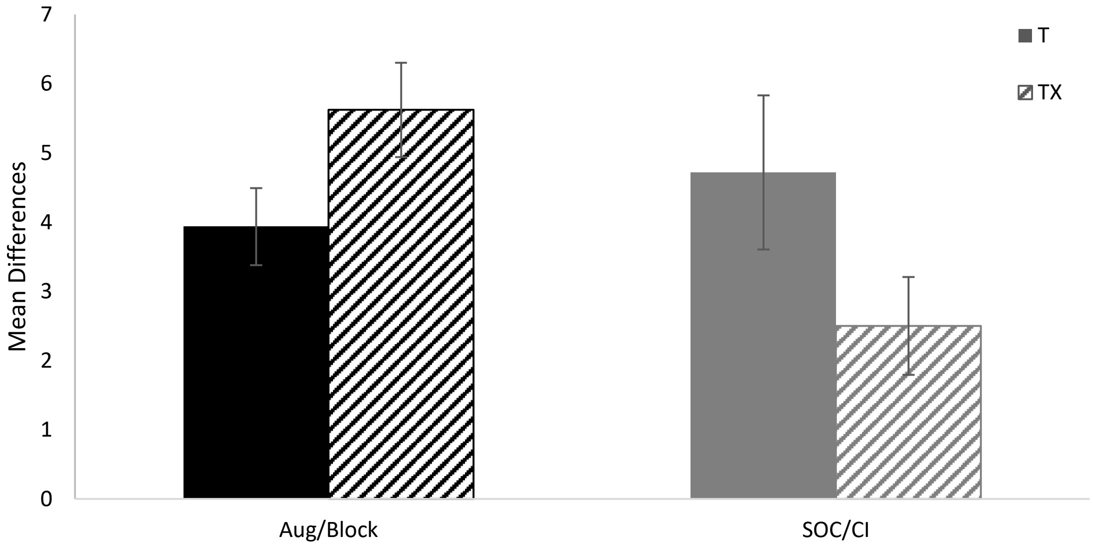


Note. PreT-T differences (±SEM) for each trial of the two transfer excitor conditioning sessions. The black line represents Group Aug/Bloc, which was trained with 18 A+, 6 AX+, 18 F- and 3 X- presentations per session in conditioning. The grey line represents Group SOC/CI, which was trained with 18 A+, 6 AX-, 18 F- and 3 X- presentations per session in conditioning. In the transfer excitor conditioning phase, both groups received 10 T+ presentations.

In Figure 6, results to the summation test for each group are depicted. As can be seen, subjects in the group that received the A+/AX+ training (Aug/Block) showed a slightly higher responding to the TX- compound than to the transfer excitor (T+) alone. However, the opposite was true for the group that received the A+/AX- training (SOC/CI), as responding to TX- was lower than to T+.

Figure 6

Summation test in Experiment 2



Note. Full bars represent the preT-T differences (±SEM) averaged for the eight T+ presentations per session in summation test. Stripped bars represent the preTX-TX differences (±SEM) averaged for the two TX- presentations per session in summation test. Bars in black represent Group Aug/Block, which received 18 A+, 6 AX+, 18 F- and 3 X- presentations per session in conditioning, whereas grey bars represent Group SOC/CI, which received 18 A+, 6 AX-, 18 F- and 3 X- presentations per session in conditioning.

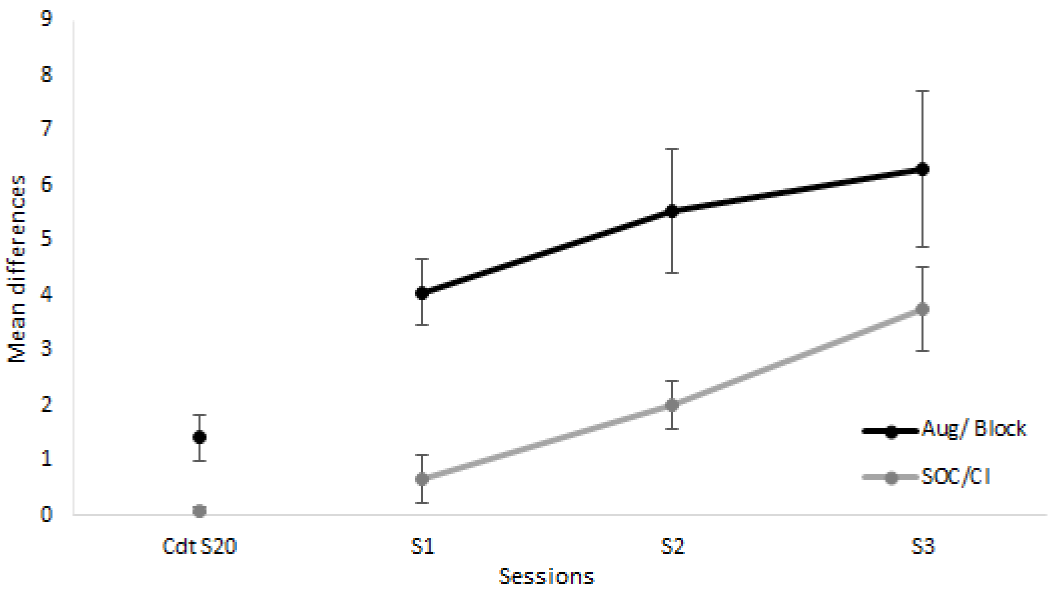
A mixed model ANOVA with the within-subjects factor Stimulus and the between subjects factor Group found only a significant effect of the Stimulus×Group interaction [$F(1, 14) = 10.006$, $p = .007$, $\eta_p^2 = .417$]. Bonferroni corrected pairwise comparisons showed that, for Group Aug/Block, although close, differences between T and TX failed to reach significance [$MD = -1.688$, $SE = .873$, $p = .074$]. For Group SOC/CI, there were significant differences between T and TX [$MD = 2.219$, $SE = .873$, $p = .024$]. This analysis indicated that subjects in Aug/Block group showed similar responding to T+ and TX, thus indicating that, in this group, X did not acquire inhibitory properties. In fact, although non-significant, there was a tendency in the opposite direction, that is, that subjects responded more in the presence of TX than in the presence of T. However, lower responding to TX than T in SOC/CI could indicate that X gained inhibitory properties that lowered responding to the transfer excitor.

As can be seen in Figure 7, responding to X increased in both groups when reinforced. In the group that received the A+/AX+ training in conditioning (Aug/Block) responding increased faster than in the group that received the A+/AX- training in conditioning (SOC/CI), especially when compared with the last session of conditioning phase.

A mixed-model ANOVA for the three retardation sessions showed a significant effect of the factor Session [$F(1.821, 25.488) = 8.74$, $p = .002$, $\eta_p^2 = .384$] and Group [$F(1, 14) = 9.936$, $p = .007$, $\eta_p^2 = .415$]. If the last session of conditioning and the first session of the retardation test are analyzed, all effects are significant [Session: $F(1, 14) = 23.947$, $p < .001$, $\eta_p^2 = .631$; Group: $F(1, 14) = 15.428$, $p = .002$, $\eta_p^2 = .524$; and the Session×Group interaction: $F(1, 14) = 9.834$, $p = .007$, $\eta_p^2 = .413$]. These analyses indicated that, although responding to X increased in both groups, group SOC/CI showed a lower responding than group Aug/Block throughout the retardation test sessions. If this was due to X acquiring inhibitory properties in group SOC/CI was not so clear, as the A+/AX+ treatment that received the Aug/Blocking group is not most adequate control. However, even when this difference was also present during conditioning phase, the significant Session×Group interaction when comparing the last conditioning session and first session of the retardation test indicated that the increase in responding in group Aug/Block was significantly bigger than the increase in group SOC/CI.

Figure 7

Retardation test in Experiment 2



Note. PreX-X differences averaged for the 3 X- presentations of last session of the conditioning phase and for the 10 X- presentations in each of the 3 sessions of the retardation test are displayed. The black line represents Group Aug/Bloc, which was trained with 18 A+, 6 AX+, 18 F- and 3 X- presentations per session in conditioning. The grey line represents Group SOC/CI, which was trained with 18 A+, 6 AX-, 18 F- and 3 X- presentations per session in conditioning. In the retardation test, both groups received 10 X+ presentations.

Taken together, the results of this experiment replicated the previous finding that indicate that in both A+/AX+ and A+/AX- design, there was an increase in responding in the first sessions of training, and that this increase was no longer evident in the last sessions of training, thus suggesting a transition from positive to negative mediation as a function of the training sessions. Also, it has been replicated that when AX is reinforced there is a higher responding throughout the experiment than when AX is not reinforced. The results from the inhibitory tests confirmed that in the A+/AX+ design, X did not acquire inhibitory properties, what would be consistent with the development of blocking. On the other hand, in the A+/AX- design, the inhibitory tests suggested that X developed CI, as there is a significant decrease in responding to T when X is present, and also because there is a slower acquisition of responding to X when reinforced, compared with the group that was trained with the A+/AX+ design. Again, these conclusions rely on within-subjects comparisons along sessions, so in the next experiments, a proper control group for each experimental group was included.

EXPERIMENT 3: A+/AX+ design with control group

In this experiment, the A+/AX+ design used in the previous experiments was replicated, and a proper control group was introduced, to confirm the results that point to the development of Augmentation on the first sessions and Blocking in the last sessions of the previous experiments.

Method

Subjects and apparatus

The subjects were 32 experimentally naive male Wistar rats that were 120 days old and had an ad libitum weight of 401 g (range, 343–474 g). Animal maintenance and apparatus were identical to the previous experiments.

Procedure

Rats were randomly assigned to two groups (Experimental and Control) of 16 subjects each and then received four days of magazine training followed by 20 sessions of conditioning. On the conditioning phase, Group Experimental was presented with 18 reinforced tones (A+), 6 reinforced click compounds (AX+), 18 unreinforced levers (F-) and 3 unreinforced clicks (X-) in each session. Group Control received a similar treatment, except for 18 reinforced lights (B+) were presented instead of 18 reinforced tones (A+) in each session (see Table 7). All other details were identical to Experiment 1.

Table 7

Experimental design for Experiment 3

Group	Training			
Exp	18 A+	6 AX+	18 F-	3 X-
Ctrl	18 B+	6 AX+	18 F-	3 X-

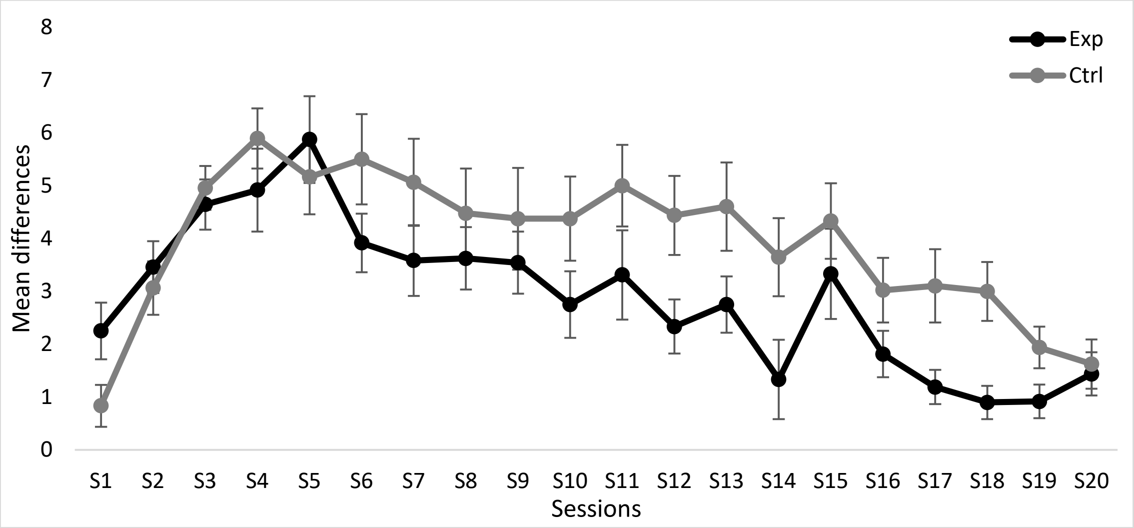
Note. A means tone presentation, B means light presentation, F means lever presentation, AX means tone-click compound presentation and X means click presentation. The numbers before the letters represent the number or trials of that stimulus that was presented in each session. The + means that the stimulus was followed by the US and the – means that the stimulus was not followed by the US.

Results

As it can be seen in Figure 8 responses to X increased in the first sessions for both groups, being higher in the first session for the group that received A+/AX+ training. After session 6, responses in Group Experimental, the one that received A+/AX+ training, start to decrease. In Group Control, which received B+/AX+ training, responses held constant till session 15, decreasing after it. This decrement can be explained as extinction to X, given the fact that it appears alone and without reinforcement several times.

Figure 8

Conditioning phase in Experiment 3



Note. Mean preX-X differences (±SEM) per session are displayed. The black line represents Group Experimental, which was trained with 18 A+, 6 AX+, 18 F- and 3 X- presentations per session in conditioning. The grey line represents Group Control, which was trained with 18 B+, 6 AX+, 18 F- and 3 X- presentations per session in conditioning.

A mixed-model ANOVA with the within-subjects factor Session and the between-groups factor Group was carried out and there were significant effects of the Session [F(9.688, 290.651) = 13.434, p < .001, η_p^2 = .309] and the Session×Group interaction [F(9.688, 290.651) = 2.068, p = .029, η_p^2 = .064]. Bonferroni corrected pairwise comparisons found differences between Groups Experimental and Control in sessions 1 [MD = 1.417, SE = .665, p = .041], 12 [MD = -2.104, SE = .905, p = .027], 14 [MD = -2.313, SE = 1.055, p = .036], 17 [MD = -1.917, SE = .764, p = .041] and 18 [MD = -2.104, SE = .642, p = .003]. In session 1, responding was higher in Group Experimental than in Group Control. In all the other sessions that showed significant differences, responding was higher in Group Control than in Group Experimental.

These analyses indicate that the group that received A+/AX+ training (Group Experimental) responded higher than its control (B+/AX+ training, Group Control) in the first session, a result consistent with the development of excitatory training, a result that is consistent with previous demonstrations of augmentation. In the following sessions, responding in both groups equated, and in the final half of the experiment, responding was higher in control group. As in Group Control excitatory conditioning to X is expected, this lower responding would indicate blocking in Group Experimental. Thus, in this experiment, the transition from positive to negative mediation as a function of the sessions was further confirmed. Likewise, the present results confirmed the results found in Experiments 1 and 2 where the increase in responding in the first sessions in comparison with the last session was interpreted as augmentation. Nevertheless, this effect, when compared with a control group in which X also acquired excitatory properties, was less extended than our previous results suggested, maybe due to a ceiling effect in responding. Also, the absence of responding found in previous experiments was indeed due to blocking of the response to X, as the treatment in the A+/AX+ design employed here was the same as in previous experiments.

This set of three experiments showed a transition from positive to negative mediation as function of sessions when a stimulus A was always reinforced and under different contingencies of reinforcement of AX. This replicates the results in which a transition from SOC to CI was found with increasing number of session within the same training (Rescorla, 1972; Holland & Rescorla, 1975) and extended this finding to the A+/AX+ design, confirming that this transition also happens from augmentation to blocking. Additionally, the overall level of responding was demonstrated to depend on the contingency of reinforcement of AX, a results that is consistent with the predictions of SDT based on changes in the pay-off matrix. This would be further addressed in the general discussion section.

CHAPTER 3: The effect of A+ and AX- trial number

In this chapter, a set of 6 experiments that aimed to examine the effect that the number of both A+ and AX- trials per session have in cue interactions are presented. In these experiments, the design used was always A+/AX- trials, in which the positive mediation phenomenon is SOC, and the negative mediation phenomenon is CI. For this reason, the retardation tests were included at the end of training in all experiments. Also, as in the previous experiments a control group for the A+/AX- design was not included, in Experiments 4 to 8, experimental groups were compared with a control. In the studies that manipulated the number of AX- trials per sessions (Yin et al., 1994; Stout et al., 2004), the total number of trials and the ITI differed between groups, thus being potentially confounding variables. The present set of experiments hold constant the total number of trials per session and ITI and by manipulating the number of A+ and AX- trials per session. An overview of the designs of Experiments 4 to 8 is depicted in Table 8. Experiment 9 compared the level of responding of the different experimental groups used in Experiments 4 to 8.

Table 8

Experimental design for Experiments 4-8

Exp	Group		Conditioning					Retardation test
Exp4	14-2	exp	14 A+	2 AX-	12 F-		2 X-	10X+
		ctrl	14 A+	2 BX-	12 F-		2 X-	10X+
Exp5	11-5	exp	11 A+	5 AX-	3 F+	9 F-	2 X-	10X+
		ctrl	11 A+	5 BX-	3 F+	9 F-	2 X-	10X+
Exp6	8-8	exp	8 A+	8 AX-	6 F+	6 F-	2 X-	10X+
		ctrl	8 A+	8 BX-	6 F+	6 F-	2 X-	10X+
Exp7	5-11	exp	5 A+	11 AX-	9 F+	3 F-	2 X-	10X+
		ctrl	5 A+	11 BX-	9 F+	3 F-	2 X-	10X+
Exp8	2-14	exp	2 A+	14 AX-	12 F+		2 X-	10X+
		ctrl	2 A+	14 BX-	12 F+		2 X-	10X+

Note. A represents tone presentation, B represents light presentation, AX represents tone-click compound presentation, F represents lever presentation and X represents click presentation. The numbers before the letters indicate the number of trials that the stimulus was presented in each session. The + symbol represents that the stimuli were followed by a food pellet and the - symbol represents that the stimuli were not followed by a food pellet.

EXPERIMENT 4: 14 A+ and 2 AX- trials

The design of Experiments 4-8 is depicted in Table 8. In Experiment 4, two groups of rats were trained with an A+/AX- design, similarly to as in previous experiments. During training, both groups received 14 A+ trials and 2 non-reinforced compound trials per session. The difference between groups was that in one group the compound was formed by A and X, whereas in the other group, the compound was formed by B and X, thus acting as a control for SOC and CI. After conditioning, both groups were tested for inhibitory properties using a retardation test, i.e. presenting X followed by the US. It was expected that the subjects in the experimental group would develop a higher responding to X in the first sessions of the experiment, which would indicate SOC, and that, with extended training, responding would equate with the control group. Regarding CI, according to the results reported by Rescorla (1972) and by Holland and Rescorla (1975), it would be expected to occur, but based on the results by Yin et al. (1994) and Stout et al. (2004), with few AX- trials only SOC would be expected.

Method

Subjects and apparatus

Subjects were 16 experimentally naive male Wistar rats that were 100 days old and had an ad libitum weight of 408 g (range, 343–474 g). Housing, deprivation schedule and apparatus were the same as in previous experiments.

Procedure

Rats were randomly assigned to two groups of eight subjects each and then received 4 days of magazine training followed by 20 sessions of conditioning and 4 sessions of the retardation test. The groups were labelled 14-2Exp and 14-2Ctrl.

The effect of A+ and AX- trial number

Each conditioning session lasted 40 min. The subjects in Group 14-2Exp received 14 tones followed by a food pellet (A+), 2 unreinforced tone-click compounds (AX-),12 unreinforced levers (F-) and 2 unreinforced clicks (X-) per session. The training for 14-2Ctrl Group was identical to the one to 14-2Exp, except for 2 light-click compounds (BX-) were presented instead 2 tone-click compounds (AX-). All other details were identical to the previous experiments.

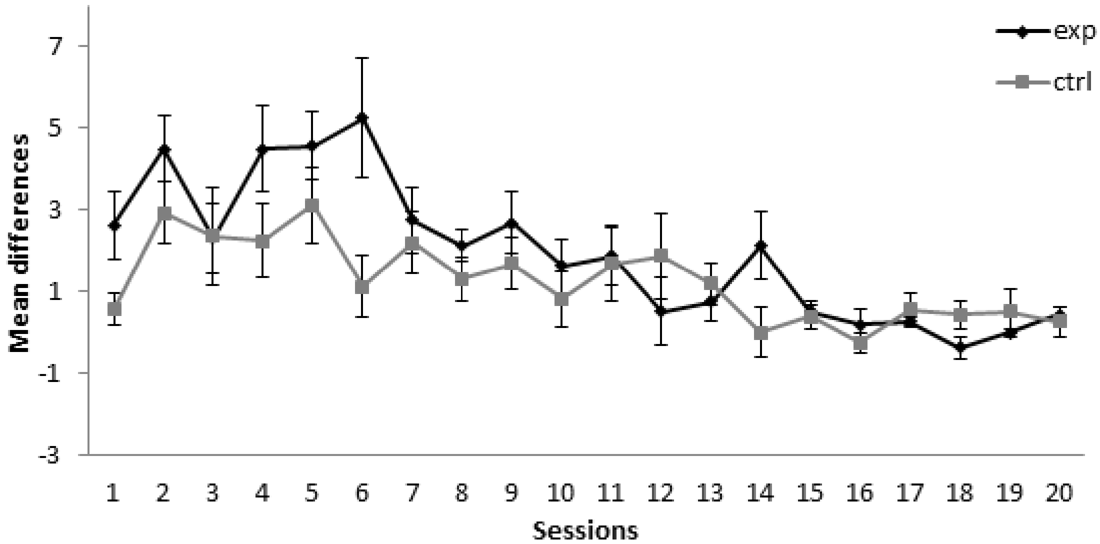
Results

During conditioning phase, subjects in Group 14-2Exp, the one in which A+ was presented 14 times and AX- was presented twice, showed higher responding to X than its control, where BX- was presented instead of AX-, in the first sessions, equating with it around session 7, as can be seen in Figure 9.

A mixed model ANOVA with the between-subjects factor Group and the within-subjects factor Session found significant main effect of the Session [$F(19, 266) = 7.001$, $p < .001$, $\eta_p^2 = .333$] and the Session×Group interaction [$F(19, 266) = 1.876$, $p = .016$, $\eta_p^2 = .118$]. Bonferroni-corrected pairwise comparisons for the interaction showed that there were significant differences between the experimental and control groups in session 1 [$MD = 2.063$, $SE = 0.912$, $p = 0.04$] and session 6 [$MD = 4.125$, $SE = 1.663$, $p = 0.026$]. These analyses indicate that the subjects in the group that received 14 A+ and 2 AX- presentations per session developed a significantly higher response to the click (X) than the subjects that received 14 A+ and 2 BX- presentations per session in sessions 1 and 6, a result that is congruent with the development of SOC.

Figure 9

Conditioning phase in Experiment 4



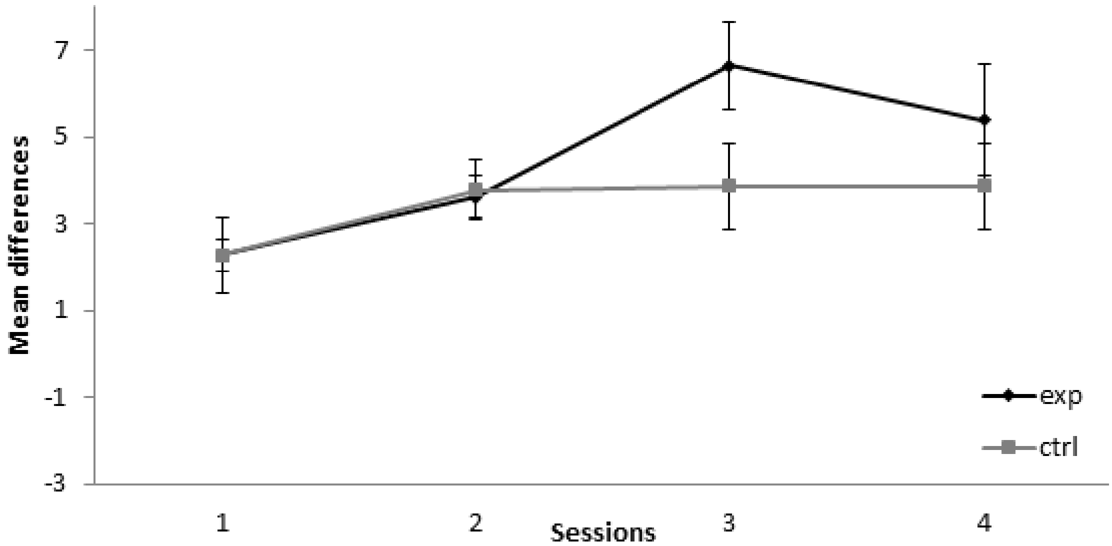
Note. PreX-X differences (±SEM), averaged for the two X– presentations per session in conditioning, are displayed. The black line represents the group that was trained with 14 A+, 2 AX–, 12 F–, and 2 X– presentations per session in conditioning. The grey line represents the group that was trained with 14 A+, 2 BX, 12 F–, and 2 X– presentations per session.

In the retardation test, responses to X in the group that received the 14A+/2AX- treatment (group 14-2Exp) showed no differences with the control group in the first two sessions. In contrast, responding to X by group 14-2Exp was higher than in the control group in sessions 3 and 4, as can be seen in Figure 10.

A mixed-model ANOVA with the between-subjects factor Group and the within-subjects factor Session found only a significant main effect of Session [$F(3,42) = 7.344$, $p < 0.001$, $\eta_p^2 = 0.344$]. This analysis indicated that both groups increased their responding to X over sessions in a similar way. The absence of a significant group effect in the analysis indicated that, in group 14-2Exp, X did not gain inhibitory properties.

Figure 10

Retardation test in Experiment 4



Note. PreX-X differences (±SEM), averaged for the 10 X+ presentations per session in the retardation test, are displayed. The black line represents the group that was trained with 14 A+, 2 AX–, 12 F–, and 2 X– presentations per session in conditioning. The grey line represents the group that was trained with 14 A+, 2 BX, 12 F–, and 2 X– presentations per session. In the retardation test, both groups received 10 X+ presentations per session.

Taken together, the results of this experiment indicated that the group that was trained with 14 A+ and 2 AX- presentations per session showed an increase in responding to X in sessions 1 and 6, which might indicate the development of SOC in those sessions. However, the absence of a difference between the two groups in the retardation test indicates that it did not develop CI.

EXPERIMENT 5: 11 A+ and 5 AX- trials

The purpose of Experiment 5 was to further examine the effect of A+ trials/AX- trials ratio. The experiment was virtually identical to Experiment 1, except for the treatment in conditioning, where Group 11-5Exp received 11 A+ and 5 AX- presentations per session and Group 11-5Ctrl received 11 A+ and 5 BX- presentations per session. It was expected that lowering the number of A+ trials and increasing the number of AX- trials would lead to the development of CI at the end of training, without abolishing SOC in the first sessions.

Method

Subjects and apparatus

Subjects were 16 experimentally naive male Wistar rats that were 71 days old and had an ad libitum weight of 293 g (range, 254–356 g). Housing, deprivation schedule and apparatus were identical to the previous experiments.

Procedure

Rats were randomly assigned to two groups of 8 subjects each and then received 4 days of magazine training followed by 20 sessions of conditioning and 4 sessions of the retardation test. The groups were labelled 11-5Exp and 11-5Ctrl.

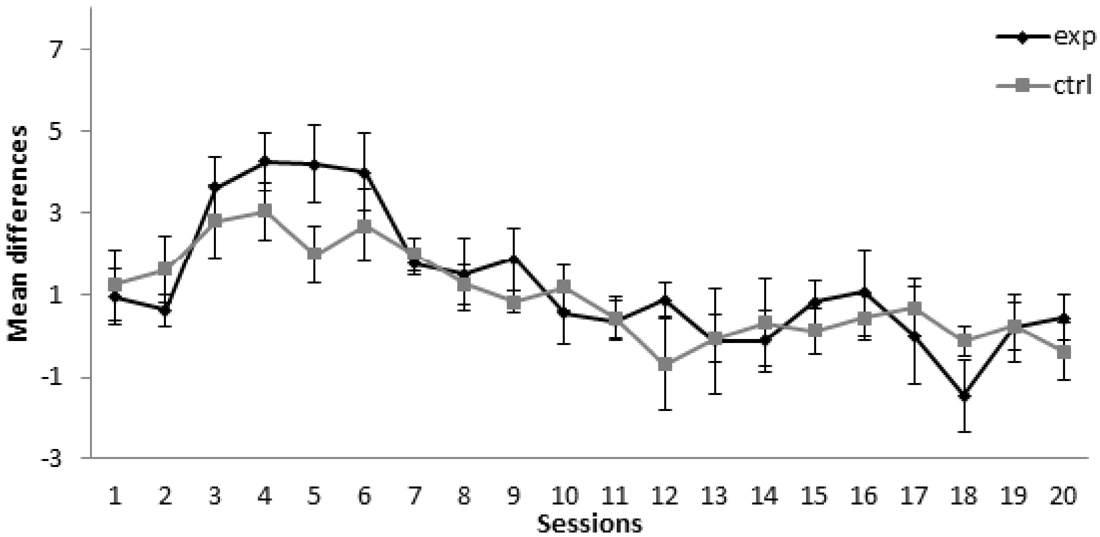
The subjects in Group 11-5Exp received 11 tones followed by a food pellet (A+), 5 unreinforced tone-click compounds (AX-), 9 unreinforced levers (F-), 3 levers followed by a food pellet (F+) and 2 unreinforced clicks (X-) per session. The training for 11-5Ctrl Group was identical to the one to 11-5Exp, except for 5 light-click compounds (BX-) were presented instead 5 tone-click compounds (AX-). All other details were identical to Experiment 4.

Results

During conditioning, subjects in Group 11-5Exp, the one where A+ was presented 11 times and AX- was presented 5, showed higher responding to X than its control, where BX- was presented instead of AX-, in sessions 3 to 6, equating around session 7, as can be seen in Figure 11.

Figure 11

Conditioning phase in Experiment 5



Note. PreX-X differences (±SEM), averaged for the two X– presentations per session in conditioning, are displayed. The black line represents the group that was trained with 11 A+, 5 AX–, 3 F+, 9 F–, and 2 X– presentations per session in conditioning. The grey line represents the group that was trained with 11 A+, 5 BX, 3 F+, 9 F–, and 2 X– presentations per session.

A mixed-model ANOVA with the between-subjects factor Group and the within-subjects factor Session found statistically significant differences for Session [F(19, 266) = 5.805, p < .001, η_p^2 = .293, but not for the Group nor for the

Session×Group interaction. A simple contrast found statistically significant differences between sessions from 3 to 7 and 9 with session 20. The absence of Group and Session×Group might be due to the high number of sessions in which responding was similar between both groups. It is worth noting the ANOVA was repeated for the sessions 3 to 6, a significant effect of the Group was found [$F(1, 14) = 5.043$, $p = .041$, $\eta_p^2 = .265$]. Group effect is no longer significant if the rest of sessions are analyzed. These analyses indicate that in sessions 3 to 6, subjects that received a 11A+/5AX- treatment responded significantly higher than subjects that received a 11A+/5BX- treatment, suggesting that X gained excitatory properties in these sessions. However, in the absence of Group and Session×Group interaction in the omnibus ANOVA, these results should be taken prudently.

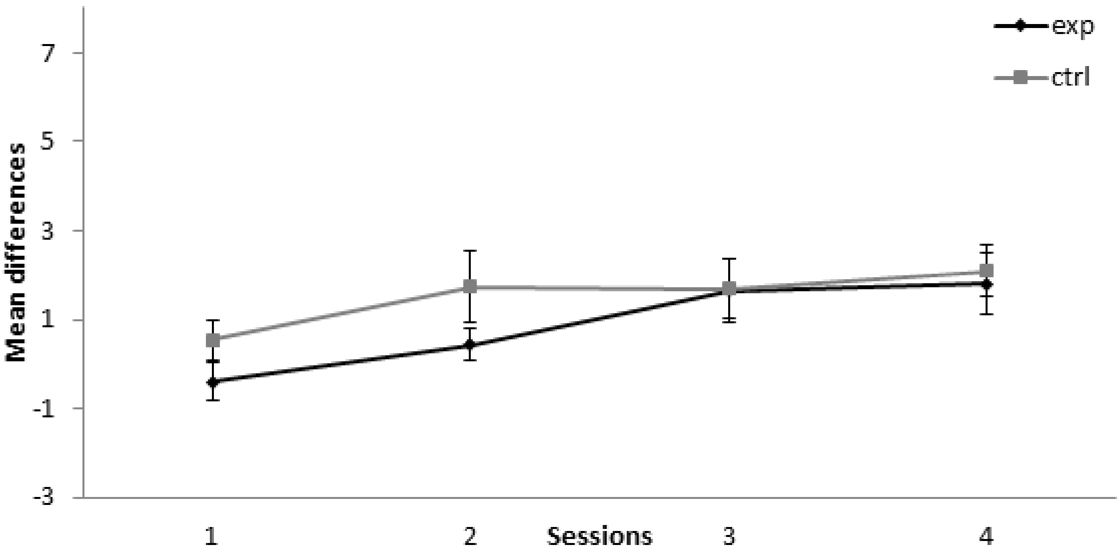
As can be seen in Figure 12, in the retardation test, for the Group that received the 11A+/5AX- treatment, responding was lower than its control in sessions 1 and 2, equating with it in sessions 3 and 4.

A mixed-model ANOVA with the between-subjects factor Group (Exp or Ctrl) and the within-subjects factor Session found significant the main effect of the Session [$F(3, 42) = 4.654$, $p = .007$, $\eta_p^2 = .25$]. A simple contrast found differences between session 1 and session 4. The absence of Group effect in this analysis indicates that inhibitory learning was not developed in 11-5Exp Group.

All in all, the results of Experiment 5 showed that the group that was trained with 11 A+ and 5 AX- presentations per session exhibited an increase in responding to X in the first sessions congruent with the development of SOC. In the retardation test, Group 11-5Exp showed a tendency to CI, although this tendency was not statistically significant.

Figure 12

Retardation test in Experiment 5



Note. PreX-X differences (±SEM), averaged for the 10 X– presentations per session in the retardation test, are displayed. The black line represents the group that was trained with 11 A+, 5 AX–, 3 F+, 9 F–, and 2 X– presentations per session in conditioning. The grey line represents the group that was trained with 11 A+, 5 BX, 3 F+, 9 F–, and 2 X– presentations per session. Both groups received 10 X- presentations in the retardation test.

EXPERIMENT 6: 8 A+ and 8 AX- trials

Experiment 3 aimed to broaden these series of experiments with a group in which the amount of A+ and AX- trials was equal, i.e. eight trials of each type per session. With this treatment, it was expected to find excitatory properties at the beginning of training and inhibitory properties at the end. This experiment included a control group and a retardation test identical to the ones employed in the experiments above. In this experiment, as the number of both A+ and AX- trials was intermediate, both SOC (in the first trials) and CI (at the end) were expected.

Method

Subjects and apparatus

Subjects were 15 experimentally naive male Wistar rats that were 86 days old and that had an ad libitum weight of 459 g (range, 420–515 g). Housing, deprivation schedule and apparatus were identical to previous experiments.

Procedure

Rats were randomly assigned to two groups and then received 4 days of magazine training followed by 20 sessions of conditioning and 4 sessions of the retardation test. The groups were labelled 8-8Exp and 8-8Ctrl. Group 8-8Exp had 8 subjects and Group 8-8Ctrl had 7 subjects.

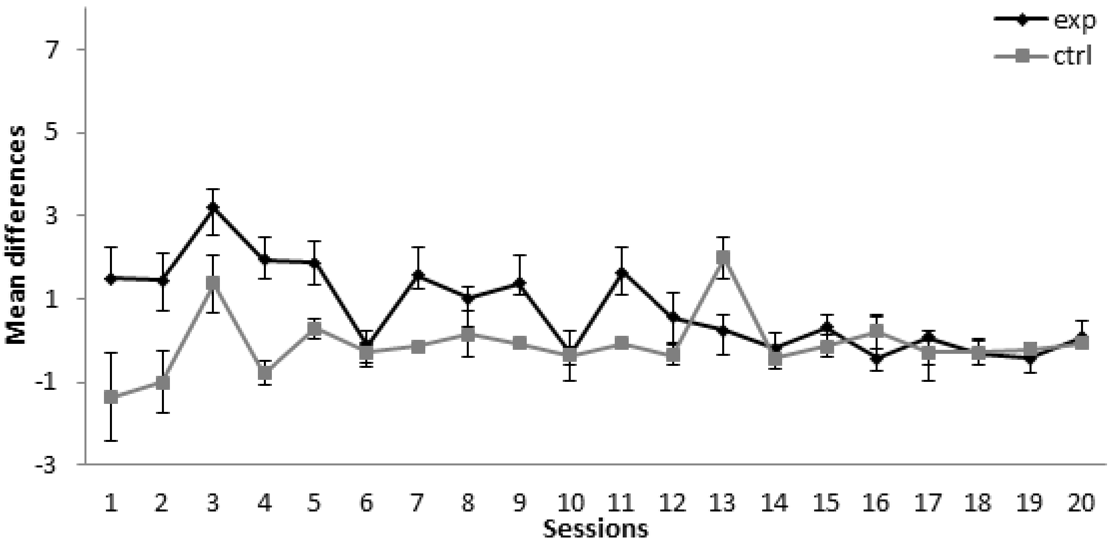
The subjects in Group 8-8Exp received 8 tones followed by a food pellet (A+), 8 unreinforced tone-click compounds (AX-), 6 unreinforced levers (F-), 6 levers followed by a food pellet (F+) and 2 unreinforced clicks (X-) per session. The training for 8-8Ctrl Group was identical to the one to 8-8Exp, except for 8 light-click compounds (BX-) were presented instead 8 tone-click compounds (AX-). All other details were identical to Experiments 4 and 5.

Results

During conditioning, subjects in Group 8-8Exp, those that were presented 8A+ and 8AX-, showed a higher responding to X than its control (8-8Ctrl), that were presented BX- instead of AX-, in the first 12 sessions, as can be seen in Figure 13.

Figure 13

Conditioning phase of Experiment 6



Note. PreX-X differences (±SEM), averaged for the two X– presentations per session in conditioning, are displayed. The black line represents the group that was trained with 8 A+, 8 AX–, 6 F+, 6 F–, and 2 X– presentations per session in conditioning. The grey line represents the group that was trained with 8 A+, 8 BX–, 6 F+, 6 F–, and 2 X– presentations per session.

A mixed-model ANOVA found statistically significant effects for the main effects Session [$F(19, 247) = 3.777$, $p < .001$, $\eta_p^2 = .225$], Group [$F(1, 13) = 18.485$, $p = .001$, $\eta_p^2 = .587$] and Session×Group interaction [$F(19, 247) = 3.081$, $p < .001$, $\eta_p^2 = .192$]. Bonferroni-corrected pairwise comparisons for the interaction showed that there were significant differences between the experimental and the control groups in session 1 [*MD* = 2.857, *SE* = 1.258, *p* = 0.041], session 2 [*MD*= 2.438, *SE* = 0.992, *p* = 0.029], session 3 [*MD* = 1.83, *SE* = 0.79, *p* = 0.038], session 4 [*MD* = 2.723, *SE* = 0.652, *p* = 0.001], session 5 [*MD* = 1.589, *SE* = 0.606, *p* = 0.021], session 7 [*MD* = 1.705, *SE* = 0.712, *p* = 0.032], session 11 [*MD* = 1.696, *SE* = 0.682, *p* = 0.027] and session 13 [*MD* = -1.75, *SE* = 0.6, *p* = 0.012]. The experimental group showed an increase in responding to X in sessions 1, 2, 3, 4, 5, 7, and 11, which is congruent with subjects acquiring SOC. There was also a significant higher responding in control group in session 13.

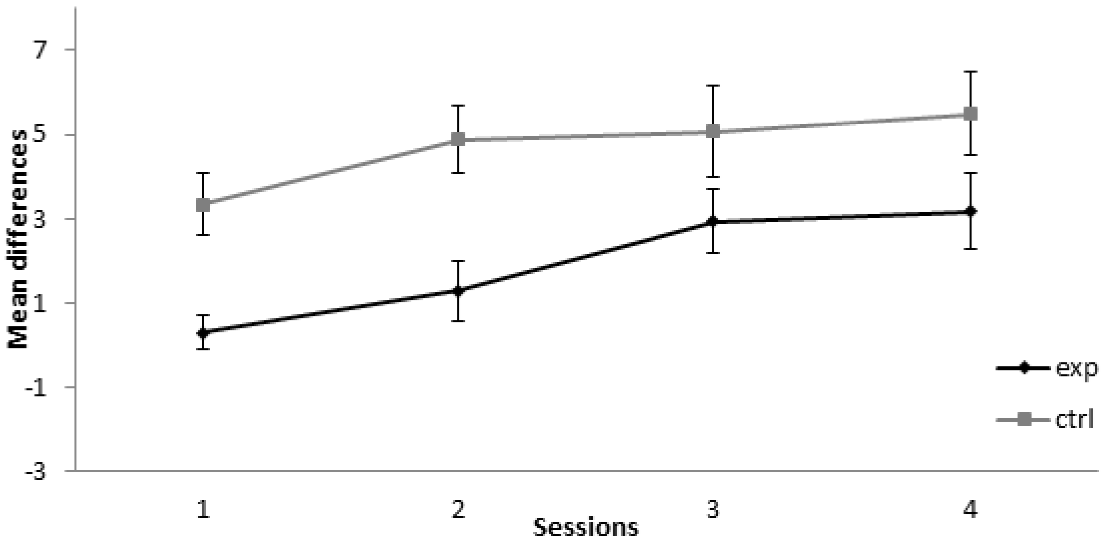
As can be seen in Figure 14, during the retardation test, experimental group, the one that received the 8A+/8AX- treatment, showed a lower responding than control Group along all sessions.

A mixed-model ANOVA found statistically significant effects for the main effects Session [$F(2.246, 29.202) = 10.688$, $p < .001$, $\eta_p^2 = .451$] and Group [$F(1, 13) = 7.745$, $p = .016$, $\eta_p^2 = .373$] but not for the Session×Group interaction. These analyses showed that there was retardation in the acquisition of conditioning in experimental Group compared with its control, thus indicating that X gained inhibitory properties.

Altogether, the results of this experiment indicated that, when 8A+ and 8AX- trials are presented per sessions, responding to X increases in the first sessions, a result consistent with SOC, and at the end of training, that X showed a significant retardation in conditioning when paired with reinforcement, thus indicating inhibitory properties consistent with CI.

Figure 14

Retardation test of Experiment 6



Note. PreX-X differences (±SEM), averaged for the 10 X– presentations per session in the retardation test, are displayed. The black line represents the group that was trained with 8 A+, 8 AX–, 6 F+, 6 F–, and 2 X– presentations per session in conditioning. The grey line represents the group that was trained with 8 A+, 8 BX–, 6 F+, 6 F–, and 2 X– presentations per session. In the retardation test, both groups received 10 X- presentations per session.

EXPERIMENT 7: 5 A+ and 11 AX- trials

It would be interesting to assess if a greater number of AX- trials would prevent that development of SOC while not affecting the development of CI. Experiment 7 was designed to assess this question by increasing the number of AX- trials and decreasing, accordingly, the number of A+ trials. In order to achieve this aim, the experimental group received 5 A+ and 11 AX- presentations per session. It was compared with a control group that received 5 A+ and 11 BX- presentations per session.

Method

Subjects and apparatus

Subjects were 14 experimentally naive male Wistar rats that were 71 days old and had an ad libitum weight of 247 g (range, 224–279 g). Housing, deprivation schedule and apparatus were identical to Experiments 4, 5 and 6.

Procedure

Rats were randomly assigned to two groups of 7 subjects each and then received 4 days of magazine training followed by 20 sessions of conditioning and 4 sessions of the retardation test. The groups were labelled 5-11Exp and 5-11Ctrl.

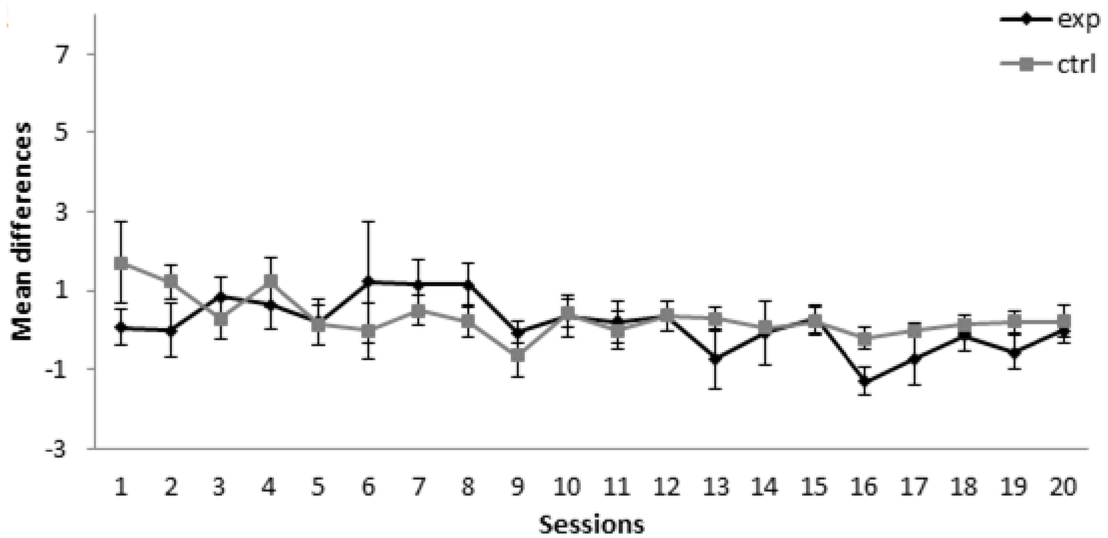
The subjects in Group 5-11Exp received 5 tones followed by a food pellet (A+), 11 unreinforced tone-click compounds (AX-), 3 unreinforced levers (F-), 9 levers followed by a food pellet (F+) and 2 unreinforced clicks (X-) per session. The training for 5-11Ctrl Group was identical to the one to 5-11Exp, except for 11 light-click compounds (BX-) were presented instead 11 tone-click compounds (AX-). All other details were identical to Experiments 4, 5 and 6.

Results

During conditioning, subjects in groups 5-11Exp and 5-11Ctrl, in which A+ was presented 5 times and AX- or BX- were presented 11 times, had a similar level of responding throughout the experiment, as can be seen in Figure 15.

Figure 15

Conditioning phase of Experiment 7



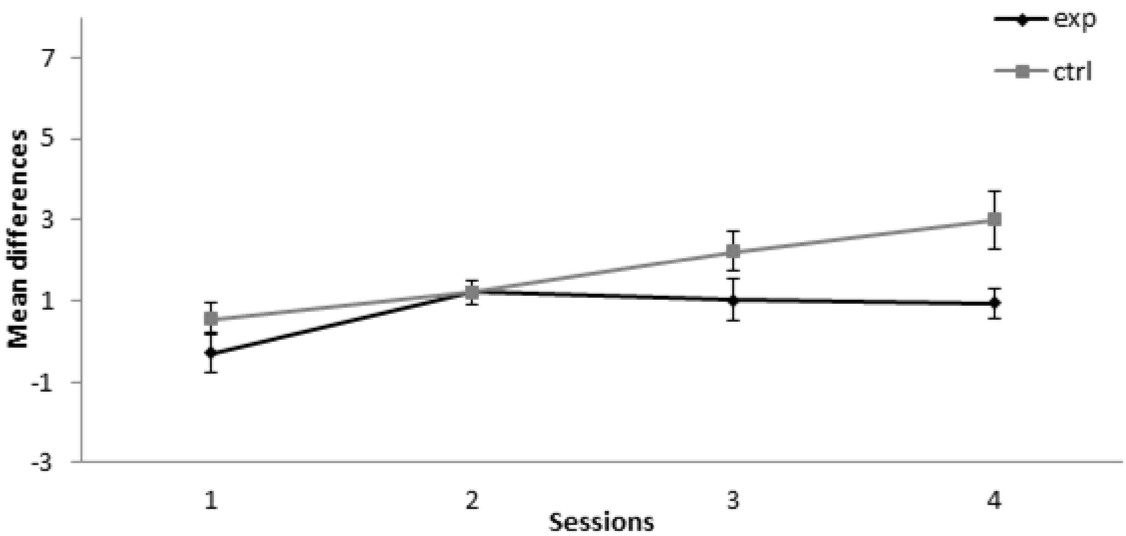
Note. PreX-X differences (±SEM), averaged for the two X– presentations per session in conditioning, are displayed. The black line represents the group that was trained with 5 A+, 11 AX–, 3 F+, 9 F–, and 2 X– presentations per session in conditioning. The grey line represents the group that was trained with 5 A+, 11 BX–, 3 F+, 9 F–, and 2 X– presentations per session.

A mixed-model ANOVA with the between-subjects factor Group and the within-subjects factor Session found no statistically significant effects nor significant interaction. The absence of significant differences indicated that subjects in Group 5-11Exp did not develop excitatory learning for X at any point of the experiment.

In the retardation test, the Group that received the 5A+/11AX- treatment showed a response level lower than its control in all sessions except for session 2, as can be seen in Figure 16.

Figure 16

Retardation test of Experiment 7



Note. PreX-X differences (±SEM), averaged for the 10 X– presentations per session in the retardation test, are displayed. The black line represents the group that was trained with 5 A+, 11 AX–, 3 F+, 9 F–, and 2 X– presentations per session in conditioning. The grey line represents the group that was trained with 5 A+, 11 BX–, 3 F+, 9 F–, and 2 X– presentations per session. In the retardation test, both groups received 10 X- presentations per session.

A mixed-model ANOVA with the between-subjects factor Group and the within-subjects factor Session found significant the main effect of the Session [$F(3, 36) = 7.18$, $p = .001$, $\eta_p^2 = .374$] and the effect of the Group [$F(1, 12) = 5.692$, $p = .034$, $\eta_p^2 = .322$]. This analysis indicated that there was a lower responding in the group that was trained with 5 A+ and 11 AX- trials, thus indicating that inhibitory conditioning was developed for X in 5-11Exp Group.

All in all, the results of Experiment 7 showed that the group that was trained with 5 A+ and 11 AX- presentations per session did not exhibit an increase in responding to X at any point of the experiment, thus indicating that SOC was not developed. However, in the retardation test, Group 5-11Exp showed a lower responding, a result congruent with the development of CI in this Group.

EXPERIMENT 8: 2 A+ and 14 AX-

The purpose of Experiment 8 was to complete the experimental series with a group that received 2 A+ trials and 14 AX- trials during conditioning. A control group that received 14 BX- trials instead 14 AX- trials was also included. In this experiment, SOC was not expected as in the previous one, but CI should be evident at the end of training.

Method

Subjects and apparatus

Subjects were 16 experimentally naive male Wistar rats that were 78 days old and had an ad libitum weight of 414 g (range, 352–447 g). Housing, deprivation schedule and apparatus were identical to Experiments 4, 5, 6 and 7.

Procedure

Rats were randomly assigned to two groups of 8 subjects each and then received 4 days of magazine training followed by 20 sessions of conditioning and 4 sessions of the retardation test. The groups were labelled 2-14Exp and 2-14Ctrl.

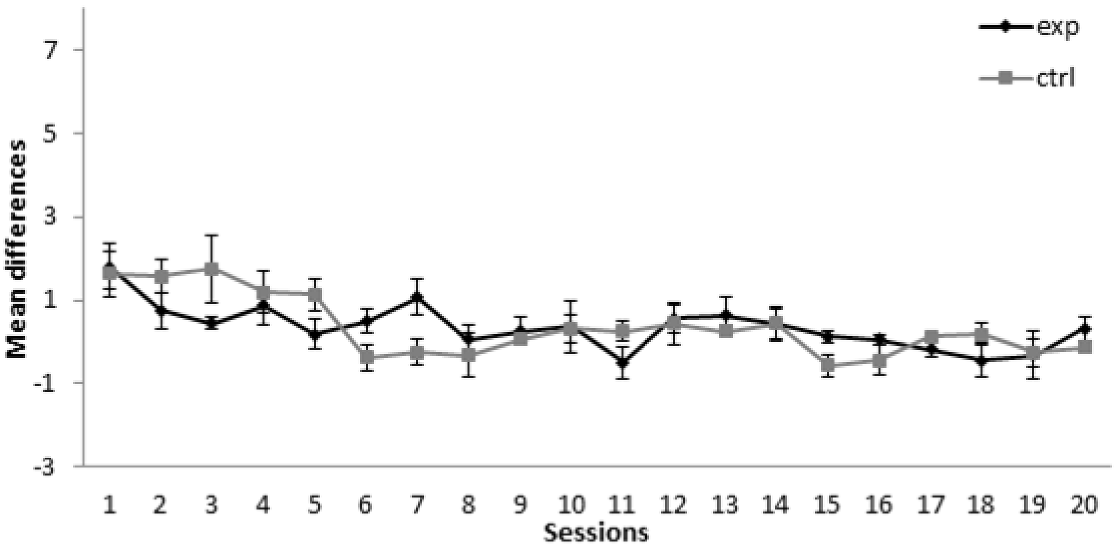
The subjects in Group 2-14Exp received 2 tones followed by a food pellet (A+), 14 unreinforced tone-click compounds (AX-), 12 levers followed by a food pellet (F+) and 2 unreinforced clicks (X-) per session. The training for 2-14Ctrl Group was identical to the one to 2-14Exp, except for 14 light-click compounds (BX-) were presented instead 14 tone-click compounds (AX-). All other details were identical to Experiments 4, 5, 6 and 7.

Results

As can be seen in Figure 17, both groups, in which A+ was presented twice and AX- or BX- were presented 14 times, had a similar responding throughout the conditioning phase.

Figure 17

Conditioning phase of Experiment 8



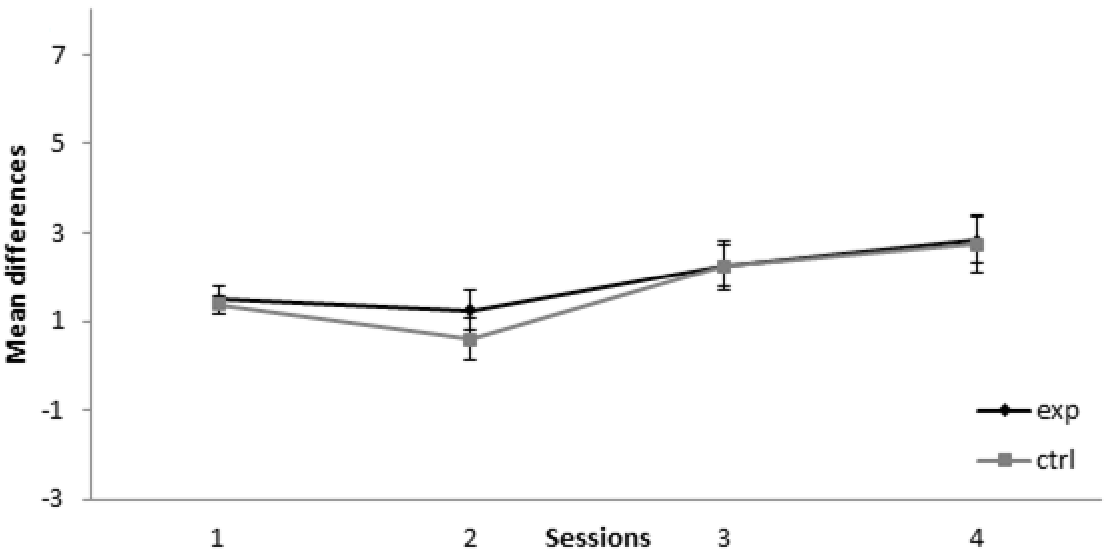
Note. PreX-X differences (±SEM), averaged for the two X– presentations per session in conditioning, are displayed. The black line represents the group that was trained with 2 A+, 14 AX–, 12 F+, and 2 X– presentations per session in conditioning. The grey line represents the group that was trained with 2 A+, 14 BX–, 12 F+, and 2 X– presentations per session.

A mixed-model ANOVA with the between-subjects factor Group and the within-subjects factor Session found statistically significant the effect of Session [F(19, 266) = 4.067, p < .001, η_p^2 = .225] but not the Group nor their interaction. A simple contrast found statistically significant differences between sessions 1, 2, 3 and 4 with the last session, what indicates that the level of responding was higher in the first sessions and decreased as the sessions passed. The absence of significant differences indicated that subjects in Group 2-14Exp did not develop excitatory learning for X at any point of the experiment.

For the Group that received the 2A+/14AX- treatment (2-14Exp), the response level was similar to its control throughout the sessions of the retardation test, as can be seen in Figure 18.

Figure 18

Retardation test of Experiment 8



Note. PreX-X differences (±SEM), averaged for the 10 X– presentations per session in the retardation test, are displayed. The black line represents the group that was trained with 2 A+, 14 AX–, 12 F+, and 2 X– presentations per session in conditioning. The grey line represents the group that was trained with 2 A+, 14 BX–, 12 F+, and 2 X– presentations per session. In the retardation test, both groups received 10 X-presentations per session.

A mixed-model ANOVA with the between-subjects factor Group and the within-subjects factor Session found statistically significant the main effect of Session [$F(3, 42) = 9.751$, $p < .001$, $\eta_p^2 = .411$]. A simple contrast found differences between the sessions 1 and 2 with session 4. The absence of a significant Group effect in all the analyses indicated that X in Group 2-14Exp did not gain inhibitory properties.

All in all, the results of Experiment 8 showed that the Group that was trained with 2 A+ and 14 AX- presentations per session did not exhibit an increase in responding to X at any point of the experiment nor a lower responding in the retardation test, thus indicating that subjects in Group 2-14Exp did not developed nor SOC neither CI developed, maybe due to the so few A+ trials employed in training.

EXPERIMENT 9: Comparison of the level of responding as a function of A+ and AX- trials

The aim of Experiment 9 was to directly compare the level of responding reached both in conditioning and in the retardation test of the experimental groups of the previous experiments in which the number of A+ and AX- trials was varied. Based on the previous results, it was expected that the higher was the A+/AX- proportion, the higher would be responding in both the conditioning phase and the retardation test.

Method

Subjects and apparatus

Subjects were 40 experimentally naive male Wistar rats that were 80 days old and had an ad libitum weight of 257 g (range, 122–307 g). Housing, deprivation schedule and apparatus were identical to Experiments 4 to 8.

Procedure

Rats were randomly assigned to five groups of eight subjects each and then received 4 days of magazine training followed by 20 sessions of conditioning followed by 4 sessions of the retardation test. The groups were labelled 14-2, 11-5, 8-8, 5-11 and 2-14 according to the training in the conditioning sessions.

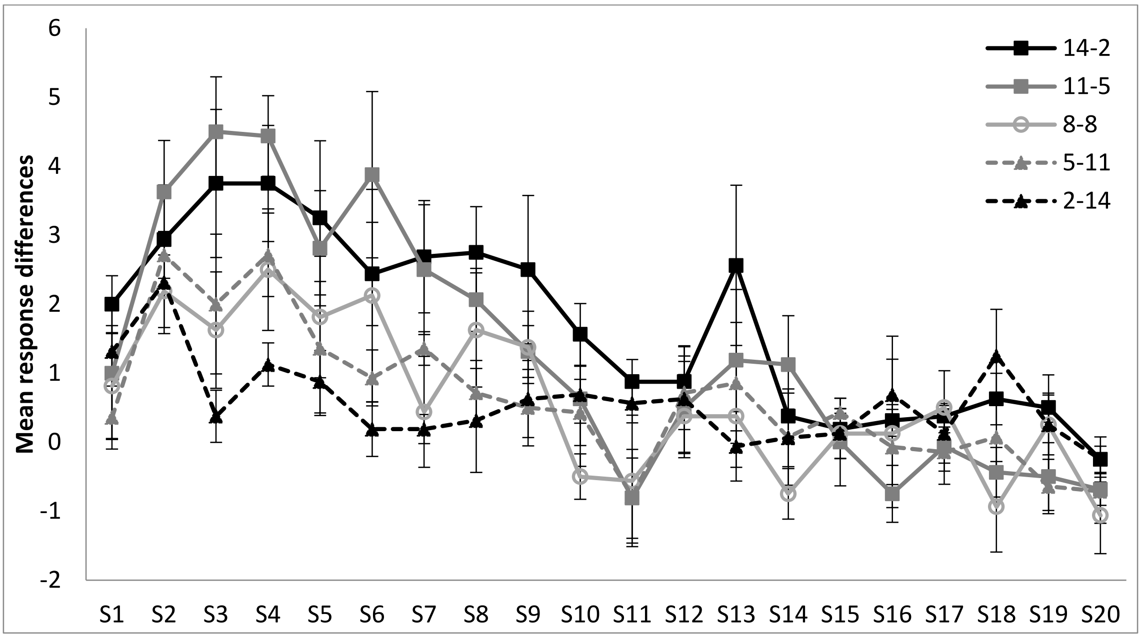
Subjects in Group 14-2 received 14 tones followed by a food pellet (A+), 2 non-reinforced tone-click compounds (AX-), 12 non-reinforced presentations of the lever (F-) and 2 non-reinforced clicks (X-) per session. Subjects in Group 11-5 received 11 tones followed by a food pellet (A+), 5 non-reinforced tone-click compounds (AX-), 3 presentations of the lever followed by a food pellet (F+), 9 non-reinforced presentations of the lever (F-) and 2 non-reinforced clicks (X-) per session. Group 8-8 received 8 tones followed by a food pellet (A+), 8 non-reinforced tone-click compounds (AX-), 6 presentations of the lever followed by a food pellet (F+), 6 non-reinforced presentations of the lever (F-) and 2 non-reinforced clicks (X-) per session. Group 5-11 received 5 tones followed by a food pellet (A+), 11 non-reinforced tone-click compounds (AX-), 9 presentations of the lever followed by a food pellet (F+), 3 non-reinforced presentations of the lever (F-) and 2 non-reinforced clicks (X-) per session. Subjects in Group 2-14 received 2 tones followed by a food pellet (A+), 14 non-reinforced tone-click compounds (AX-), 12 presentations of the lever followed by a food pellet (F+) and 2 non-reinforced clicks (X-) per session. All other details were identical to Experiments 4 to 8.

Results

As can be seen in Figure 19, all groups showed a higher responding in the first sessions of the conditioning phase than in the last sessions. However, this progression was different for each group. Responding was similar in all groups on the first session. Group 14-2 showed a higher responding than Groups 8-8, 5-11 and 2-14 from session 3 to session 10, then had a similar responding to the rest of the groups, except for a peak in responding in session 13. Group 11-5 showed the highest responding in sessions 2 to 4 and 6. In sessions 5 and 7 showed a similar responding to Group 14-2, still higher than Groups 8-8, 5-11 and 2-14, and responding matched these groups around session 9 to the end of the conditioning phase. Groups 8-8 and 5-11 showed a similar intermediate level of responding, lower than in Groups 14-2 and 11-5 and higher in than Group 2-14, in sessions 3 and 4. Responding in those groups remained higher than in Group 2-14 until session 9, with responding in Group 8-8 being higher than in Group 5-11, except for session 7, when Group 8-8 had a similar responding to Group 2-14.

Figure 19

Conditioning phase in Experiment 9



Note. PreX-X differences (±SEM), averaged for the two X– presentations per session in conditioning, are displayed. The black continuous line represents the group that was trained with 14 A+, 2 AX–, 12 F-, and 2 X– presentations per session in conditioning. The dark grey continuous line represents the group that was trained 11 A+, 5 AX–, 9 F–, 3 F+, and 2 X– presentations per session in conditioning. The light grey continuous line represents the group that was trained 8 A+, 8 AX–, 6 F–, 6 F+, and 2 X– presentations per session in conditioning. The dark grey discontinuous line represents the group that was trained 5 A+, 11 AX–, 3 F–, 9 F+, and 2 X– presentations per session in conditioning. The black discontinuous line represents the group that was trained with 2 A+, 14 AX–, 12 F+, and 2 X– presentations per session in conditioning.

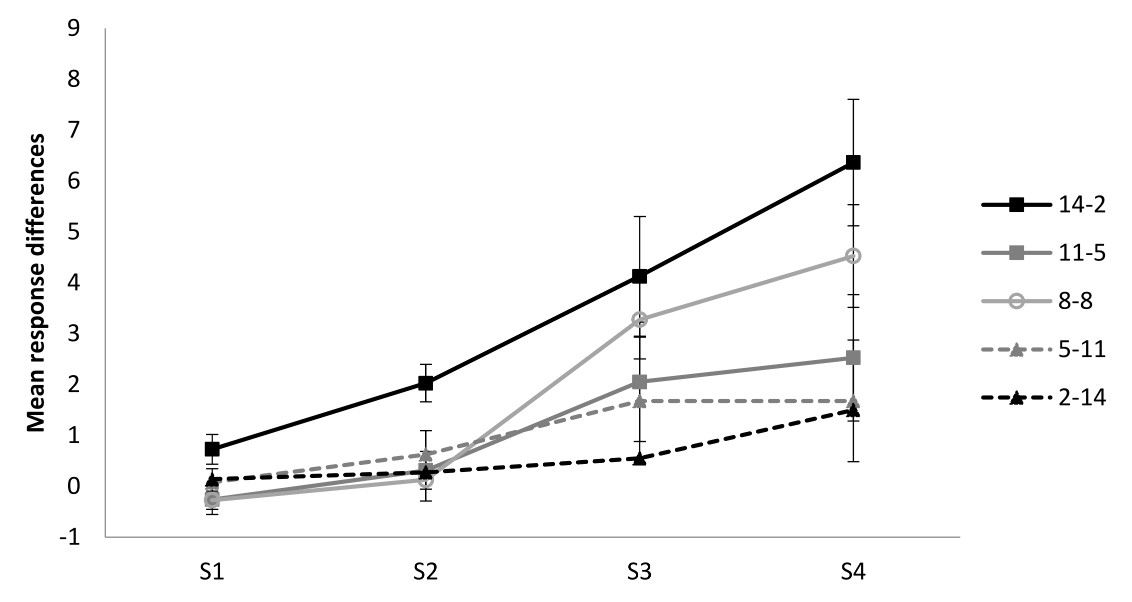
A mixed model ANOVA with a between-subjects factor Group and a within-subjects factor Session found a significant main effect of Session [F(9.652, 2180.248) = 12.622, p < .001, η_p^2 = .266] and Group [F(4, 35) = 5.867, p = .001, η_p^2 = .401] but not of the Session×Group interaction. Games-Howell post-hoc comparisons found significant differences between Group 14-2 and Groups 8-8 (p = .033), 5-11 (p = .031) and 2-14 (p =.01). This analysis indicated that all groups showed an increase in responding in the first sessions that progressively decreased until the end of the conditioning sessions, and that the level of responding was different for each group. Group 14-2 (trained with 14 A+ and 2 AX- trials per session) showed the higher responding, Group 11-5 (trained with 11 A+ and 5 AX- trials per session) showed an intermediate level, and Groups 8-8, 5-11 and 2-14 (trained with 8 A+ and 8 AX- trials, 5 A+ and 11 AX- trials, and 2 A+ and 14 AX- trials, respectively, per session) showed a similar lower level of responding.

In the retardation test, all groups showed an increase in responding to X, as can be seen in Figure 20. However, this increase was not the same in all groups: Group 14-2 showed a faster increase that reached a higher level than the rest of groups, Group 8-8 showed a similar increase to Groups 11-5, 5-11 and 2-14 in the first two sessions, then rising to an intermediate level in the last two sessions, and Groups 11-5, 5-11 and 2-14 showed a similar slower increase.

A mixed-model ANOVA with the between-subjects factor Group and the within-subjects factor Session found a significant main effect of Session [F(2.167, 75.861) = 25.311, p < .001, η_p^2 = .42] and of the Group [F(4, 35) = 5.438, p = .002, η_p^2 = .383]. The Session×Group interaction, although close, failed to reach significance [F(8.670, 75.861) = 1.921, p = .064, η_p^2 = .18]. Tukey post-hoc analyses found significant differences between Group 14-2 and Groups 11-5 (p = .016), 5-11 (p = .009) and 2-14 (p = .002). This analysis indicated that all groups showed an increase in responding, and that responding was higher in Group 14-2, intermediate in Group 8-8, and lower in Groups 11-5, 5-11, and 2-14.

Figure 20

Retardation test in Experiment 9



Note. PreX-X differences (±SEM), averaged for the 10 X– presentations per session in the retardation test, are displayed. The black continuous line represents the group that was trained with 14 A+, 2 AX–, 12 F-, and 2 X– presentations per session in conditioning. The dark grey continuous line represents the group that was trained 11 A+, 5 AX–, 9 F–, 3 F+, and 2 X– presentations per session in conditioning. The light grey continuous line represents the group that was trained 8 A+, 8 AX–, 6 F–, 6 F+, and 2 X– presentations per session in conditioning. The dark grey discontinuous line represents the group that was trained 5 A+, 11 AX–, 3 F–, 9 F+, and 2 X– presentations per session in conditioning. The black discontinuous line represents the group that was trained with 2 A+, 14 AX–, 12 F+, and 2 X– presentations per session in conditioning. All groups received 10 X- presentations per session in the retardation test.

Taken together, the results of this experiment indicated that the group that was trained with 14 A+ and 2 AX- presentations per session showed the highest level of responding both in the training phase in the retardation test. Group 11-5 showed an intermediate level of responding in training, but a low level of responding in the retardation test. Group 8-8 showed a low level of responding in the training phase, but an intermediate level of responding in the retardation test. Groups 5-11 and 2-14 showed a low level of responding both in the training phase and in the retardation test. Although there were no control groups in this experiment, direct comparisons between the groups are interesting to complete previous results.

In Experiments 4 to 8, a group trained with 14 A+ and 2 AX- trials showed results that, compared with its control, indicated the development of SOC in the first phases of conditioning, but no CI in the retardation test; the group trained with 11 A+ and 5 AX- behaved in a way that indicated a non-significant tendency to both SOC and CI; the group trained with 8 A+ and 8 AX- developed a pattern of responding that indicated both SOC during the first sessions of conditioning and CI in the retardation test; the group trained with 5 A+ and 11 AX- showed no SOC during training but CI in the retardation test; and the group trained with 2 A+ and 14 AX- showed neither SOC nor CI. Experiment 9 further confirmed these results, as the subjects showed a higher responding and less retardation when trained with more A+ and less AX-, and vice-versa, less responding and more retardation with less A+ and more AX- trials.

CHAPTER 4: General discussion and conclusions

In Experiment 1, an increase in responding to X in the first sessions, that was no longer evident after the middle of training, was found when a stimulus A was always reinforced and when a compound AX was reinforced with different contingencies (1, 0.66, 0.33 and 0). Also, the magnitude of responding was directly related to the contingency of reinforcement, in such a way that the higher was the contingency, the higher was responding. In this experiment, for the group in which AX was always reinforced, the increase in responding in the first sessions might indicate augmentation, and the absence of responding in the last sessions might indicate blocking, whereas for the group in which AX was never reinforced, the increase might indicate SOC and the absence of responding, CI. Thus, when AX was reinforced, stimulus X was not expected to develop inhibitory properties, but this was expected when AX was non-reinforced. This was confirmed in Experiment 2, when, after replicating the groups that were trained with contingency 1 and 0 for the AX compound, summation and retardation tests were included. Further, in Experiment 3, the group trained with A+/AX+ was compared with a control group, and augmentation was confirmed in the first session of the experiment, and blocking in sessions 12, 14, 17 and 18. In Experiments 4 to 8, two groups were employed, an experimental group trained in an A+/AX- design, and a control. In Experiment 4, when 14 A+ trials and 2 AX- trials were presented in each session of training, subjects showed an increase in responding to X congruent with SOC in the first sessions, that faded out in the last sessions. However, these subjects did not show retardation of conditioning to X at the end of training, thus indicating that CI was not developed. Similarly, in Experiment 5, subjects that were trained with 11 A+ and 5 AX- trials per session also showed an increase in responding to X at the beginning of training congruent with the development of SOC, and, in retardation test, there was a tendency toward the development of CI, although both were statistically non-significant. Most importantly, in Experiment 6, subjects that were trained with 8 A+ and 8 AX- trials in each session showed an increase in responding to X in the first half of the training sessions that could indicated that SOC was developed, and a retardation of conditioning to X in retardation test, that could indicate that CI was developed. Nevertheless, those subjects that, in training, received 5 A+ and 11 AX- trials per session (Experiment 7), did not show an increase in responding to X at any moment of the experiment, so SOC was not developed, but they did show a retarded acquisition of conditioning to X in retardation test, thus indicating that CI was developed. Subjects that were trained with 2 A+ and 14 AX- trials in each session (Experiment 8), did not show an increase in responding to X during training nor retardation in retardation test, thus indicating that neither SOC nor CI was developed. Finally, in Experiment 9, a comparison of the experimental groups in Experiments 4 to 8 was performed, and found that the proportion of A+/AX- trials was directly related to responding both in the conditioning phase and in the retardation test.

The series of experiments presented indicated that in situations of cue interaction with the same design, two opposite results can occur. The interaction can be positive, that is, the response to the target cue X is positively related to the response to the non-target cue A. In these experiments, we have two examples of positive interaction phenomena: augmentation (with the A+/AX+ design) and SOC (with the A+/AX- design). The interaction can also be negative, that is, the response to the target cue X is negatively related to the response of the non-target cue A. In these experiments, we have two examples of negative interaction phenomena: blocking (with the A+/AX+ design) and CI (with the A+/AX- design). Other mayor conclusion that can be drawn from these experiments is that the number of training sessions is a modulatory factor of cue interactions, as with few training sessions positive interaction phenomena are found, whereas negative interaction phenomena are evident later in training. Also, the number of trials of each type that are present in the sessions is another modulatory factor of cue interaction, at least in the A+/AX- design, as with many A+ and few AX- trials, only positive interaction is developed, and with few A+ and many AX- trials, only negative interaction is found.

The results of the experiments reported in this work are consistent with the finding by Rescorla (1972) and Holland and Rescorla (1975). In these experiments, they found that, with an A+/AX- design, the number of training sessions was a critical variable to observe positive or negative mediation: they reported SOC at the beginning of training and CI at the end of it, assessed by a summation test. We replicated the finding, with both summation and retardation test for the inhibitory properties. Also, this finding is extended to a different design, A+/AX+, founding augmentation at the beginning of training and blocking at the end of it, and constituting the first demonstration of augmentation and blocking within the same treatment.

The results in Experiments 1-3 extend the literature on augmentation, as this is the only demonstration of this phenomenon using a one-phase training, that is, intermixing the presentations of A+ and AX+ in all sessions, instead of presenting all the A+ trials in one block of sessions and all the AX+ presentations in other block. So, the timing of the presentation of the trials is not a determining variable in cue interactions, consistently with the finding of Yin et al. (1994), where SOC was found both when A+ and AX- trials were presented intermixed and when presented in two phases. Also, these results are the first demonstration of this phenomenon in an appetitive magazine procedure with rats. This is especially important as most of the demonstrations of augmentation have used conditioned taste aversion procedures with odours and tastes (Batsell & Batson, 1999; Batson & Batsell, 2000; Batsell et al., 2001; Allswede et al., 2014; Good et al., 2015; Jensen et al., 2018; Batsell et al., 2020). However, the fact that extended training abolishes augmentation and promotes the development of blocking is not consistent with the results found by Good et al. (2015) using a conditioned taste aversion induced by rotation procedure. This study found that both increasing the number of A+ and AX+ trials increased the strength of augmentation. However, it is important to note that the number of trials used by Good et al. were 1, 2 or 4 in the case of A+ trials, and 1 or 3 in the case of AX+ trials. These results are difficult to compare, as different procedures are used, and taste aversion learning is known to proceed faster than other types of learning (Garcia & Koelling, 1967), even if the aversion is induced by rotation (Braun & McIntosh, 1973).

The results from Experiments 4-9, in which the number of A+ and AX- trials determined if SOC, CI or both effects are developed, are consistent with the previous literature that indicated that with few AX- presentations SOC is found, and with many AX- presentation, CI is developed (Yin et al., 1994; Stout et al., 2004). The experiments reported here have the advantage that the total number of trials per session and the ITI was held constant, but, as both the number of A+ and AX- trials was varied, it is not clear if the effect is only due to the number of AX- trials, the A+ trials, or the conjoint effect of both trial numbers. It is worth noting that in experiments 4-8, CI was assessed by a retardation test. Rescorla (1969) argued that the two-test strategy, that is, using both summation and retardation test, was needed to test the inhibitory properties of a stimulus as it allows to rule out alternative explanations based on attentional shifts. Reduced attention can account for the retardation effect, but will not affect responding to a transfer excitor, i.e., there will be no reduction in responding in the summation test. Conversely, increased attention to a stimulus would decrease responding to a transfer excitor in a summation test but would not result in a retardation effect. So, if a stimulus passes both summation and retardation test, it cannot be due to an attentional shift. Nevertheless, some authors have claimed that both test might not be sufficient nor necessary to assess the inhibitory properties of a stimulus (Williams et al., 1992). In fact, according to Papini and Bitterman (1993), in the A+/AX- design, a retardation test would be sufficient as long as the experiment includes a control group in which the putative inhibitory stimulus receives a treatment that is assumed to be less inhibitory than the treatment received by the experimental group. That is the case for the present experiments, as attention to the putative inhibitory stimulus in the experimental group cannot be assumed to be lower than in the control group.

As noted in the introduction, most models of learning were developed focusing on the prediction of negative mediation phenomena, and thus, are not able to account for positive interaction phenomena (e.g., Rescorla & Wagner, 1972; Mackintosh, 1975a; Pearce & Hall, 1980; Miller & Maztel, 1988; Pearce, 1994). Thus, the existence of augmentation and SOC constitutes a challenge for these models, as can be concluded from the simulations of some of the most important models that are detailed in Appendix II. Furthermore, the transition from positive to negative interaction reported here is a core problem for the concept of association itself, as it is difficult to predict how an association can first promote responding to the target cue, and then prevent that same responding, and even promote the development of inhibitory properties in the case of the A+/AX- design.

The only formal models that can account for the transition from positive to negative interaction are those that distinguish between acquisition and performance (see Miller, 2006, for a review). The models previously mentioned share the assumption that the response to a stimulus depends only on the associative status of that stimulus and that cue competition occurs in acquisition. In performance-focused models, such as the comparator hypothesis proposed by Miller and Matzel (1988), associations are acquired in a non-competitive fashion, in such a way that all associations are excitatory, and inhibition is a result of the interaction between them, so negative mediation is due to a process of comparison between stimuli at the moment of responding, in such a way that responding to a stimulus depends not only on its association with the US but also on the association with the US that has been acquired by other stimuli. In our experiments, CI would be the result of this comparison process, as the association between X and the US is 0, given that they are never presented together, and the comparison term value is high, as it depends on the association between X and A, and the association between A and the US. SOC would be predicted by the presence of a switching operator in the response rule that makes the result of the comparison excitatory in the first sessions and that, with the repeated presentation of the stimulus X, switches so that the net result of the comparison becomes inhibitory (Stout & Miller, 2007). This switching operator works different depending on the pairing or not of X with the US. It is assumed that the switch from positive to negative mediation is faster when X is directly paired with the US than when X is not paired. This makes sense with our findings that augmentation appears only in the first trial (Experiment 3), whereas SOC can be found later on training (Experiments 4 and 6). However, it does not account for the higher responding found in Experiment 1 in the A+/AX+ group than in the A+/AX-, as the comparator term is predicted to be less facilitative when X is paired with the US. It is important to note that Pineño (2007) proposed a similar response rule but that can be applied in conjunction with acquisition rules from competitive acquisition models. According to this rule, competition occurs during acquisition, whereas facilitation occurs during performance, as a result of summing the associative strength of the stimulus X and the associative strength of the stimuli associated with it, weighted by the strength of the within-stimuli association and the novelty of the stimulus X. The transition from positive to negative mediation is due to the decreased novelty of the stimulus X as training progresses. This model can predict both the transition from SOC to CI, and from augmentation to blocking, and also the higher responding in augmentation compared to SOC. However, is worth noting that finding augmentation is parameter dependent, specifically, it depends in the learning rate for the CS-CS associations being higher than the learning rate for the CS-US associations. This would be in accordance with the finding that simultaneous AX parings are needed to find augmentation (Batsell & Batson, 1999; Batsell et al., 2001), although the study by Dickinson et al. (1983) found augmented responding in both sequential and simultaneous parings.

Although the contributions of formal models that take into account the transition from positive to negative mediation are noteworthy, other hypothesis underlying cue facilitation, not linked to a formal model, deserve consideration.

One explanation that has been given for positive mediation is the configural processing of the compound, that leads to it being processed as a unit, different from its elements, and more salient than the sum of them (Rescorla, 1981; Kucharski & Spear, 1985). So, when X is presented in the test, it is mistaken for the compound and thus, respond to it. However, configural theories (Pearce, 1987, 1994), assume that cue competition occurs due to large generalization decrements between the AX and X, so they cannot account for facilitation. It might be the case that the interaction between cues depends on the amount of generalization from the compound to the tested cue, so with large generalization, positive interaction occurs, and with no generalization, negative interaction occurs. This is supported by the results that show that the interval between the CS and the US presentation has an important role in finding positive or negative interaction. Overshadowing is typically found when the US immediately follows the presentation of the AX compound, and potentiation is found when a trace interval is included between them (Urcelay & Miller, 2009; Batsell et al., 2012; Cunha et al., 2015). It has been demonstrated that in trace procedures generalization is bigger and more persistent than in delay procedures (Pavlov, 1927/1960; Honey & Hall, 1992). Despite this, some findings contradict this perspective. For example, augmentation has been found to be stronger than potentiation (Batsell et al., 2001), which is not congruent with this view, as in augmentation there are presentations of A alone, whereas in potentiation there are just AX presentations, so generalization is expected to be lower in the augmentation design, as one of the elements of the compound has already been presented alone. Furthermore, preexposition to X, which should decrease generalization, did not alter augmentation (Jensen et al., 2018). Also, although this hypothesis can account for the transition from positive to negative mediation as a function of the session reported in these experiments due to a better discrimination with more experience with A, AX and X, it is not clear how this view can account for SOC, as the compound (presumably being processed configurally as different from its elements) is always non-reinforced, and excitation from A needs to generalize to that unreinforced AX compound, and then generalize from AX to X.

Some theories (Durlach & Rescorla, 1980; Sutton & Barto, 1981; Wagner, 1981) have relied on within-compound associations to account for positive mediation effects. In this view, associations can be formed not only between CS and US, but also between CSs. Positive interaction is explained as a chain involving an association between X and A, and an association between A and the US, in such a way that when X is presented in the test, X indirectly activates the representation of the US. The support for this explanation in the available literature is mixed. On one hand, the results in conditioned taste aversion that indicate that simultaneous but not sequential AX+ parings are needed for augmentation to develop (Batsell & Batson, 1999; Batsell et al., 2001) are interpreted as support for the within-compound hypothesis. It is worth noting that the sequential arrangement did not lead to blocking. On the other hand, Dickinson et al. (1983) found that both simultaneous and sequential arrangements lead to augmentation using visual and auditory cues, simultaneous presentations can also lead to blocking, as reported in the present experiments and in the literature (e.g. Kamin, 1969; Kohler & Ayres, 1982), and Stout et al. (2004) found that, with an intermediate amount of AX- trials, sequential pairings lead to SOC and simultaneous pairings lead to CI. Also, increasing the familiarity of X by preexposing it before augmentation training did not decrease the effect (Jensen et al., 2018). Further examinations of the within-compound hypothesis involved manipulations thought to lead to a decrease on the strength of the A-US associations. Batsell & Batson (1999) found that unreinforced presentations of A, both before the training and after phase 1 A+ training, decreased the strength of odour-mediated taste augmentation. However, in this set of experiments, unreinforced presentations of A after the complete A+/AX+ training, did not alter the strength of augmentation, but a subsequent study (Batsell et al., 2001) with this post-training extinction found that taste-mediated odour augmentation was abolished, and Allswede et al. (2014) confirmed this extinction effect in both odour-mediated and taste-mediated preparations with a different taste. In the latter case, the taste used was saccharin, and in the former, the taste was denatonium (a bitter taste). Saccharin is a sweet flavour for which rats show preference, whereas denatonium is a bitter substance for which rats do not show preference, but that is consumed when they are fluid deprived. This differential preference for the tastes might explain the different effect of A extinction. It is important to note that studies of SOC have found equally conflicting results. Posttraining extinction of A did not affect SOC when this was established in sequential AX parings (Rizley & Rescorla, 1972; Holland & Rescorla, 1975; Davey & Arulampalam, 1982; Davey & McKenna, 1983; Jara et al., 2006; but see Rashotte et al., 1977) but it did attenuate SOC when established in simultaneous AX pairings (Rescorla, 1982). Furthermore, various studies showed that the extinction treatment also attenuates negative mediation effects such as overshadowing (Kaufman & Bolles, 1981), blocking (Blaisdell et al., 1999), relative stimulus validity (Cole et al., 1995), degraded contingency (Witnauer & Miller, 2007) and conditioned inhibition (Lysle & Fowler, 1985). Thus, to date, there is not strong support that the formation of a within-compound association determines whether positive or negative interaction would be observed, as the predictions derived from this hypothesis lead both to mixed results on positive mediation, and to results that support that within-compound associations are also involved in negative mediation. In fact, in the present results, positive mediation is found at the beginning of training, where both the association between A and the US and X and A are presumed to be of low strength.

Some authors have proposed flexible processing explanations, in which positive mediation is due to configural processing of the stimuli and negative mediation is due to elemental processing (Williams et al., 1994; Melchers et al., 2008; Urcelay & Miller, 2009). Melchers et al. (2008) review evidence on the factors that influence whether stimuli are processed configurally or elementally. One of this factors is the previous knowledge, usually manipulated as previous training with different stimuli in both human and non-human animals. It has been showed that when pretraining encourages elemental processing, a subsequent discrimination with different stimuli is solved elementally, and when pretraining encourages configural processing, the discrimination is solved configurally (Alvarado & Rudy, 1992; Williams et al., 1994; Williams &

Braker, 1999; Melchers et al., 2004; Urcelay & Miller, 2009). Also, giving participants instructions to learn elementally strengthened elemental processing (Williams et al., 1994), and so does using stimuli from different sensorial modalities compared with using stimuli from the same sensorial modality (Kehoe et al., 1994; Miller, 1971). However, as explained earlier, it is difficult to integrate how a configural explanation can account for SOC, given that in this account AX would be processed as a configuration different from its elements which is non-reinforced, so X should not gain excitatory properties. It is also worth noting that, even when SOC is possible with both simultaneous and sequential pairings, as demonstrated by Stout et al. (2004) sequential parings of the compound favour SOC with an intermediate number of AX- trials.

There are other non-associative variables that influence cue interaction, that are not related to the way in which stimuli are processed. One such example is the type of task. In studies with human participants, it has been reported that cue competition is not evident in implicit learning tasks. For example, Schmidt and De Houwer (2019) found no overshadowing nor blocking when the task used was a modification of the colour-word contingency learning task, in which participants are presented with colour-unrelated words, shapes or word-shape compounds and asked to respond to the colour the stimuli are printed in. The stimuli are presented most often in one colour (80% of times), and responding is faster in this high contingency condition. In the first experiment, they tested overshadowing in word-shapes compound, and found that both the reaction time and the errors in the overshadowing group did not significantly differ with the control group. In a second experiment, the same task was used to asses blocking, again finding that there was not an effect of the blocking treatment. Furthermore, when participants were explicitly instructed to learn the stimuli-colour contingencies, both overshadowing and blocking were found. Similarly, Beesley and

Shanks (2012) examined blocking in another implicit learning task: contextual cuing task. In this task, participants have to search a target stimulus in a set of distractors. Some configurations of distractors predict the target location, whereas others are randomly arranged. Target detection was faster on the predicting patterns than on randomly arranged patterns. In this study, participants were trained in one phase blocking, presenting both single and compound distractors sets. Learning was evident for both the single and compound patterns, but when each distractor set was tested individually, there was no evidence of cue competition. In a subsequent experiment, a two phase blocking design was used. Again, blocking was not found, in fact, there was an augmentation of the cue that was trained only in compound. It is also worth noting that, in human contingency learning, Mitchell et al. (2005b) used an A+/AX+ intermixed blocking procedure, and found blocking when the causal relationship between X and the outcome was assessed, but augmentation when the associative strength of X was assessed by cued-recall, that is, identification of the outcome with which X was paired. Vadillo and Matute (2010) found that time pressure (3 s to respond) promoted augmentation in a human contingency learning task. When subjects had more time to think (6 s) augmentation was abolished, but blocking was not found either. This experiment was carried online, but results were replicated both online and in the laboratory in Vadillo and Matute (2011). Similarly, Karazinov and Boakes (2007), in Experiment 1, using a two-phases A+ /AX- design, found that when the participants were required to respond quickly (limiting the time available to respond to 3 s), SOC appears. In Experiment 2, with an intermixed A+/AX- design, participants showed CI when they had plenty of time to respond. Lee and Livesey (2012) replicated this effect of promoting either speed or accuracy within a single experiment using an intermixed design, and including explicit instructions to either respond fast or respond accurately.

Interestingly, after training participant were presented with a self-paced inference test, in which they were asked how likely the cues predicted the outcome, all participants showed CI, suggesting that when subject are given time to think, CI is the most likely outcome.

These results in human studies sum up to the growing literature that indicates that cue competition is modulated by variables that do not affect the formation of associations, but the establishment of causal inferences. For example, blocking is reported more often when the stimuli are described as causes of the reinforcer than when the stimuli are described as effects (Waldmann & Holyoak, 1992; Waldmann, 2000). Also, some studies indicate that the awareness of the additive effect of the causes is a necessary condition to find blocking (De Houwer et al., 2002; Mitchell & Lovibond, 2002; Lovibond et al., 2003), and blocking is abolished by replacing the additivity assumption for a new rule, either explicitly trained (Shanks & Darby, 1998; Beckers et al, 2005) or instructed (Mitchell et al., 2005a). Finally, studies on higher order retrospective reevaluation show that after AB+ and AX+ training, blocking of X is evident after B- training, but not after B+ training (De Houwer & Beckers, 2002a; 2002b). All these findings led De Houwer (2009) to propose an alternative explanation to association formation as the primary mechanism that governs Associative Learning: a propositional approach in which Associative Learning is the result of the generation and evaluation of propositions regarding the relationship between events. This approach has the advantage that, whereas associations just reflect the strength of a relationship between events, propositions also take into account the structure of that relationships. Under this approach, it is easy to understand that Associative Learning can be affected by the type of task, the instructions, the additivity assumption or deductive reasoning.

Although this propositional approach might seem restricted to humans, there are some studies that indicate that non-human animals are sensitive to these manipulations. Blaisdell et al. (2006) found that rats can make causal inferences. Rats were trained in an observational Pavlovian procedure, being presented with trials in which a stimulus L was followed by a stimulus T and trials in which that stimulus L was followed by food, thus establishing a common-cause in which T predicts, via L, the presentation of food. In a subsequent phase, some animals received a T presentation each time they pressed a lever, whereas other animals received T presentations independently of any lever press. Animals that received the T presentations after lever pressing showed less expectancy of the food (less magazine entries) than animals that received the T presentations independently of the lever press. This result indicates that rats expect the food when T is presented independently of their behaviour, but not when T is a consequence of their behaviour. Also, Beckers et al. (2006), showed that forward blocking in rats was abolished when the rats where explicitly trained against the additivity assumption. Similarly, Packheiser et al. (2020) found no overexpectation unless the pigeons where explicitly trained in outcome additivity. However, when overexpectation was achieved by explicitly training outcome additivity, it was just moderate. De Houwer (2009) affirmed that Associative Learning in neurologically unsophisticated species like aplysia is not likely to be due to the formation of propositions. However, complex associative effects have been demonstrated in invertebrates, such as conditioned inhibition, extinction, latent inhibition, blocking or overshadowing (for a review, see Álvarez et al., 2017). Positive mediation effects, such as SOC, have also been demonstrated in invertebrates (Loy et al., 2006). Given the widespread presence of cue interaction phenomena in very different animal species, a view that is restricted to the so called higher animals would be incomplete.

As noted in the introduction, an analysis in terms of SDT might be a suitable and more simple approach to understand the finding of opposite phenomena with the same design. The acquisition-performance distinction that Stout and Miller (2007) and Pineño (2007) implement is similar to the central distinction that SDT does between sensitivity and response criterion. According to this theory, the responding to a particular stimulation depends on both what the organism perceives (sensitivity) and how the organism decides to respond to it (response criterion). Thus, sensitivity depends on the physical properties of the stimuli and the ability of the organism to detect them, and response criterion depends on subjective factors that modulate the willingness of the subject to respond in a particular way. In SDT, the response criterion is adjusted in such a way that it optimizes the costs-benefits trade-off of emitting a response (Green & Swets, 1966; Swets, 1988). In fact, the transition from positive to negative mediation could represent the strategy that best promotes the fitness of the subjects: when there is little experience with the stimuli, they respond to any stimuli that directly or indirectly signal a certain outcome, whereas with greater experience, they discriminate between stimuli that directly signal the outcome and stimuli that just signal other stimuli (Stout & Miller, 2007). In this way, Lynn and Barrett (2014) pointed out that in conditions of uncertainty the sensitivity is lower, which promotes more extreme criteria in order to minimize the number of errors. That would explain the change in responding as sessions progressed: uncertainty is reduced by repeated experience with the stimuli, thus increasing subjects' sensitivity and reducing bias. This would explain the transition from positive to negative interaction that is observed in the present experiments with the progression of sessions.

According to Macmillan and Creelman (2005), the optimal response criterion (β_{opt}) varies as a function of the pay-off matrix of the four different outcomes of the

Yes/No task (see Table 2) and the probabilities of presentation of the Signal and the Noise, as depicted in Equation 2:

$$\beta_{opt} = \frac{(V_{CR} - C_{FA})}{(V_H - C_O)} + \frac{P_N}{P_S} \qquad (2)$$

in which V_{CR} represents the associated value of a Correct Rejection, C_{FA} represents the associated value of a False Alarm, V_H represents the associated value of a Hit and C_O represents the associated value of an Omission. P_N represents the probability of presentation of the Noise and P_S represents probability of presentation of a Signal. β_{opt} < 1 represents a liberal criterion, that is, less willingness to produce a CR, and β_{opt} > 1 represents a conservative criterion, that is, more willingness to produce a CR.

In Experiments 1 and 2, the only difference between treatments is the reinforcement following AX pairings. As could be seen in that experiments, with a high contingency of reinforcement of AX, responding was higher in the first sessions of the experiment. This is an effect congruent with the variations on the pay-off matrix predicted by Equation 2. In all the designs, the value of P_N/P_S remains constant, as the number of trials of each type is the same for all the conditions, and the value of $(V_{CR} - C_{FA})$ is also constant, as A is always followed by a US. However, the value of $(V_H - C_O)$ depends on the contingency of reinforcement of AX. The higher is this contingency, the smaller will be this term, as it is less valuable to not produce a CR when X is present (a Hit), and it is less costly to produce a CR when X is present (an Omission), given that in great number of occasions the presentation of X precedes the presentation of a US. If this term is small, the value of β_{opt} will be high, thus predicting a more conservative criterion, that is, more willingness to produce a CR. Conversely, the lower is the contingency, the larger the value of $(V_H - C_O)$ would be, as it is more valuable to not produce a CR when X is present (a Hit), and it is more costly to produce a CR when X is present (an Omission), given that in great number of occasions the presentation of X does not precede the presentation of a US. If this term is large, the value of β_{opt} will be small, thus predicting a more liberal criterion, that is, less willingness to produce a CR. This results are consistent with the previous findings (Perales et al., 2005; Allan et al., 2008) that, in studies on contingency learning with humans, varying the pay-off matrix directly varied the response criterion placement. However, the analysis in terms of SDT of Experiment 1 (included in Appendix I) do not fully confirmed this, as groups that received any reinforcement in AX trials (Groups 1, 0.66 and 0.33) showed a similar criterion. It is worth noting that in all cases, the criterion was higher than in the group in which AX trials were never reinforced (Group 0).

It is important to note that, in Experiments 4-9, where the proportion of trials was varied, the results are consistent with changes in the response criterion due to the probability of presentation of Noise and Signal. In these experiments, the contingencies of reinforcement were maintained equal, so the pay-off matrix was the same for all the conditions, and the value of β_{opt} depends on P_N/P_S. The higher is the proportion of A trials (N) with respect to AX trials (S+N), the higher would be the value of β_{opt}, thus reflecting a more conservative criterion, that is, more willingness to emit a CR. Conversely, the lower is the proportion of A trials with respect to AX trials, the lower would be the value of β_{opt}, thus reflecting a more liberal criterion, that is, less willingness to emit a CR. This is consistent with the findings that the higher the A/AX proportion was, the higher was responding in the first sessions of the experiment and the retardation test, and vice versa (Experiment 9). They are also consistent with the finding that with a high and intermediate proportion of A/AX trials (14/2, 11/5 and 8/8), SOC is found, and that with an intermediate and low A/AX proportion (8/8 and 5/11), CI was found (Experiments 4-8). These predictions were confirmed with an analysis in terms of SDT of these Experiments, which can be found in Appendix I.

For all of the above, SDT offers an interesting framework to understand cue interactions as changes in the response criterion. Furthermore, it can integrate other findings that modulate these interactions, as it is the type of task, the instructions and the prior experience. All of these factors can modulate the placement of the response criterion. The type of task would determine what organisms expect to obtain for each type of response, that it, the pay-off matrix. Also, it is known that the instructions highly modulate the placement of the response criterion, as organisms are already biased to behave in a particular way. Finally, the prior experience would determine a placement of the criterion that best optimizes the cost-benefit trade-off in similar prior situations, so in the subsequent situation the criterion assumed will be similar, unless the subsequent task proves that criterion wrong. Moreover, this framework is valuable in the sense that it puts the subject in the centre of the learning process. Associative theories focus on the formation of associations based on the probabilities of occurrence of events on the world, and the subject is just a passive receiver of that associations that just behaves reflecting them. The distinction between acquisition and performance steps forward in the importance of the subject in its own learning, as it has to compare between multiple associations. However, the comparison process relies only in the weight of associations, not taking into account other factors that might influence performance, as instructions, type of task or prior experience. The propositional approach takes another step forward, in that the subjects form propositions and check the truth of these propositions with what they observe. The SDT puts the subject in the centre of the learning process, as it is the subject who has to perceive the occurrence of events in the world, decide how to respond to these events, and change its decisions based on the consequences of that decisions. Also, as SDT is based on an optimization of the fitness, provides a connection with the evolutionary theory, that should never be overlooked in the study of learning, as it is a very important way to adapt to the environment and be able to survive. In such a way, SDT can account for the behaviour of any subject, as it takes into account both the perceptual variety by taking into account the ability of the subject to detect (sensitivity) and the different necessities that organisms need to fulfil and how they determine how subjects decide to behave (response criterion). Thus, it is of value to continue to investigate how this account, based on the decisions of the subject, can contribute to widen our understanding of learning processes.

CAPÍTULO 4: Discusión general y conclusiones

En el Experimento 1 se encontró un incremento en la respuesta a X en las primeras sesiones, que deja de ser evidente en la segunda mitad del entrenamiento, cuando un estímulo A fue siempre reforzado y un compuesto AX fue reforzado con diferentes contingencias (1, 0.66, 0.33 y 0). Además, la magnitud de respuesta estaba directamente relacionada con la contingencia de reforzamiento, de manera que cuanto mayor fue la contingencia, mayor era la respuesta. En este experimento, en el grupo en el que AX siempre fue reforzado, el incremento en la respuesta en las primeras sesiones podría indicar aumentación, y la ausencia de respuesta en las últimas sesiones podría indicar bloqueo, mientras que para el grupo en el que AX nunca fue reforzado, el incremento podría indicar Condicionamiento de Segundo Orden (CSO), y la ausencia de respuesta, inhibición condicionada (IC). Por tanto, cuando AX fue reforzado, no se esperaba que el estímulo X desarrolle propiedades inhibitorias, pero sí cuando AX no fue reforzado. Esto fue confirmado en el Experimento 2, cuando, tras replicar los grupos que fueron entrenados con contingencia 1 y 0 para el compuesto AX, se incluyeron pruebas de sumación y retraso. Además, en el Experimento 3, el grupo entrenado con A+/AX+ fue comparado con un grupo de control, confirmando la presencia de aumentación en la primera sesión del experimento, y bloqueo en las sesiones 12, 14, 17 y 18. En los Experimentos 4 a 8, se utilizaron dos grupos, un grupo experimental entrenado con un diseño A+/AX-, y un control. En el Experimento 4, cuando se presentaron 14 ensayos A+ y 2 ensayos AX- en cada sesión del entrenamiento, los sujetos mostraron un incremento de respuesta a X congruente con el CSO en las primeras sesiones, que desapareció en las últimas. Sin embargo, estos sujetos no mostraron retraso del condicionamiento de X al final del entrenamiento, indicando por tanto que la IC no se desarrolló. De manera similar, en el Experimento 5, los sujetos entrenados con 11 ensayos A+ y 5 ensayos AX- en cada sesión también mostraron un incremento en la respuesta a X al principio del entrenamiento congruente con el desarrollo de CSO, y, en la prueba de retraso, hubo una tendencia hacia el desarrollo de IC, si bien ambas tendencias fueron estadísticamente no significativas. De manera más importante, en el Experimento 6, los sujetos que fueron entrenados con 8 ensayos A+ y 8 ensayos AX- en cada sesión mostraron un incremento en la respuesta a X en la primera mitad de las sesiones de entrenamiento que podría indicar que se desarrolló CSO, y un retraso del condicionamiento de X en la prueba de retraso, que podría indicar que se desarrolló IC. Sin embargo, aquellos sujetos que, durante el entrenamiento, recibieron 5 ensayos A+ y 11 ensayos AX- en cada sesión (Experimento 7), no mostraron un incremento en la respuesta a X en ningún momento del experimento, de manera que no se desarrolló CSO, pero sí mostraron una adquisición retardada del condicionamiento a X en la prueba de retraso, indicando por ello que se desarrolló IC. Los sujetos entrenados con 2 ensayos A+ y 14 ensayos AX- en cada sesión (Experimento 8), no mostraron un incremento de la respuesta a X durante el entrenamiento ni retraso en la prueba de retraso, indicando por ello que no se desarrolló ni CSO ni IC. Finalmente, en el Experimento 9, se llevó a cabo una comparación de los grupos experimentales de los Experimentos 4 a 8, encontrando que la proporción de ensayos A+/AX- estaba directamente relacionada con la respuesta tanto en la fase de condicionamiento como en la prueba de retraso.

La serie de experimentos presentada indicó que, en situaciones de interacción entre claves con el mismo diseño, pueden ocurrir dos resultados opuestos. La interacción puede ser positiva, es decir, la respuesta a la clave objetivo X está positivamente relacionada con la respuesta a la clave no-objetivo A. En estos experimentos tenemos dos ejemplos de fenómenos de interacción positiva: aumentación (en el diseño A+/AX+) y CSO (con el diseño A+/AX-). La interacción también puede ser negativa, es decir, la respuesta a la clave objetivo X está negativamente relacionada con la respuesta a la clave no-objetivo A. en estos experimentos, tenemos dos ejemplos de fenómenos de interacción negativa: bloqueo (con el diseño A+/AX+) e IC (con el diseño A+/AX-). Otra conclusión principal que se puede derivar de estos experimentos es que el número de sesiones de entrenamiento es un factor modulador en las interacciones entre claves, dado que con pocas sesiones de entrenamiento se encuentran fenómenos de interacción positiva, mientras que los fenómenos de interacción negativa son evidentes más adelante. Además, el número de ensayos de cada tipo que se presentan en las sesiones es otro factor modulador de la interacción entre claves, por lo menos en el diseño A+/AX-, ya que con muchos ensayos A+ y pocos ensayos AX-, solo se desarrolla interacción positiva, y con pocos ensayos A+ y muchos ensayos AX-, solo se desarrolla interacción negativa.

Los resultados de los experimentos presentados en este trabajo son consistentes con el hallazgo de Rescorla (1972) y Holland y Rescorla (1975). En estos experimentos encontraron que, con un diseño A+/AX-, el número de sesiones de entrenamiento era una variable crítica para encontrar mediación positiva o negativa: encontraron CSO al principio del entrenamiento y, medida con una prueba de sumación, IC al final del entrenamiento. Hemos replicado este hallazgo con pruebas de sumación y de retraso para las propiedades inhibitorias. Además, este hallazgo se extiende a un diseño diferente, A+/AX+, encontrado aumentación al principio del entrenamiento y bloqueo al final, constituyendo la primera demonstración de aumentación y bloqueo durante el mismo tratamiento.

Los resultados de los Experimentos 1-3 amplían la literatura sobre aumentación, dado que esta es la única demostración de este fenómeno utilizando un entrenamiento en una fase, es decir, entremezclando las presentaciones de A+ y AX+ en todas las sesiones, en vez de presentar todos los ensayos A+ en un bloque de sesiones y todas las presentaciones de AX+ en otro bloque. Por ello, el orden de presentación de los ensayos no es una variable determinante en la interacción entre claves, consistentemente con los resultados de Yin et al. (1994), en los que se encuentra CSO tanto cuando los ensayos A+ y AX- se presentan entremezclados como cuando se presentan en dos fases. Además, estos resultados son la primera demostración de este fenómeno en un procedimiento apetitivo de entrada al comedero con ratas. Esto es especialmente importante dado que la mayoría de demonstraciones de aumentación han utilizado procedimientos de aversión condicionada al sabor con olores y sabores (Batsell & Batson, 1999; Batson & Batsell, 2000; Batsell et al., 2001; Allswede et al., 2014; Good et al., 2015; Jensen et al., 2018; Batsell et al., 2020). No obstante, que un mayor entrenamiento suprima la aumentación y facilite el desarrollo de bloqueo no es consistente con los resultados encontrados por Good et al. (215) utilizando un procedimiento de aversión condicionada al sabor inducida por rotación. Este estudio encontró que incrementar el número de ensayos tanto A+ como AX+ incrementaba la magnitud de la aumentación. No obstante, es importante tener en cuenta que el número de ensayos empleados por Good et al. fueron 1, 2 o 4 en el caso de ensayos A+, y 1 o 3 en el caso de ensayos AX+. Estos resultados son difíciles de comparar, dado que se utilizaron distintos procedimientos, y que el aprendizaje de aversión al sabor se desarrolla más rápidamente que otros tipos de aprendizaje (Garcia & Koelling, 1967), incluso si la aversión se induce mediante rotación (Braun & McIntosh, 1973).

Los resultados de los Experimentos 4-9, en los cuales el número de ensayos A+ y AX- determinaron si se desarrollaban CSO, IC o ambos efectos, son consistentes con la literatura previa que indicaba que con pocas presentaciones de AX- se encuentra

CSO, y con muchas presentaciones de AX-, se encuentra IC (Yin et al., 1994; Stout et al., 2004). Los experimentos aquí reflejados presentan la ventaja de mantener constante el número total de ensayos por sesiones y el intervalo entre ensayos, pero, dado que tanto el número de ensayos A+ como el número de ensayos AX- varía, no está claro si el efecto se debe sólo al número de ensayos AX-, el número de ensayos A+, o el efecto conjunto de ambos. Cabe destacar que en los experimentos 4-8, la IC se evalúa con una prueba de retraso. Rescorla (1969) argumentó que la estrategia de doble prueba, es decir, usar tanto la prueba de sumación como la de retraso, era necesaria para evaluar las propiedades inhibitorias de un estímulo, ya que permite descartar explicaciones alternativas basadas en cambios atencionales. Una atención reducida puede explicar el efecto de retraso, pero no afectaría a la respuesta al estímulo excitatorio de trasferencia, es decir, no habría una reducción en la respuesta en la prueba de sumación. En cambio, un incremento en la atención a un estímulo disminuiría la respuesta al estímulo excitatorio de transferencia en la prueba de retraso, pero no daría lugar al efecto de retraso. Así, si un estímulo pasa tanto la prueba de sumación como la de retraso, se descartan las explicaciones basadas en cambios atencionales. Sin embargo, algunos autores han afirmado que ambas pruebas podrían no ser ni suficientes ni necesarias para evaluar las propiedades inhibitorias de un estímulo (Williams et al., 1992). De hecho, de acuerdo con Papini y Bitterman (1993), en el diseño A+/AX-, una prueba de retraso sería suficiente siempre y cuando el experimento incluya un grupo control en el cual el posible estímulo inhibitorio reciba un tratamiento presumiblemente menos inhibitorio que el tratamiento recibido por el grupo experimental. Este es el caso de los experimentos aquí presentados, dado que no se puede asumir que la atención prestada al posible estímulo inhibitorio en el grupo experimental sea menor que en el grupo control.

Como se señaló en la introducción, la mayoría de los modelos de aprendizaje se desarrollaron centrándose en la predicción de fenómenos de mediación negativa y, por tanto, no son capaces de explicar los fenómenos de interacción positiva (p.e., Rescorla & Wagner, 1972; Mackintosh, 1975a; Pearce & Hall, 1980; Miller & Maztel, 1988; Pearce, 1994). Por lo tanto, la existencia de aumentación y CSO representa un desafío para estos modelos, como puede concluirse de las simulaciones de algunos de los modelos más importantes, detalladas en el Apéndice II. Es más, la transición de interacción negativa a positiva encontrada en los presentes experimentos es un problema central para el concepto mismo de asociación, ya que es difícil predecir como una asociación puede promover la respuesta a la clave objetivo, y luego prevenir esa misma respuesta, e incluso promover el desarrollo de propiedades inhibitorias en el caso del diseño A+/AX-.

Los únicos modelos formales que pueden explicar la transición de interacción positiva a negativa son aquellos que distinguen entre adquisición y desempeño (para una revisión, véase Miller, 2006). Los modelos anteriormente mencionados comparten el supuesto de que la respuesta a un estímulo depende solo del estado asociativo de ese estímulo, y que la competición entre claves ocurre durante la adquisición. En los modelos centrados en el desempeño, como la hipótesis del comparador propuesta por Miller y Matzel (1988), las asociaciones se adquieren de manera no competitiva, de modo que todas las asociaciones son excitatorias, y la inhibición es el resultado de la interacción entre ellas, por lo que la mediación negativa se debe a un proceso de comparación entre estímulos en el momento de la respuesta, de tal manera que responder a un estímulo no depende solo de su asociación con el estímulo incondicionado (EI), sino también de la asociación que otros estímulos han adquirido con el EI. En nuestros experimentos, la IC sería el resultado de este proceso de comparación, dado que la asociación entre X y el EI es 0, ya que nunca se presentan juntos, y el valor del término de comparación es alto, dado que depende de la asociación entre X y A, y la asociación entre A y el EI. El CSO se predice por la presencia de un *switching operator* en la regla de respuesta que hace el resultado de la comparación excitatorio en las primeras sesiones y que, con la presentación repetida del estímulo X, cambia de manera que el resultado neto de la comparación se vuelve inhibitorio (Stout & Miller, 2007). Este *switching operator* funciona de manera diferente dependiendo de si X se empareja o no con el EI. Se asumen que el cambio de mediación positiva a negativa es más rápido cuando X es emparejado directamente con el EI que cuando no lo es. Esto coincide con nuestros resultados en los que la aumentación aparece solo en el primer ensayo (Experimento 3), mientras que el CSO puede encontrarse más tarde en el entrenamiento (Experimentos 4 y 6). Sin embargo, no explica que se encuentre una mayor respuesta en el Experimento 1 en el grupo A+/AX+ que en el grupo A+/AX-, dado que se predice que el término de comparación será menos facilitador cuando X se empareja con el EI. Pineño (2007) propuso una regla de respuesta similar pero que puede aplicarse en combinación con reglas de adquisición propias de modelos de adquisición competitiva. De acuerdo con esta regla, la competición ocurre durante la adquisición, mientras que la facilitación ocurre durante el desempeño, como resultado de sumar la fuerza asociativa del estímulo X con la fuerza asociativa de los estímulos asociados a éste, ponderada por la fuerza de la asociación entre estímulos y la novedad del estímulo X. la transición de mediación positiva a negativa se debe al decremento en la novedad del estímulo X a medida que el entrenamiento progresa. Este modelo puede predecir tanto la transición de CSO a IC, como de aumentación a bloqueo, y también la mayor respuesta en aumentación comparada con CSO. Sin embargo, encontrar aumentación es dependiente de parámetros, específicamente, de que la tasa de aprendizaje de las asociaciones entre estímulos condicionados (EC) sea más rápida que la tasa de aprendizaje de las asociaciones EC-EI. Esto podría estar en consonancia con el hecho de que se necesitan emparejamientos simultáneos de AX para encontrar aumentación (Batsell & Batson, 1999; Batsell et al., 2001), aunque el estudio de Dickinson et al. (1983) encontró respuesta aumentada tanto en presentaciones simultáneas como secuenciales.

Aunque son notables las contribuciones de los modelos formales que tienen en cuenta la transición de mediación positiva a negativa, otras hipótesis subyacentes a la facilitación entre claves, no vinculadas a un modelo formal, deben considerarse.

Una explicación que ha sido dada para la mediación positiva es el procesamiento configural del compuesto, que lleva a que sea procesado como una unidad, diferente de sus elementos, y más saliente que la suma de ellos (Rescorla, 1981; Kucharski & Spear, 1985). Así, cuando X se presenta en la prueba, se confunde con el compuesto y, por ello, responde a él. Sin embargo, las teorías configurales (Pearce, 1987, 1994) asumen que la competición entre estímulos ocurre debido a grandes decrementos de generalización entre AX y X, por lo que no pueden explicar la facilitación. Podría darse el caso en el que la interacción entre claves depende de la cantidad de generalización del compuesto a la clave evaluada, de manera que con mucha generalización se encuentra mediación positiva, y sin generalización, se encuentra mediación negativa. Esto se ve apoyado por los resultados que muestran que el intervalo de presentación entre el EC y el EI tiene un rol importante en que se encuentre mediación positiva o negativa. El ensombrecimiento se encuentra normalmente cuando el EI sigue inmediatamente la presentación del compuesto AX, y la potenciación se encuentra cuando se incluye un intervalo de huella entre las presentaciones (Urcelay & Miller, 2009; Batsell et al., 2012; Cunha et al., 2015). Se ha demostrado que en los procedimientos de huella la generalización es mayor y más persistente que en los procedimientos de demora (Pavlov, 1927/1960; Honey & Hall, 1992). A pesar de ello, algunos hallazgos contradicen esta perspectiva. Por ejemplo, se ha encontrado que la aumentación es más fuerte que la potenciación (Batsell et al., 2001), lo cual no es congruente con esta explicación, ya que la aumentación implica presentaciones del estímulo A solo, mientras que en la potenciación solo hay presentaciones de AX, por lo que se espera que la generalización sea menor en el diseño de aumentación, dado que uno de los elementos del compuesto se ha presentado solo. Es más, la preexposición a X, que debería disminuir la generalización, no tiene efecto en la aumentación (Jensen et al., 2018). Además, aunque esta hipótesis puede explicar la transición de mediación positiva a negativa en función de la sesión encontrada en los presentes experimentos como una mejor discriminación debida a la mayor experiencia con A, AX y X, no está claro como esto puede explicar el CSO, dado que el compuesto (presumiblemente procesado de manera configural, diferente de sus elementos) nunca se refuerza, y la excitación necesita generalizarse de A al compuesto no reforzado AX, y luego generalizarse de AX a X.

Algunas teorías (Durlach & Rescorla, 1980; Sutton & Barto, 1981; Wagner, 1981) se basan en asociaciones intra-compuesto para explicar los efectos de mediación positiva. Bajo este enfoque, las asociaciones se pueden formar no solo entre EC y EI sino también entre ECs. La interacción positiva se explica como una cadena que une la asociación entre X y A, y la asociación entre A y el EI, de manera que cuando X se presenta en la prueba, X activa indirectamente la representación de EI. El respaldo a esta explicación en la literatura disponible es variado. Por un lado, los resultados en aversión condicionada al sabor que indican que son necesarios emparejamientos simultáneos, pero no secuenciales, de AX+ para encontrar aumentación (Batsell &

Batson, 1999; Batsell et al., 2001), se interpretan como respaldo de la hipótesis intra-compuesto. Cabe destacar que los emparejamientos secuenciales no dieron lugar a bloqueo. Por otro lado, Dickinson et al. (1983) encontró que tanto emparejamiento secuenciales como simultáneos dan lugar a aumentación utilizando claves visuales y auditivas, emparejamiento simultáneos pueden dan lugar también a bloqueo, como se plasma en los presentes experimentos y en la literatura (e.g. Kamin, 1969; Kohler & Ayres, 1982), y Stout et al. (2004) encontraron que, con una cantidad intermedia de ensayos AX-, emparejamientos secuenciales dan lugar a CSO y emparejamientos simultáneos dan lugar a CI. Además, la aumentación no disminuye al incrementar la familiaridad de X preexponiéndolo antes del entrenamiento de aumentación (Jensen et al., 2018). Ulteriores análisis de la hipótesis intra-compuesto conllevaron manipulaciones pensadas para disminuir la fuerza de las asociaciones A-EI. Batsell & Batson (1999) encontraron que incluir presentaciones no reforzadas de A, tanto antes como después de la fase 1 de entrenamiento A+, disminuyó la fuerza de la aumentación de sabores mediada por olores. Sin embargo, en esta serie de experimentos, incluir presentaciones no reforzadas de A después del entrenamiento completo A+/AX+, no alteró la fuerza de la aumentación, pero un estudio subsecuente (Batsell et al., 2001) con esta extinción post-entrenamiento abolía la aumentación de olores mediada por sabores, lo cual fue confirmado por Allswede et al. (2014) tanto en preparaciones mediadas por olor como por sabor en un sabor diferente. En este último caso, el sabor utilizado fue sacarina, y en el anterior, fue denatonio (un sabor amargo). La sacarina es un sabor dulce por el cual las ratas muestran preferencia, mientras que el denatonio es una sustancia amarga por la cual las ratas no muestran preferencia, pero que consumen si han sido privadas de líquidos. Esta diferencia en la preferencia por los sabores podría explicar el efecto diferente de la extinción de A. Es importante tener en cuenta que los estudios sobre CSO han encontrado resultados igualmente conflictivos. La extinción post-entrenamiento de A no afectó al CSO cuando este fue establecido con emparejamientos secuenciales de AX (Rizley & Rescorla, 1972; Holland & Rescorla, 1975; Davey & Arulampalam, 1982; Davey & McKenna, 1983; Jara et al., 2006; pero véase Rashotte et al., 1977), pero si atenuó el CSO cuando fue establecido con emparejamientos simultáneos de AX (Rescorla, 1982). Es más, varios estudios mostraron que la extinción también atenúa efectos de mediación negativa como ensombrecimiento (Kaufman & Bolles, 1981), bloqueo (Blaisdell et al., 1999), validez relativa del estímulo (Cole et al., 1995), degradación de la contingencia (Witnauer & Miller, 2007) e IC (Lysle & Fowler, 1985). Por ello, hasta el momento, no existe respaldo suficiente para afirmar que la formación de asociaciones intra-compuesto determine si se observará interacción positiva o negativa, dado que las predicciones de esta hipótesis dan lugar tanto a resultados contradictorios en la mediación positiva, como a resultados que respaldan que las asociaciones intra-compuesto también están implicadas en la mediación negativa. De hecho, en los resultados aquí presentados, la mediación positiva se encuentra el principio del entrenamiento, cuando las asociaciones entre A y el EI, y entre A y X son presumiblemente de poca fuerza.

Algunos autores han propuesto explicaciones basadas en un procesamiento flexible, en las cuales la mediación positiva se debe a un procesamiento configural de los estímulos y la mediación negativa se debe a un procesamiento elemental (Williams et al., 1994; Melchers et al., 2008; Urcelay & Miller, 2009). Melchers et al. (2008) realizaron una revisión sobre los factores que influyen en si los estímulos se procesan de manera configural o elemental. Uno de estos factores es el conocimiento previo, normalmente manipulado a través del entrenamiento previo de diferentes estímulos tanto en animales humanos como no humanos. Se ha demostrado que cuando el pre-entrenamiento fomenta el procesamiento elemental, una discriminación posterior con estímulos distintos se soluciona de manera elemental, y cuando el pre-entrenamiento fomenta el procesamiento configural, la discriminación se resuelve de manera configural (Alvarado & Rudy, 1992; Williams et al., 1994; Williams & Braker, 1999; Melchers et al., 2004; Urcelay & Miller, 2009). Además, si los participantes reciben instrucciones de aprender de manera elemental, el procesamiento elemental se ve fortalecido (Williams et al., 1994), igual que si se utilizan estímulos de distintas modalidades sensoriales en comparación con usar estímulos de la misma modalidad sensorial (Kehoe et al., 1994; Miller, 1971). Sin embargo, como se explica anteriormente, es difícil integrar como una explicación configural puede justificar el CSO, dado que en esta explicación AX se procesaría como una configuración diferente de sus elementos que no es reforzada, así que X no debería de adquirir propiedades excitatorias. También cabe destacar que, aunque el CSO es posible tanto con emparejamientos simultáneos como secuenciales, Stout et al. (2004) demostraron que emparejamientos secuenciales del compuesto favorecen la aparición de CSO utilizando un número intermedio de ensayos AX-.

Existen otras variables no asociativas que tiene influencia en la interacción entre claves, que no están relacionadas con la manera en la que los estímulos se procesan. Un ejemplo de estas variables es el tipo de tarea. Se ha encontrado en estudios con participantes humanos que la competición entre claves no es evidente en tareas de aprendizaje implícito. Por ejemplo, Schmidt y De Houwer (2019) no encontraron ni ensombrecimiento ni bloqueo cuando la tarea empleada fue una modificación de la tarea de aprendizaje de contingencias color-palabra, en la cual a los participantes se les presentan palabras no relacionadas con colores, formas o compuestos palabra-forma y se les pedía que respondieran al color en el que los estímulos estaban impresos. Los estímulos se presentaban más habitualmente en un color (80% de las veces), y la respuesta es más rápida en esta condición de alta contingencia. En el primer experimento, hicieron una prueba de ensombrecimiento sobre el compuesto palabra-forma, encontrando que tanto los tiempos de reacción como los errores en el grupo de ensombrecimiento no difirieron significativamente del grupo control. En un segundo experimento, la misma tarea fue utilizada para medir bloqueo, volviendo a encontrar que no había un efecto del tratamiento de bloqueo. Asimismo, cuando los participantes recibieron instrucciones explicitas de aprender las contingencias estímulo-color, se encontraron tanto ensombrecimiento como bloqueo. De manera similar, Beesley y Shanks (2012) estudiaron bloqueo con otra tarea de aprendizaje implícito: la tarea de señalización contextual. En esta tarea los participantes tienen que buscar un estímulo target en una matriz de distractores. Algunas configuraciones de distractores predicen la localización del target, mientras que otras se disponen al azar. La detección del target fue más rápida en los patrones predictivos que en los patrones al azar. En este estudio, los participantes fueron entrenados en bloqueo en una fase, presentando matrices de distractores tanto simples como compuestas. Existió un aprendizaje tanto de los patrones simples como en los compuestos, pero cuando cada matriz de distractores se evaluó individualmente, no se encontraron indicios de competición entre claves. En un experimento posterior, se utilizó un diseño de bloqueo en dos fases. Tampoco se encontró bloqueo esta vez, de hecho, apareció aumentación de la clave que se había entrenado solo en compuesto. Cabe también destacar que, en aprendizaje de contingencias con humanos, Mitchell et al. (2005b) utilizaron un procedimiento de bloqueo entremezclado A+/AX+, encontrando bloqueo cuando se evaluó la relación causal entre X y la consecuencia, pero aumentación cuando la fuerza asociativa de X se evaluó mediante recuerdo señalizado, es decir, identificar con qué consecuencia se había emparejado X. Vadillo y Mature (2010) encontraron que la presión temporal (3 s para responder) fomentaba la aumentación en una tarea de aprendizaje de contingencias en humanos. Cuando los sujetos tenían más tiempo para pensar (6 s) no se encontraba aumentación, pero tampoco se encontró bloqueo. Este experimento se llevó a cabo online, pero los resultados fueron replicados tanto online como en el laboratorio en Vadillo y Matute (2011). De manera similar, Karazinov y Boakes (2007), en el Experimento 1, utilizando un diseño A+/AX- en dos fases, encontraron que cuando a los participantes se les pedía responder rápidamente (limitando el tiempo para responder a 3 s), aparece CSO. En el Experimento 2, con un diseño A+/AX- entremezclado, los participantes mostraban IC cuando tenían tiempo abundante para responder. Lee and Livesey (2012) replicaron este efecto de fomentar velocidad o precisión en un mismo experimento utilizando un diseño entremezclado, e incluyendo instrucciones explícitas para o bien responder rápido o responder con precisión. Curiosamente, tras el entrenamiento, a los participantes se les presentó un test de inferencia autoguiado, en el cual se les preguntó con qué probabilidad las claves predecían la consecuencia, todos los participantes mostraron IC, sugiriendo que cuando a los sujetos se les da tiempo para pensar, la IC es el resultado más probable.

Estos resultados en humanos se suman a la creciente literatura que indica que la competición entre claves se ve modulada por variables que no afectan a la formación de asociaciones, sino al establecimiento de inferencias causales. Por ejemplo, el bloqueo se encuentra más a menudo cuando los estímulos se describen como causas del reforzador que cuando los estímulos se describen como efectos (Waldmann & Holyoak, 1992; Waldmann, 2000). Además, algunos estudios indican que el conocimiento del efecto aditivo de las causas es condición necesaria para encontrar bloqueo (De Houwer et al., 2002; Mitchell & Lovibond, 2002; Lovibond et al., 2003), y que el bloqueo se anula remplazando el supuesto de aditivita por una nueva regla, ya sea entrenándola explícitamente (Shanks & Darby, 1998; Beckers et al, 2005) o mediante instrucciones (Mitchell et al., 2005a). Finalmente, existen estudios sobre reevaluación retrospectiva de alto orden que muestran que tras un entrenamiento AB+ y AX+, se encuentra bloqueo de X tras entrenar B-, pero no tras B+ (De Houwer & Beckers, 2002a; 2002b). Todos estos hallazgos llevaron a De Houwer (2009) a proponer una explicación alternativa a la formación de asociaciones como mecanismo primario del Aprendizaje Asociativo: un enfoque proposicional en el cual el Aprendizaje Asociativo es el resultado de la generación y evaluación de proposiciones sobre la relación entre eventos. Este enfoque presenta la ventaja de que, mientras las asociaciones solo reflejan la fuerza de una relación ente eventos, las proposiciones también tienen en cuenta la estructura de dichas relaciones. Bajo este enfoque es fácil de entender que el Aprendizaje Asociativo puede verse afectado por el tipo de tarea, las instrucciones, el supuesto de aditividad o el razonamiento deductivo.

A pesar de que este enfoque proposicional podría parecer estar limitado a los humanos, existen algunos estudios que indican que los animales no-humanos son sensibles a estas manipulaciones. Blaisdell et al. (2006) encontró que las ratas pueden hacer inferencias causales. Las ratas fueron entrenadas en un procedimiento Pavloviano observacional, en el cual se les presentaban ensayos en los que un estímulo L fue seguido por un estímulo T y ensayos en los que el estímulo L fue seguido de comida, estableciendo de esta manera una causa común en la cual T predice, a través de L, la presentación de comida. En la siguiente fase, algunos animales recibieron una presentación de T cada vez que presionaban una palanca, mientras que otros animales recibieron presentaciones de T independientemente de que presionaran la palanca. Los animales que recibieron las presentaciones de T tras presionar la palanca mostraron una menor expectación de la comida (menos entradas al comedero) que los animales que recibieron presentaciones de T independientes de las presiones de palanca. Este resultado indica que las ratas esperan la comida cuando T se presenta independientemente de su comportamiento, pero no cuando T es una consecuencia de su comportamiento. Además, Beckers et al. (2006) mostraron que el bloqueo hacia atrás en ratas se suprimía cuando las ratas eran explícitamente entrenadas en el supuesto de aditividad. De manera similar, Packheiser et al. (2020) encontraron que la sobre-expectativa solo aparecía en palomas si estas eran explícitamente entrenadas en el supuesto de aditividad. Sin embargo, esta sobre-expectativa era solo moderada. De Hower (2009) afirmó que, en especies poco sofisticadas neurológicamente como la aplysia, no es probable que el Aprendizaje Asociativo se deba a la formación de proposiciones. Sin embargo, se han demostrado efectos asociativos complejos en invertebrados, como inhibición condicionada, extinción, inhibición lateen, bloqueo o ensombrecimiento (para una revisión, véase Álvarez et al., 2017). Efectos de mediación positive, como CSO, también han sido demostrados en invertebrados (Loy et al., 2006). Dada la amplia presencia de fenómenos de interacción entre claves en especies animales muy distintas, un enfoque que se restrinja solo a los llamados animales superiores estará incompleta.

Cómo ya se indicaba en la introducción, un análisis en términos de la Teoría de Detección de Señales (TDS) podría ser un enfoque apropiado y más simple para entender el hallazgo de fenómenos opuestos con el mismo diseño. La distinción entre adquisición y desempeño que Stout y Miller (2007) y Pineño (2007) implementan es similar a la distinción central en la TDS entre sensibilidad y criterio de respuesta. De acuerdo con esta teoría, responder a una estimulación concreta depende tanto de lo que el organismo percibe (sensibilidad) cómo de la manera en la que el organismo decide responder a ello (criterio de respuesta). Por lo tanto, la sensibilidad depende de las propiedades físicas de los estímulos y de la habilidad de sujeto para percibirlos, y el criterio de respuesta depende de los factores subjetivos que modulan la predisposición del sujeto a responder de una manera concreta. En la TDS, el criterio de respuesta se ajusta de manera que optimiza la relación costes-beneficios de producir una respuesta (Green & Swets, 1966; Swets, 1988). De hecho, la transición de mediación positiva a negativa podría representar la estrategia que mejor fomenta la adaptabilidad de los sujetos: cuando se tiene poca experiencia con los estímulos, los sujetos responden a cualquier estímulo que señala directa o indirectamente una consecuencia concreta, mientras que cuando se tiene mayor experiencia, los sujetos discriminan mejor los estímulos que señalan directamente la consecuencia y los estímulos que sólo señalizan otros estímulos (Stout & Miller, 2007). De este modo, Lynn y Barrett (2014) señalaron que en condiciones de incertidumbre la sensibilidad es menor, lo cual da lugar a criterios más extremos para minimizar el número de errores. Esto explicaría el cambio en la respuesta con el avance de las sesiones: la incertidumbre se reduce por la experiencia repetida con los estímulos, incrementando por tanto la sensibilidad de los sujetos y reduciendo el sesgo. Esto explicaría la transición de interacción positiva a negativa que se observa en los presentes experimentos con el avance de las sesiones.

De acuerdo con Macmillan y Creelman (2005), el criterio de respuesta óptimo (β_{opt}) varía en función de la matriz de pagos de los cuatro resultados diferentes de la tarea Sí/No (véase la Tabla 2) y las probabilidades de presentación de la Señal y el Ruido, como se puede ver en la Ecuación 2:

$$\beta_{opt} = \frac{(V_{CR} - C_{FA})}{(V_H - C_O)} + \frac{P_N}{P_S} \qquad (2)$$

en la cual V_{CR} representa el valor asociado a un Rechazo Correcto, C_{FA} representa el valor asociado a una Falsa Alarma, V_H representa el valor asociado de un Acierto y C_O

representa el valor asociado a una Omisión. P_N se refiere a la probabilidad de presentación del Ruido y P_S se refiere a la probabilidad de presentación de una Señal. $\beta_{opt} < 1$ representa un criterio liberal, es decir, menos predisposición a producir una respuesta condicionada (RC), y $\beta_{opt} > 1$ representa un criterio conservador, es decir, más predisposición a producir una RC.

En los Experimentos 1 y 2, la única diferencia entre los tratamientos es el reforzamiento que sigue a los emparejamientos AX. Como puede observarse en estos experimentos, con una alta contingencia de reforzamiento de AX, la respuesta es mayor en las primeras sesiones del experimento. Este efecto es congruente con las variaciones de la matriz de pagos predichas por la Ecuación 2. En todos los diseños, el valor de P_N/P_S se mantiene constante, dado que el número de ensayos de cada tipo es el mismo en todas las condiciones, y el valor de $(V_{CR} - C_{FA})$ también es constante, dado que A siempre va seguido del EI. Sin embargo, el valor de $(V_H - C_O)$ depende de la contingencia de reforzamiento de AX. Cuanto mayor sea esta contingencia, menor será este término, pues será menos valioso no producir una RC cuando se presenta X (un Acierto), y es menos costoso producir una CR cuando X está presente (una Omisión), dado que en un gran número de ocasiones la presentación de X precede a la presentación del EI. Si este término es pequeño, el valor de β_{opt} será grande, por tanto, prediciendo un criterio más conservador, es decir, más predisposición a producir una CR. Por el contrario, cuanto menor es la contingencia, mayor será el valor de $(V_H - C_O)$, dado que es más valioso no producir una RC cuando se presenta X (un Acierto), y más costoso producir una RC cuando X se presenta (una Omisión), dado que en un gran número de ocasiones la presentación de X no precede a la presentación del EI. Si este término es grande, el valor de β_{opt} será pequeño, por lo tanto, prediciendo un criterio más liberal, es decir, menos predisposición a producir una RC. Este resultado es consistente con hallazgos anteriores (Perales et al., 2005; Allan et al., 2008) en los cuales, en estudios de aprendizaje de contingencias con humanos, variar la matriz de pagos variaba directamente la localización del criterio de respuesta. Sin embargo, el análisis en términos de TDS del Experimento 1 (incluido en el Apéndice I) no confirmó totalmente esto, dado que los grupos que recibieron algún reforzamiento en los ensayos AX (Grupos 1, 0.66 y 0.33) mostraron un criterio similar. Cabe destacar que, en todos los casos, el criterio fue mayo en el grupo en el cual los ensayos AX nunca fueron reforzados (Grupo 0).

Se debe tener en cuenta que, en los Experimentos 4-9, donde la proporción de ensayos se varía, los resultados son consistentes con cambios en el criterio de respuesta debido a la probabilidad de presentación de Ruido y Señal. En estos experimentos, las contingencias de reforzamiento se mantuvieron iguales, de manera que la matriz de pagos fue igual para todas las condiciones, y el valor de β_{opt} depende de P_N/P_S. Cuanto mayor es la proporción de ensayos A (Ruido) respecto a los ensayos AX (Señal + Ruido), mayor será el valor de β_{opt}, reflejando por ello un criterio más conservador, es decir, más predisposición a emitir una RC. Por otro lado, cuanto menor es la proporción de ensayos A respecto a los ensayos AX, menor será el valor de β_{opt}, reflejando un criterio más liberal, es decir, menos predisposición a emitir una RC. Esto es consistente con los hallazgos de que cuanto mayor fue la proporción A/AX, mayor fue la respuesta en las primeras sesiones del experimento y la prueba de retraso, y viceversa (Experimento 9). También son consistentes con el hallazgo de que con proporciones altas e intermedias de ensayos A/AX (14/2, 11/5 y 8/8), se encuentra CSO, y con proporciones intermedias y bajas de ensayos A/AX (8/8 y 5/11), se encuentra IC (Experimentos 4-8). Estas predicciones se fueron confirmadas con un análisis en términos de la TDS de estos experimentos, que pueden encontrarse en el Apéndice I.

Por todo lo anterior, la TDS ofrece un esquema interesante para entender las interacciones entre claves como cambios en el criterio de respuesta. Asimismo, puede integrar otros hallazgos que modulan estas interacciones, como son el tipo de tarea, las instrucciones y la experiencia previa. Todos estos factores pueden modular la localización del criterio de respuesta. El tipo de tarea determinaría lo que el organismo espera obtener por cada tipo de respuesta, es decir, la matriz de pagos. Además, es sabido que las instrucciones modifican enormemente la localización del criterio de respuesta, dado que los organismos están ya sesgados a comportarse de una manera determinada. Por último, la experiencia previa determinaría la localización del criterio que mejor optimiza la relación coste-beneficio en situaciones similares previas, de manera que el criterio adoptado en situaciones posteriores será similar, a no ser que la tarea posterior demuestre que el criterio es erróneo. Asimismo, este esquema es valioso dado que pone al sujeto en el centro del proceso de aprendizaje. Las teorías asociativas se centran en la formación de asociaciones basada en las probabilidades de ocurrencia de eventos en el mundo, y el sujeto es solo un receptor pasivo de las asociaciones que simplemente se comporta reflejándolas. La distinción entre adquisición y desempeño da un paso adelante en la importancia del sujeto en su propio aprendizaje, dado que ha de comparar entre múltiples asociaciones. Sin embargo, el proceso de comparación se basa solo en la fuerza de las asociaciones, no teniendo en cuenta otros factores que podrían influenciar al desempeño, como las instrucciones, el tipo de tarea o la experiencia previa. El enfoque proposicional da aún otro paso adelante, dado que los sujetos forman proposiciones y revisan su veracidad de acuerdo a lo que observan. La TDS pone al sujeto en el centro del proceso de aprendizaje, dado que es el sujeto quién ha de percibir la ocurrencia de eventos en el mundo, decidir cómo responder a esos eventos, y cambiar sus decisiones basándose en las consecuencias de esas decisiones. Además, dado que la

TDS se basa en la optimización de la adaptabilidad, ofrece una conexión con la teoría evolutiva, que nunca debería pasarse por alto en el estudio del aprendizaje, dada la importancia de este como forma de adaptarse al medio y ser capaz de sobrevivir. De esta manera, la TDS puede explicar el comportamiento de cualquier sujeto, ya que tiene en cuenta tanto la variedad perceptual al tomar en consideración la habilidad de los sujetos para detectar (sensibilidad) y las diferentes necesidades que los organismos necesitan satisfacer y como determinan la manera en la que los sujetos deciden comportarse (criterio de respuesta). Por ello, resulta interesante continuar investigando cómo este enfoque, basado en las decisiones del sujeto, puede contribuir a ampliar nuestro entendimiento de los procesos de aprendizaje.

References

Acebes, F., Solar, P., Carnero, S., & Loy, I. (2009). Blocking of tentacle lowering in the snail (*Helix aspersa*). *The Quarterly Journal of Experimental Psychology*, *62*(7), 1315-1327. https://doi.org/10.1080/17470210802483545

Acebes, F., Solar, P., Moris, J., & Loy, I. (2012). Associative learning phenomena in the snail (*Helix aspersa*): Conditioned inhibition. *Learning & Behavior*, *40*(1), 34–41. https://doi.org/10.3758/s13420-011-0042-6

Allan, L. G. (1980). A note on measurement of contingency between two binary variables in judgment tasks. *Bulletin of the Psychonomic Society*, *15*(3), 147–149. https://doi.org/10.3758/BF03334492

Allan, L. G., Hannah, S. D., Crump, M. J. C., & Siegel, S. (2006). Psychophysics of causality: Detecting contingencies is like detecting signals. *Proceedings of Fechner Day*, *22*, 50-70.

Allan, L. G., Hannah, S. D., Crump, M. J. C., & Siegel, S. (2008). The psychophysics of contingency assessment. *Journal of Experimental Psychology: General*, *137*(2), 226–243. https://doi.org/10.1037/0096-3445.137.2.226

Allan, L. G., Siegel, S., & Tangen, J. M. (2005). A signal detection analysis of contingency data. *Learning & Behavior*, *33*(2), 250–263. https://doi.org/10.3758/BF03196067

Allswede, D., Curley, K., Cullen, N., & Batsell, W. R., Jr. (2014). Within-compound associations mediate augmented flavor aversions. *Learning and Motivation*, *48*, 33–46. https://doi.org/10.1016/j.lmot.2014.10.001

Alsop, B., & Porritt, M. (2006). Discriminability and sensitivity to reinforcer magnitude in a detection task. *Journal of the Experimental Analysis of Behavior*, *85*(1), 41–56. https://doi.org/10.1901/jeab.2006.91-04

Alvarado, M. C., & Rudy, J. W. (1992). Some properties of configural learning: An investigation of the transverse-patterning problem. *Journal of Experimental Psychology: Animal Behavior Processes, 18*(2), 145–153. https://doi.org/10.1037/0097-7403.18.2.145

Álvarez, B., Loy, I., & Prados, J. (2017). Evolución y distribución del aprendizaje en el árbol filogenético. In J. Nieto, & R. Bernal-Gamboa (Eds.), *Estudios Contemporáneos en Cognición Comparada* (pp. 251-315). Universidad Nacional Autónoma de México.

Azorlosa, J. L., & Cicala, G. A. (1986). Blocking of conditioned suppression with 1 or 10 compound trials. *Animal Learning & Behavior, 14*(2), 163–167. https://doi.org/10.3758/BF03200051

Azorlosa, J. L., & Cicala, G. A. (1988). Increased conditioning in rats to a blocked CS after the first compound trial. *Bulletin of the Psychonomic Society, 26*(3), 254–257. https://doi.org/10.3758/BF03337303

Baker, A. G., Mercier, P., Vallée-Tourangeau, F., Frank, R., & Pan, M. (1993). Selective associations and causality judgments: Presence of a strong causal factor may reduce judgments of a weaker one. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 19*(2), 414–432. https://doi.org/10.1037/0278-7393.19.2.414

Batsell, W. R., Jr., & Batson, J. D. (1999). Augmentation of taste conditioning by a preconditioned odor. *Journal of Experimental Psychology: Animal Behavior Processes, 25*(3), 374–388. https://doi.org/10.1037/0097-7403.25.3.374

Batsell, W. R., Jr., Dandar, C., Girard, R., Miller, C., & Shimko, G. (2020). Can an augmented flavor augment another flavor? Evidence from second-order augmentation. *Learning and Motivation, 69*, 101609. https://doi.org/10.1016/j.lmot.2019.101609

Batsell, W. R., Jr., Paschall, G. Y., Gleason, D. I., & Batson, J. D. (2001). Taste preconditioning augments odor-aversion learning. *Journal of Experimental Psychology: Animal Behavior Processes, 27*(1), 30–47. https://doi.org/10.1037/0097-7403.27.1.30

Batsell, W. R., Jr., Wakefield, E., Ulrey, L. A., Reimink, K., Rowe, S. L., & Dexheimer, S. (2012). CS–US interval determines the transition from overshadowing to potentiation with flavor compounds. *Learning & Behavior, 40*(2), 180–194. https://doi.org/10.3758/s13420-011-0054-2

Batson, J. D., & Batsell, W. R., Jr. (2000). Augmentation, not blocking, in an A+/AX+ flavor-conditioning procedure. *Psychonomic Bulletin & Review, 7*(3), 466–471. https://doi.org/10.3758/BF03214358

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*(2), 238–249. https://doi.org/10.1037/0278-7393.31.2.238

Beckers, T., Miller, R. R., De Houwer, J., & Urushihara, K. (2006). Reasoning rats: Forward blocking in Pavlovian animal conditioning is sensitive to constraints of causal inference. *Journal of Experimental Psychology: General, 135*(1), 92–102. https://doi.org/10.1037/0096-3445.135.1.92

Beesley, T., & Shanks, D. R. (2012). Investigating cue competition in contextual cuing of visual search. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *38*(3), 709–725. https://doi.org/10.1037/a0024885

Bellingham, W. P., & Gillette, K. (1981). Attenuation of overshadowing as a function of nondifferential compound conditioning trials. *Bulletin of the Psychonomic Society, 18*(4), 218–220. https://doi.org/10.3758/BF03333608

Blaisdell, A. P., Gunther, L. M., & Miller, R. R. (1999). Recovery from blocking achieved by extinguishing the blocking CS. *Animal Learning & Behavior, 27*(1), 63–76. https://doi.org/10.3758/BF03199432

Blaisdell, A. P., Sawa, K., Leising, K. J., & Waldmann, M. R. (2006). Causal Reasoning in Rats. *Science, 311*(5763), 1020–1022. https://doi.org/10.1126/science.1121872

Blough, D. S. (1967). Stimulus generalization as signal detection in pigeons. *Science, 158*(3803), 940–941. https://doi.org/10.1126/science.158.3803.940

Boldero, J., Davison, M., & McCarthy, D. (1985). Reinforcer frequency and reinforcer duration as biasers of signal detection. *Behavioural Processes, 10*(1-2), 131–143. https://doi.org/10.1016/0376-6357(85)90124-X

Boneau, C. A., Holland, M. K., & Baker, W. M. (1965). Color-discrimination performance of pigeons: Effects of reward. *Science, 149*(3688), 1113–1114. https://doi.org/10.1126/science.149.3688.1113

Braun, J. J., & McIntosh, H. Jr. (1973). Learned taste aversions induced by rotational stimulation. *Physiological Psychology, 1*, 301-304. https://doi.org/10.3758/BF03326928

Brosvic, G. M., Hecht, G. S., LaHaye, S., Rowe, M. M., Risser, J. M., Clementson, E., & Dihoff, R. E. (1991). Quality-specific differences in rat taste detection performance as a function of stimulus volume. *Physiology & Behavior, 50*(4), 711–716. https://doi.org/10.1016/0031-9384(91)90007-B

Byers, J., Mondragón, E., & Alonso, E. (2017). *SOP Model Simulator* (Version 1) [Computer software]. CAL-R. Available from https://www.cal-r.org/index.php?id=SOP-sim

Carnero, S. (2011). Percepción de la contingencia en el condicionamiento pavloviano desde una perspectiva psicofísica [Doctoral dissertation, Universidad de Oviedo]. Repositorio Institucional de la Universidad de Oviedo. http://hdl.handle.net/10651/12692

Carr, A. F. (1974). Latent inhibition and overshadowing in conditioned emotional response conditioning with rats. *Journal of Comparative and Physiological Psychology*, *86*(4), 718–723. https://doi.org/10.1037/h0036159

Chapman, G. B., & Robbins, S. J. (1990). Cue interaction in human contingency judgment. *Memory & Cognition*, *18*(5), 537–545. https://doi.org/10.3758/BF03198486

Cheng, P. W. (1997). From covariation to causation: A causal power theory. *Psychological Review*, *104*(2), 367–405. https://doi.org/10.1037/0033-295X.104.2.367

Clopton, B. M. (1972). Detection of increments in noise intensity by monkeys. *Journal of the Experimental Analysis of Behavior*, *17*(3), 473–481. https://doi.org/10.1901/jeab.1972.17-473

Cole, R. P., Barnet, R. C., & Miller, R. R. (1995). Temporal encoding in trace conditioning. *Animal Learning & Behavior*, *23*(2), 144–153. https://doi.org/10.3758/BF03199929

Collins, D. J., & Shanks, D. R. (2006). Summation in causal learning: Elemental processing or configural generalization? *The Quarterly Journal of Experimental Psychology*, *59*(9), 1524–1534. https://doi.org/10.1080/17470210600639389

Couvillon, P. A., & Bitterman, M. E. (1989). Reciprocal overshadowing in the discrimination of colour-odor compounds by honeybees: Further tests of a continuity model. *Animal Learning & Behavior*, *17*(2), 213–222. https://doi.org/10.3758/BF03207637

Couvillon, P. A., Arakaki, L., & Bitterman, M. E. (1997). Intramodal blocking in honeybees. *Animal Learning & Behavior*, *25*(3), 277–282. https://doi.org/10.3758/BF03199085

Crump, M. J. C., Hannah, S. D., Allan, L. G., & Hord, L. K. (2007). Contingency judgments on the fly. *The Quarterly Journal of Experimental Psychology, 60*(6), 753–761. https://doi.org/10.1080/17470210701257685

Cunha, M., Jr., Forehand, M. R., & Angle, J. W. (2015). Riding coattails: When co-branding helps versus hurts less-known brands. *Journal of Consumer Research, 41*(5), 1284–1300. https://doi.org/10.1086/679119

Daneri, M. F., & Muzio, R. N. (2013). Bloqueo y ensombrecimiento en un grupo de vertebrados filogenéticamente antiguo: los anfibios [Blocking and overshadowing in a phylogenetically ancient vertebrate group: Amphibians]. *Revista Latinoamericana de Psicología*, *45*(2), 185–200. https://doi.org/10.14349/rlp.v45i2.1138

Daneri, M. F., & Muzio, R. N. (2015). Evolución de fenómenos básicos de aprendizaje en tareas de memoria espacial: Bloqueo, ensombrecimiento e inhibición latente en anfibios [Evolution of basic learning phenomena in spatial memory tasks: Blocking, overshadowing and latent inhibition in amphibians]. *Interdisciplinaria*, 32(2), 275–288.

Davey, G. C., & Arulampalam, T. (1982). Second-order "fear" conditioning in humans: Persistence of CR2 following extinction of CR1. *Behaviour Research and Therapy, 20*(4), 391–396. https://doi.org/10.1016/0005-7967(82)90099-7

Davey, G. C., & McKenna, I. (1983). The effects of postconditioning revaluation of CS_1 and UCS following Pavlovian second-order electrodermal conditioning in humans. *The Quarterly Journal of Experimental Psychology B: Comparative and Physiological Psychology, 35B*(2), 125–133. https://doi.org/10.1080/14640748308400899

De Houwer, J. (2009). The propositional approach to associative learning as an alternative for association formation models. *Learning & Behavior, 37*(1), 1–20. https://doi.org/10.3758/LB.37.1.1

De Houwer, J., & Beckers, T. (2002a). Higher-order retrospective revaluation in human causal learning. *The Quarterly Journal of Experimental Psychology B: Comparative and Physiological Psychology, 55B*(2), 137–151. https://doi.org/10.1080/02724990143000216

De Houwer, J., & Beckers, T. (2002b). Second-order backward blocking and unovershadowing in human causal learning. *Experimental Psychology, 49*(1), 27–33. https://doi.org/10.1027/1618-3169.49.1.27

De Houwer, J., Beckers, T., & Glautier, S. (2002). Outcome and Cue Properties Modulate Blocking. *The Quarterly Journal of Experimental Psychology Section A, 55*(3), 965–985. https://doi.org/10.1080/02724980143000578

Denniston, J. C., Savastano, H. I., & Miller, R. R. (2001). The extended comparator hypothesis: Learning by contiguity, responding by relative strength. In R. R. Mowrer & S. B. Klein (Eds.), *Handbook of contemporary learning theories* (p. 65–117). Lawrence Erlbaum Associates Publishers.

Dickinson, A., & Burke, J. (1996). Within-compound associations mediate the retrospective revaluation of causality judgements. *The Quarterly Journal of Experimental Psychology B: Comparative and Physiological Psychology, 49B*(1), 60–80. https://doi.org/10.1080/713932614

Dickinson, A., Nicholas, D. J., & Mackintosh, N. J. (1983) A re-examination of one-trial blocking in conditioned suppression. *The Quarterly Journal of Experimental Psychology B, 35*(1), 67-79. https://doi.org/10.1080/14640748308400914

Dickinson, A., Shanks, D., & Evenden, J. (1984). Judgement of act-outcome contingency: The role of selective attribution. *The Quarterly Journal of Experimental Psychology A: Human Experimental Psychology*, *36*(1-A), 29–50. https://doi.org/10.1080/14640748408401502

Durlach, P. J., & Rescorla, R. A. (1980). Potentiation rather than overshadowing in flavor-aversion learning: An analysis in terms of within-compound associations. *Journal of Experimental Psychology: Animal Behavior Processes*, *6*(2), 175–187. https://doi.org/10.1037/0097-7403.6.2.175

Fechner, G. (1966). *Elements of psychophysics* (H. E. Adler, Trans., D. H. Howes & E. G. Boring, Eds.). Holt, Rinehart and Winston. (Original work published 1860).

Garcia, J., & Koelling, R. A. (1967). A comparison of aversion induced by x-rays, drugs, and toxins in the rat. *Radiation Research Supplement*, *7*, 439-450. https://doi.org/10.2307/3583736

Gibbs, C. M., Kehoe, E. J., & Gormezano, I. (1991). Conditioning of the rabbit's nictitating membrane response to a CSA-CSB-US serial compound: Manipulations of CSB's associative character. *Journal of Experimental*

Psychology: Animal Behavior Processes, 17(4), 423–432. https://doi.org/10.1037/0097-7403.17.4.423

Gigerenzer, G., & Murray, D. J. (1987). *Cognition as intuitive statistics*. Lawrence Erlbaum Associates, Inc.

Gillan, D. J., & Domjan, M. (1977). Taste-aversion conditioning with expected versus unexpected drug treatment. *Journal of Experimental Psychology: Animal Behavior Processes, 3*(4), 297-309. https://doi.org/10.1037//0097-7403.3.4.297

Good, I., Allswede, D., Curley, K., & Batsell, W. R., Jr. (2015). Increasing trial number produces augmentation, not blocking, in flavor-aversion conditioning. *Learning and Motivation*, *49*, 38–50. https://doi.org/10.1016/j.lmot.2015.01.002

Green, D. M., & Swets, J. A. (1966). *Signal detection theory and psychophysics*. John Wiley and Sons, Inc.

Grice, G. R. (1972) Conditioning and a decision theory of response evocation. *Psychology of Learning and Motivation*, *5*, 1-65. https://doi.org/10.1016/S0079-7421(08)60439-9

Grikietis, R., Mondragón, E., & Alonso, E. (2016). *Pearce & Hall Simulator* (Version 1) [Computer software]. CAL-R. Available from https://www.cal-r.org/index.php?id=PHsim

Hack, M. H. (1963). Signal detection in the rat. *Science, 139*(3556), 758-760. https://doi.org/10.1126/science.139.3556.758

Hannah, S. D., Crump, M. J. C., Allan, L. G., & Siegel, S. (2009). Cue-interaction effects in contingency judgments using the streamed-trial procedure. *Canadian Journal of Experimental Psychology/Revue canadienne de psychologie expérimentale*, *63*(2), 103–112. https://doi.org/10.1037/a0013521

References

Harris, J. A., Patterson, A. E., Andrew, B. J., Kwok, D. W. S., & Loy, I. (2016). Asymmetry between excitatory and inhibitory learning. *Journal of Experimental Psychology: Animal Learning and Cognition, 42*(4), 297–312. https://doi.org/10.1037/xan0000110

Herendeen, D., & Anderson, D. C. (1968). Dual effects of second-order conditioned stimulus: Excitation and inhibition. *Psychonomic Science, 13*(1), 15–16. https://doi.org/10.3758/BF03342385

Herremans, A. H. J., Hijzen, T. H., Olivier, B., & Slangen, J. L. (1995). Relation between stimulus discriminability and response bias in a delayed conditional discrimination task in the rat. *Journal of Neuroscience Methods*, *63*(1-2), 29-35. https://doi.org/10.1016/0165-0270(95)00082-8

Hobson, S. L. (1975). Discriminability of fixed-ratio schedules for pigeons: Effects of absolute ratio size. *Journal of the Experimental Analysis of Behavior, 23*(1), 25–35. https://doi.org/10.1901/jeab.1975.23-25

Hobson, S. L. (1978). Discriminability of fixed-ratio schedules for pigeons: Effects of payoff values. *Journal of the Experimental Analysis of Behavior, 30*(1), 69-81. https://doi.org/10.1901/jeab.1978.30-69

Hodos, W., & Bonbright, J. C. (1972). The detection of visual intensity differences by pigeons. *Journal of the Experimental Analysis of Behavior*, *18*(3), 471–479. https://doi.org/10.1901/jeab.1972.18-471

Holland, P. C., & Rescorla, R. A. (1975). Second-Order Conditioning with food unconditioned stimulus. *Journal of Comparative and Physiological Psychology, 88*(1), 459–467. https://doi.org/10.1037/h0076219

Holland, P. C., Asem, J. S. A., Galvin, C. P., Keeney, C. H., Hsu, M., Miller, A., & Zhou, V. (2014). Blocking in autoshaped lever-pressing procedures with rats. *Learning & Behavior, 42*(1), 1–21. https://doi.org/10.3758/s13420-013-0120-z

Hollis, K. L. (1982) Pavlovian Conditioning of Signal-Centered Action Patterns and Autonomic Behavior: A Biological Analysis of Function. *Advances in the Study of Behavior*, *12*, 1-64. https://doi.org/10.1016/S0065-3454(08)60045-5

Honey, R. C., & Hall, G. (1992). CS memory after trace conditioning. *Learning and Motivation*, *23*, 145–155. http://dx.doi.org/10.1016/0023-9690(92)90014-D

Hull, C. L. (1943). *Principles of behavior: an introduction to behavior theory*. Appleton-Century.

Hume, D. (1956) *An Enquiry Concerning Human Understanding and Other Writings*. Gateway Editions. (Original work published 1748)

IBM Corp. (2016). *IBM SPSS Statistics for Windows* (Version 24.0) [Computer software]. IBM Corp.

Jara, E., Vila, J., & Maldonado, A. (2006). Second-order conditioning of human causal learning. *Learning and Motivation*, *37*(3), 230–246. https://doi.org/10.1016/j.lmot.2005.12.001

Jensen, C., Van Til, K., Abe, A., Nicholson, P., & Batsell, W. R., Jr. (2018). Augmentation's boundary conditions? Investigation of spatial contiguity, temporal contiguity, and target flavor familiarity. *Learning and Motivation, 63*, 49–66. https://doi.org/10.1016/j.lmot.2017.12.001

Jozefowiez, J. (2021). Individual differences in the perception of cue-outcome contingencies: A signal detection analysis. *Behavioural Processes, 188*, 104398. https://doi.org/10.1016/j.beproc.2021.104398

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. 9-31). University of Miami Press.

Kamin, L. J. (1969). Predictability, Surprise, Attention, and Conditioning. In B. A. Campbell, & R. M. Church (Eds.), *Punishment Aversive Behavior* (pp. 279-296). Appleton-Century-Crofts.

Kant, I. (1929). *Critique of Pure Reason* (N. K. Smith, Trans.) Macmillan and Co. (Original work published 1787).

Karazinov, D. M., & Boakes, R. A. (2007). Second-order conditioning in human predictive judgements when there is little time to think. *The Quarterly Journal of Experimental Psychology, 60*(3), 448–460. https://doi.org/10.1080/17470210601002488

Kaufman, M. A., & Bolles, R. C. (1981). A nonassociative aspect of overshadowing. *Bulletin of the Psychonomic Society, 18*(6), 318–320. https://doi.org/10.3758/BF03333639

Kehoe, E. J. (1982). Overshadowing and summation in compound stimulus conditioning of the rabbit's nictitating membrane response. *Journal of Experimental Psychology: Animal Behavior Processes, 8*(4), 313–328. https://doi.org/10.1037/0097-7403.8.4.313

Kehoe, E. J., & White, N. E. (2004). Overexpectation: Response Loss During Sustained Stimulus Compounding in the Rabbit Nictitating Membrane Preparation. *Learning & Memory*, *11*(4), 476–483. https://doi.org/10.1101/lm.77604

Kehoe, E. J., Feyer, A.-M., & Moses, J. L. (1981). Second-order conditioning of the rabbit's nictitating membrane response as a function of the CS2–CS1 and CS1–

US intervals. *Animal Learning & Behavior*, *9*(3), 304–315. https://doi.org/10.3758/BF03197836

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*(1), 19–26. https://doi.org/10.3758/BF03199952

Khallad, Y., & Moore, J. (1996). Blocking, unblocking, and overexpectation in autoshaping with pigeons. *Journal of the Experimental Analysis of Behavior*, *65*(3), 575–591. https://doi.org/10.1901/jeab.1996.65-575

Kimmel, H. D., & Bevill, M. J. (1991). Blocking and unconditioned response diminution in human classical autonomic conditioning. *Integrative Physiological and Behavioral Science*, *26*(2), 132–138. https://doi.org/10.1007/bf02691036

Kinchla, R. A., & Atkinson, R. C. (1964) The effect of false-information feedback upon psychophysical judgments. *Psychonomic Science*, 1, 317–318. https://doi.org/10.3758/BF03342931

Kohler, E. A., & Ayres, J. J. (1982). Blocking with serial and simultaneous compounds in a trace conditioning procedure. *Animal Learning & Behavior*, *10*(3), 277–287. https://doi.org/10.3758/BF03213711

Kosaki, Y., Austen, J. M., & McGregor, A. (2013). Overshadowing of geometry learning by discrete landmarks in the water maze: Effects of relative salience and relative validity of competing cues. *Journal of Experimental Psychology: Animal Behavior Processes*, *39*(2), 126–139. https://doi.org/10.1037/a0031199

Kucharski, D., & Spear, N. E. (1985). Potentiation and overshadowing in preweanling and adult rats. *Journal of Experimental Psychology: Animal Behavior Processes*, *11*(1), 15–34. https://doi.org/10.1037/0097-7403.11.1.15

Lattal, K. M., & Nakajima, S. (1998). Overexpectation in appetitive Pavlovian and instrumental conditioning. *Animal Learning & Behavior, 26*(3), 351–360. https://doi.org/10.3758/BF03199227

Laux, J. P., Goedert, K. M., & Markman, A. B. (2010). Causal discounting in the presence of a stronger cue is due to bias. *Psychonomic Bulletin & Review, 17*(2), 213–218. https://doi.org/10.3758/PBR.17.2.213

Lee, J. C., & Livesey, E. J. (2012). Second-Order Conditioning and Conditioned Inhibition: Influences of Speed versus Accuracy on Human Causal Learning. *PLoS ONE, 7*(11), e49899. https://doi.org/10.1371/journal.pone.0049899

Leyland, C. M., & Mackintosh, N. J. (1978). Blocking of first- and second-order autoshaping in pigeons. *Animal Learning & Behavior, 6*(4), 391–394. https://doi.org/10.3758/BF03209633

Lindsey, G. P., & Best, P. J. (1973). Overshadowing of the less salient of two novel fluids in a taste-aversion paradigm. *Physiological Psychology, 1*(1), 13–15. https://doi.org/10.3758/BF03326859

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*(1), 133–142. https://doi.org/10.3758/BF03196088

Loy, I., Carnero, S., Acebes, F., Solar, P., Álvarez, I., & Morís, J. (2009). La toma de decisiones como proceso psicológico general: La supuesta excepción de la psicología experimental del condicionamiento [Decision-making as a general psychological process: The supposed exception of experimental psychology of conditioning]. *Revista de Historia de la Psicología, 30*(2/3), 195-206.

Loy, I., Fernández, V., & Acebes, F. (2006). Conditioning of tentacle lowering in the snail (*Helix aspersa*): Acquisition, latent inhibition, overshadowing, second-order conditioning, and sensory preconditioning. *Learning & Behavior*, *34*(3), 305–314. https://doi.org/10.3758/BF03192885

Luongo, A. F. (1976). Stimulus selection in discriminative taste-aversion learning in the rat. *Animal Learning & Behavior*, *4*(3), 225–230. https://doi.org/10.3758/BF03214041

Lynn, S. K., & Barrett, L. F. (2014). "Utilizing" signal detection theory. *Psychological Science*, *25*(9), 1663–1673. https://doi.org/10.1177/0956797614541991

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*(1), 71–94. https://doi.org/10.1037/0097-7403.11.1.71

Mackintosh, N. J. (1975a). A theory of attention: Variations in the associability of stimuli with reinforcement. *Psychological Review*, *82*(4), 276–298. https://doi.org/10.1037/h0076778

Mackintosh, N. J. (1975b). Blocking of conditioned suppression: Role of the first compound trial. *Journal of Experimental Psychology: Animal Behavior Processes*, *1*(4), 335–345. https://doi.org/10.1037/0097-7403.1.4.335

Mackintosh, N. J. (1983). *Conditioning and Associative Learning*. Oxford University Press.

Mackintosh, N. J., Dickinson, A., & Cotton, M. M. (1980). Surprise and blocking: Effects of the number of compound trials. *Animal Learning & Behavior*, *8*(3), 387–391. https://doi.org/10.3758/BF03199622

Macmillan, N. A., & Creelman, C. D. (2005). *Detection theory: A user's guide* (2nd ed.). Lawrence Erlbaum Associates Publishers.

Maes, E., Boddez, Y., Alfei, J. M., Krypotos, A.-M., D'Hooge, R., De Houwer, J., & Beckers, T. (2016). The Elusive Nature of the Blocking Effect: 15 Failures to Replicate. *Journal of Experimental Psychology: General*, *145*(9), e49-e71. http://doi.org/10.1037/xge0000200

Maes, E., Krypotos, A., Boddez, Y., Alfei Palloni, J. M., D'Hooge, R., De Houwer, J., & Beckers, T. (2018). Failures to replicate blocking are surprising and informative - Reply to Soto. *Journal of Experimental Psychology. General, 147*(4), 603-610. https://doi.org/10.1037/xge0000413

Maia, S., Lefèvre, F., & Jozefowiez, J. (2018). Psychophysics of associative learning: Quantitative properties of subjective contingency. *Journal of Experimental Psychology: Animal Learning and Cognition, 44*(1), 67–81. https://doi.org/10.1037/xan0000153

Maisiak, R., & Frey, P. W. (1977). Second-order conditioning: The importance of stimulus overlap on second-order trials. *Animal Learning & Behavior, 5*(3), 309–314. https://doi.org/10.3758/BF03209245

Maldonado, A., Catena, A., Cándido, A., & García, I. (1999). The belief revision model: Asymmetrical effects of noncontingency on human covariation learning. *Animal Learning & Behavior, 27*(2), 168–180. https://doi.org/10.3758/BF03199673

Martin, I., & Levey, A. B. (1991). Blocking observed in human eyelid conditioning. *The Quarterly Journal of Experimental Psychology B: Comparative and Physiological Psychology, 43*(3), 233–256. https://doi.org/10.1080/14640749108401269

Mason, C. R., Idrobo, F., Early, S. J., Abibi, A., Zheng, L., Harrison, J. M., & Carney, L. H. (2003). CS-dependent response probability in an auditory masked-detection task: Considerations based on models of Pavlovian conditioning. *The Quarterly Journal of Experimental Psychology B: Comparative and Physiological Psychology*, *56*(2), 193–205. https://doi.org/10.1080/02724990244000052

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*(1), 182–196. https://doi.org/10.1037/0278-7393.22.1.182

McCarthy, D., & Davison, M. (1979). Signal probability, reinforcement and signal detection. *Journal of the Experimental Analysis of Behavior*, *32*(3), 373–386. https://doi.org/10.1901/jeab.1979.32-373

McCarthy, D., & Davison, M. (1980). Independence of sensitivity to relative reinforcement rate and discriminability in signal detection. Journal of the *Experimental Analysis of Behavior*, *34*(3), 273–284. https://doi.org/10.1901/jeab.1980.34-273

McCarthy, D., & Davison, M. (1981). Towards a behavioral theory of bias in signal detection. *Perception & Psychophysics*, *29*(4), 371–382. https://doi.org/10.3758/BF03207347

McCarthy, D., Davison, M., & Jenkins, P. E. (1982). Stimulus discriminability in free-operant and discrete-trial detection procedures. *Journal of the Experimental Analysis of Behavior*, *37*(2), 199–215. https://doi.org/10.1901/jeab.1982.37-199

Melchers, K. G., Lachnit, H., & Shanks, D. R. (2004). Within-compound associations in retrospective revaluation and in direct learning: A challenge for comparator theory. *The Quarterly Journal of Experimental Psychology B: Comparative and Physiological Psychology*, *57B*(1), 25–53. https://doi.org/10.1080/02724990344000042

Melchers, K. G., Shanks, D. R., & Lachnit, H. (2008). Stimulus coding in human associative learning: Flexible representations of parts and wholes. *Behavioural Processes*, *77*(3), 413–427. https://doi.org/10.1016/j.beproc.2007.09.013

Merchant, H. G., & Moore, J. W. (1973). Blocking of the rabbit's conditioned nictitating membrane response in Kamin's two-stage paradigm. *Journal of Experimental Psychology*, *101*(1), 155–158. https://doi.org/10.1037/h0035784

Miles, C. G., & Jenkins, H. M. (1973). Overshadowing in operant conditioning as a function of discriminability. *Learning and Motivation*, *4*(1), 11–27. https://doi.org/10.1016/0023-9690(73)90036-2

Miller, L. (1971). Compounding of discriminative stimuli from the same and different sensory modalities. *Journal of the Experimental Analysis of Behavior*, *16*(3), 337–342. https://doi.org/10.1901/jeab.1971.16-337

Miller, R. R. (2006). Challenges facing contemporary associative approaches to acquired behavior. *Comparative Cognition & Behavior Reviews*, *1*(1), 77–93. https://doi.org/10.3819/ccbr.2008.10005

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: Advances in research and theory, Vol. 22* (p. 51–92). Academic Press. https://doi.org/10.1016/S0079-7421(08)60038-9

Mis, F. W., Lumia, A. R., & Moore, J. W. (1972). Inhibitory stimulus control of the classically conditioned nictitating membrane response of the rabbit. *Behavior*

Research Methods & Instrumentation, *4*, 297–299. https://doi.org/10.3758/BF03207309

Mitchell, C. J., & Lovibond, P. F. (2002). Backward and forward blocking in human electrodermal conditioning: Blocking requires an assumption of outcome additivity. *The Quarterly Journal of Experimental Psychology B: Comparative and Physiological Psychology*, *55B*(4), 311–329. https://doi.org/10.1080/02724990244000025

Mitchell, C. J., Killedar, A., & Lovibond, P. F. (2005a). Inference-based retrospective revaluation in human causal judgments requires knowledge of within-compound relationships. *Journal of Experimental Psychology: Animal Behavior Processes, 31*(4), 418–424. https://doi.org/10.1037/0097-7403.31.4.418

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. *The Quarterly Journal of Experimental Psychology*, *60*(3), 400–417. https://doi.org/10.1080/17470210601002512

Mitchell, C. J., Lovibond, P. F., & Gan, C. Y. (2005b). A dissociation between causal judgment and outcome recall. *Psychonomic Bulletin & Review, 12*, 950-954. https://doi.org/10.3758/BF03196791

Mondragón, E., Alonso, E., Fernández, A., & Gray, J. (2012). *Rescorla & Wagner Simulator* (Version 4) [Computer software]. CAL-R. Available from https://www.cal-r.org/index.php?id=R-Wsim

Morís, J., Carnero, S., & Loy, I. (2012). A test of Rescorla and Wagner's (1972) prediction of nonlinear effects in contingency learning. *Learning & Behavior, 40*(4), 507–519. https://doi.org/10.3758/s13420-012-0070-x

References

Morrison, G. R., & Norrison, W. (1966). Taste detection in the rat. *Canadian Journal of Psychology/Revue canadienne de psychologie, 20*(2), 208–217. https://doi.org/10.1037/h0082938

Murphy, R. A., Baker, A. G., & Fouquet, N. (2001). Relative validity of contextual and discrete cues. *Journal of Experimental Psychology: Animal Behavior Processes, 27*(2), 137–152. https://doi.org/10.1037/0097-7403.27.2.137

Nevin, J. A. (1965). Decision theory in studies of discrimination in animals. *Science, 150*(3699), 1057. https://doi.org/10.1126/science.150.3699.1057

Nevin, J. A., Jenkins, P. E., Whittaker, S., & Yarensky, P. (1982). Reinforcement contingencies and signal detection. *Journal of the Experimental Analysis of Behavior*, *37*(1), 65–79. https://doi.org/10.1901/jeab.1982.37-65

Packheiser, J., Pusch, R., Stein, C. C., Güntürkün, O., Lachnit, H., & Uengoer, M. (2020). How competitive is cue competition? *The Quarterly Journal of Experimental Psychology*, *73*(1), 104-114. https://doi.org/10.1177/1747021819866967

Papini, M. R., & Bitterman, M. E. (1993). The two-test strategy in the study of inhibitory conditioning. *Journal of Experimental Psychology: Animal Behavior Processes*, *19*(4), 342–352. https://doi.org/10.1037/0097-7403.19.4.342

Pavlov, I. P. (1960). *Conditioned Reflexes: An Investigation of the Physiological Activity of the Cerebral Cortex* (G. V. Anrep, Trans.). Dover publications. (Original work published 1927).

Pearce, J. M. (1987). A model for stimulus generalization in Pavlovian conditioning. *Psychological Review*, *94*(1), 61–73. https://doi.org/10.1037/0033-295X.94.1.61

Pearce, J. M. (1994). Similarity and discrimination: A selective review and a connectionist model. *Psychological Review*, *101*(4), 587–607. https://doi.org/10.1037/0033-295X.101.4.587

Pearce, J. M., & Hall, G. (1980). A model for Pavlovian learning: Variations in the effectiveness of conditioned but not of unconditioned stimuli. *Psychological Review*, *87*(6), 532–552. https://doi.org/10.1037/0033-295X.87.6.532

Perales, J. C., Catena, A., Shanks, D. R., & González, J. A. (2005). Dissociation Between Judgments and Outcome-Expectancy Measures in Covariation Learning: A Signal Detection Theory Approach. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *31*(5), 1105–1120. https://doi.org/10.1037/0278-7393.31.5.1105

Pierce, W. D., & Heth, C. D. (2010). Blocking of conditioned taste avoidance induced by wheel running. *Behavioural Processes*, *83*(1), 41–47. https://doi.org/10.1016/j.beproc.2009.09.005

Pineño, O. (2007). A response rule for positive and negative stimulus interaction in associative learning and performance. *Psychonomic Bulletin & Review*, *14*(6), 1115–1124. https://doi.org/10.3758/BF03193100

Prados, J., Alvarez, B., Acebes, F., Loy, I., Sansa, J., & Moreno-Fernández, M. M. (2013a). Blocking in rats, humans and snails using a within-subjects design. *Behavioural Processes*, *100*, 23–31. https://doi.org/10.1016/j.beproc.2013.07.014

Prados, J., Alvarez, B., Howarth, J., Stewart, K., Gibson, C. L., Hutchinson, C. V., Young, A. M. J., & Davidson, C. (2013b). Cue competition effects in the planarian. *Animal Cognition*, *16*(2), 177–186. https://doi.org/10.1007/s10071-012-0561-3

Rashotte, M. E., Griffin, R. W., & Sisk, C. L. (1977). Second-order conditioning of the pigeon's keypeck. *Animal Learning & Behavior*, *5*(1), 25–38. https://doi.org/10.3758/BF03209127

Rescorla, R. A. (1968). Probability of shock in the presence and absence of CS in fear conditioning. *Journal of Comparative and Physiological Psychology*, *66*(1), 1–5. https://doi.org/10.1037/h0025984

Rescorla, R. A. (1969). Pavlovian conditioned inhibition. *Psychological Bulletin*, *72*(2), 77–94. https://doi.org/10.1037/h0027760

Rescorla, R. A. (1970). Reduction in the effectiveness of reinforcement after prior excitatory conditioning. *Learning and Motivation*, *1*(4), 372–381. https://doi.org/10.1016/0023-9690(70)90101-3

Rescorla, R. A. (1972). Informational variables in Pavlovian Conditioning. *Psychology of Learning and Motivation*, *6*, 1-46. https://doi.org/10.1016/S0079-7421(08)60383-7

Rescorla, R. A. (1981). Simultaneous associations. In P. Harzem and M. D. Zeiler (Eds.), *Predictability, correlation, and contiguity* (pp. 47–80). Wiley.

Rescorla, R. A. (1982). Simultaneous second-order conditioning produces S-S learning in conditioned suppression. *Journal of Experimental Psychology: Animal Behavior Processes*, *8*(1), 23–32. https://doi.org/10.1037/0097-7403.8.1.23

Rescorla, R. A. (1999). Summation and overexpectation with qualitatively different outcomes. *Animal Learning & Behavior*, *27*(1), 50–62. https://doi.org/10.3758/BF03199431

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. Proasky (Eds.) *Classical conditioning II: Current research and theory* (pp. 64-99). Appleton-Century-Crofts.

Rilling, M., & McDiarmid, C. (1965). Signal detection in fixed-ratio schedules. *Science, 148*(3669), 526–527. https://doi.org/10.1126/science.148.3669.526

Rizley, R. C., & Rescorla, R. A. (1972). Associations in second-order conditioning and sensory preconditioning. *Journal of Comparative and Physiological Psychology, 81*(1), 1–11. https://doi.org/10.1037/h0033333

Rodrigo, T., Chamizo, V. D., McLaren, I. P. L., & Mackintosh, N. J. (1997). Blocking in the spatial domain. *Journal of Experimental Psychology: Animal Behavior Processes*, *23*(1), 110–118. https://doi.org/10.1037/0097-7403.23.1.110

Rusiniak, K. W., Hankins, W. G., Garcia, J., & Brett, L. P. (1979). Flavor-illness aversions: Potentiation of odor by taste in rats. *Behavioral & Neural Biology, 25*(1), 1–17. https://doi.org/10.1016/S0163-1047(79)90688-5

Sahley, C., Rudy, J. W., & Gelperin, A. (1981). An analysis of associative learning in a terrestrial mollusc. I. Higher-order conditioning, blocking and a transient US pre-exposure effect. *Journal of Comparative Physiology*, *144*, 1-8. https://doi.org/10.1007/BF00612791

Schmajuk, N. A. (1987). Classical conditioning, signal detection, and evolution. *Behavioural Processes*, *14*(3), 277–289. https://doi.org/10.1016/0376-6357(87)90074-X

Schmidt, J. R., & De Houwer, J. (2019). Cue competition and incidental learning: No blocking or overshadowing in the colour-word contingency learning procedure without instructions to learn. *Collabra Psychology*, *5*(1), 15. https://doi.org/10.1525/collabra.236

Shanks, D. R., & Darby, R. J. (1998). Feature- and rule-based generalization in human associative learning. *Journal of Experimental Psychology: Animal Behavior Processes*, *24*(4), 405–415. https://doi.org/10.1037/0097-7403.24.4.405

Shanks, D. R., & Dickinson, A. (1987). Associative accounts of causality judgment. In G. H. Bower (Ed.), *The psychology of learning and motivation: Advances in research and theory, Vol. 21* (p. 229–261). Academic Press.

Siegel, S., Allan, L. G., Hannah, S. D., & Crump, M. J. C. (2009). Applying signal detection theory to contingency assessment. *Comparative Cognition & Behavior Reviews*, *4*, 116–134. https://doi.org/10.3819/ccbr.2009.40012

Smith, B. H., & Cobey, S. (1994) The olfactory memory of the honeybee *Apis mellifera*. II. Blocking between odorants in binary mixtures. *Journal of Experimental Biology*, *195*(1), 91-108. https://doi.org/10.1242/jeb.195.1.91

Spetch, M. L. (1995). Overshadowing in landmark learning: Touch-screen studies with pigeons and humans. *Journal of Experimental Psychology: Animal Behavior Processes*, *21*(2), 166–181. https://doi.org/10.1037/0097-7403.21.2.166

Stout, S. C., & Miller, R. R. (2007). Sometimes-competing retrieval (SOCR): A formalization of the comparator hypothesis. *Psychological Review*, *114*(3), 759–783. https://doi.org/10.1037/0033-295X.114.3.759

Stout, S., Escobar, M., & Miller, R. R. (2004). Trial number and compound stimuli temporal relationship as joint determinants of Second-Order Conditioning and Conditioned Inhibition. *Learning & Behavior*, *32*(2), 230–239. https://doi.org/10.3758/BF03196024

Stubbs, D. A. (1976). Response bias and the discrimination of stimulus duration. *Journal of the Experimental Analysis of Behavior*, *25*(2), 243–250. https://doi.org/10.1901/jeab.1976.25-243

Suboski, M. D., & Spevack, A. A. (1968). Signal detection analysis of instrumental discrimination conditioning. *Canadian Journal of Psychology/Revue canadienne de psychologie, 22*(1), 26–34. https://doi.org/10.1037/h0082742

Sutton, R. S., & Barto, A. G. (1981). Toward a modern theory of adaptive networks: Expectation and prediction. *Psychological Review, 88*(2), 135–170. https://doi.org/10.1037/0033-295X.88.2.135

Swets, J. A. (1988). Measuring the accuracy of diagnostic systems. *Science, 240*(4857), 1285–1293. https://doi.org/10.1126/science.3287615

Tennant, W. A., & Bitterman, M. E. (1975). Blocking and overshadowing in two species of fish. *Journal of Experimental Psychology: Animal Behavior Processes*, *1*(1), 22–29. https://doi.org/10.1037/0097-7403.1.1.22

Terao, K., & Mizunami, M. (2017). Roles of dopamine neurons in mediating the prediction error in aversive learning in insects. *Scientific reports, 7*, 14694. https://doi.org/10.1038/s41598-017-14473-y

Terao, K., Matsumoto, Y., & Mizunami, M. (2015). Critical evidence for the prediction error theory in associative learning. *Scientific reports*, *5*, 8929. https://doi.org/10.1038/srep08929

Thorndike, E. L. (1898). Animal intelligence: An experimental study of the associative processes in animals. *The Psychological Review: Monograph Supplements, 2*(4), i–109. https://doi.org/10.1037/h0092987

Thorwart, A., Schultheis, H., König, S., & Lachnit, H. (2009). ALTSim: A MATLAB simulator for current associative learning theories. *Behavioral Research Methods, 41*, 29–34. https://doi.org/10.3758/BRM.41.1.29

Twitmyer, E. B. (1905). Knee-jerks without stimulation of the patellar tendon. *Psychological Bulletin, 2*, 43-44.

Urcelay, G. P. (2017). Competition and facilitation in compound conditioning. *Journal of Experimental Psychology: Animal Learning and Cognition*, *43*(4), 303–314. https://doi.org/10.1037/xan0000149

Urcelay, G. P., & Miller, R. R. (2009). Potentiation and overshadowing in Pavlovian fear conditioning. *Journal of Experimental Psychology: Animal Behavior Processes*, *35*(3), 340–356. https://doi.org/10.1037/a0014350

Vadillo, M. A., & Matute, H. (2010). Augmentation in contingency learning under time pressure. *British Journal of Psychology*, *101*(3), 579–589. https://doi.org/10.1348/000712609X477566

Vadillo, M. A., & Matute, H. (2011). Further evidence on the validity of web-based research on associative learning: Augmentation in a predictive learning task. *Computers in Human Behavior*, *27*(2), 750–754. https://doi.org/10.1016/j.chb.2010.10.020

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*(2), 127–151. https://doi.org/10.1006/lmot.1994.1008

vom Saal, W., & Jenkins, H. M. (1970). Blocking the development of stimulus control. *Learning and Motivation*, *1*(1), 52–64. https://doi.org/10.1016/0023-9690(70)90128-1

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). Erlbaum.

Wagner, A. R., Logan, F. A., & Haberlandt, K. (1968). Stimulus selection in animal discrimination learning. *Journal of Experimental Psychology, 76*(2, Pt.1), 171–180. https://doi.org/10.1037/h0025414

Waldmann, M. R. (2000). Competition among causes but not effects in predictive and diagnostic learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *26*(1), 53–76. https://doi.org/10.1037/0278-7393.26.1.53

Waldmann, M. R., & Holyoak, K. J. (1992). Predictive and diagnostic learning within causal models: Asymmetries in cue competition. *Journal of Experimental Psychology: General, 121*(2), 222–236. https://doi.org/10.1037/0096-3445.121.2.222

Wasserman, E. A., Elek, S. M., Chatlosh, D. L., & Baker, A. G. (1993). Rating causal relations: Role of probability in judgments of response-outcome contingency. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 19*(1), 174–188. https://doi.org/10.1037/0278-7393.19.1.174

Wasserman, E. A., Kao, S.-F., Van Hamme, L. J., Katagiri, M., & Young, M. E. (1996). Causation and association. In D. R. Shanks, K. Holyoak, & D. L. Medin (Eds.), *Causal learning* (p. 207–264). Academic Press.

Williams, B. A. (1984). Relative stimulus validity in conditional discrimination. *Animal Learning & Behavior, 12*(2), 117–121. https://doi.org/10.3758/BF03213129

Williams, D. A., & Braker, D. S. (1999). Influence of past experience on the coding of compound stimuli. *Journal of Experimental Psychology: Animal Behavior Processes*, *25*(4), 461–474. https://doi.org/10.1037/0097-7403.25.4.461

Williams, D. A., Overmier, J. B., & LoLordo, V. M. (1992). A reevaluation of Rescorla's early dictums about Pavlovian conditioned inhibition. *Psychological Bulletin, 111*(2), 275–290. https://doi.org/10.1037/0033-2909.111.2.275

Williams, D. A., Sagness, K. E., & McPhee, J. E. (1994). Configural and elemental strategies in predictive learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *20*(3), 694–709. https://doi.org/10.1037/0278-7393.20.3.694

Witnauer, J. E., & Miller, R. R. (2007). Degraded contingency revisited: Posttraining extinction of a cover stimulus attenuates a target cue's behavioral control. *Journal of Experimental Psychology: Animal Behavior Processes*, *33*(4), 440–450. https://doi.org/10.1037/0097-7403.33.4.440

Wright, A. A. (1972). Psychometric and psychophysical hue discrimination functions for the pigeon. *Vision Research*, *12*(9), 1447–1464. https://doi.org/10.1016/0042-6989(72)90171-X

Wright, A. A., & Nevin, J. A. (1974). Signal detection methods for measurement of utility in animals. *Journal of the Experimental Analysis of Behavior*, *21*(2), 373–380. https://doi.org/10.1901/jeab.1974.21-373

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*(4), 419–428. https://doi.org/10.1037/0097-7403.20.4.419

APPENDIXES

APPENDIX I: SDT analysis

In this appendix, an analysis in terms of SDT was performed on the data from Experiment 1 and from Experiments 4 to 9. In both cases, preCS-CS differences were computed as described in the method section of the Experiments. These differences were used to perform the analysis in terms of SDT reported hereafter.

Sensitivity and response criterion indexes can be calculated based on Hits and False Alarms probabilities. In these experiments, the trade-off between benefits and cost would be better optimized by not producing a CR when X is present, given that producing a CR is costly and X does not predict the appearance of a US for which the subject needs to be prepared. As can be seen in Table 4, a Hit would be not responding to AX, a False Alarm would be not responding to A, an Omission would be responding to AX and a Correct Rejection would be responding to A. The criterion to decide what could be considered “not responding” and “responding” was settled by calculating the mean CR for all groups in all sessions. This measure, as it takes into account all subjects and all sessions, would neutralize the differences in responding between subjects and between sessions, providing a reliable criterion of the detection of the signal.

The probability of Hits ($p(H)$) was computed following Equation 3:

$$p(H) = \frac{H}{H+O} \tag{3}$$

where H is the number of Hits and O is the number of Omissions. The probability of False Alarms ($p(FA)$) was computed following Equation 4:

$$p(FA) = \frac{FA}{FA+CR} \tag{4}$$

where FA is the number of False Alarms and CR is the number of Correct Rejections.

Based on these probabilities, and assuming that the underlying distributions are normal, sensitivity can be calculated as d', following Equation 5 (Macmillan & Creelman, 2005):

$$d' = z(H) - z(FA) \tag{5}$$

where $z(H)$ is the z-score for $(p(H)$ and $z(FA)$ is the z-score for $(p(FA)$. In a similar way, response criterion can be calculated as β, following Equation 6 (Macmillan & Creelman, 2005):

$$\beta = \varphi(z(H))/\varphi(z(FA)) \tag{6}$$

where $\varphi(z(H))$ is height of the Signal distribution and $\varphi(z(FA))$ is the height of the Noise distribution.

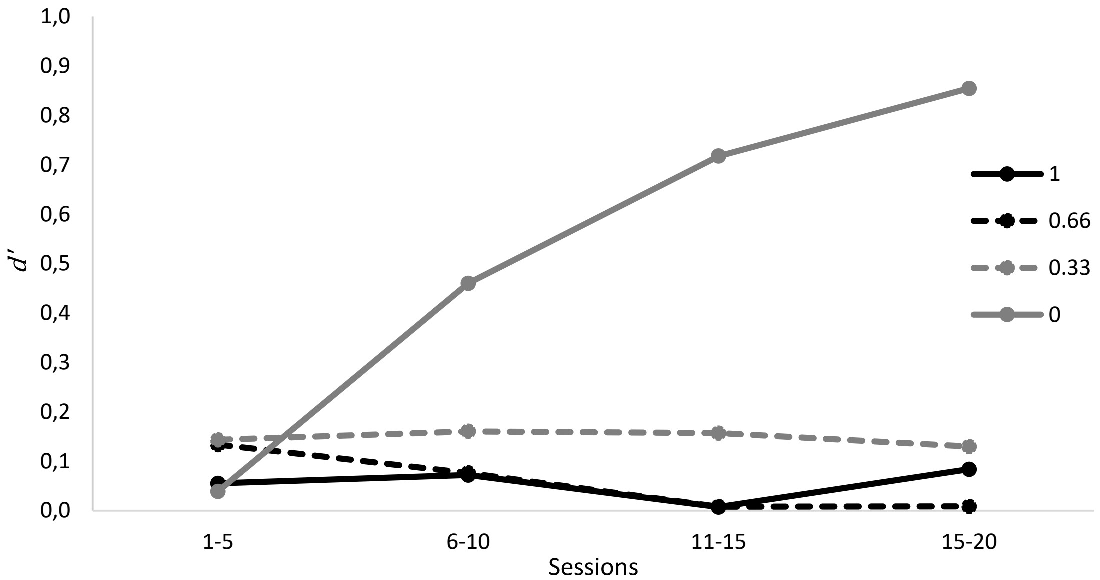
Experiment 1

The mean responding of all subjects in this Experiment was 6.752, so CRs that were equal or lower than 6 were considered “not responding” and CRs that were equal or higher than 7 were considered “responding”.

Sensitivity was measured as d' for all groups in blocks of 5 sessions, as can be seen in Figure 21. Sensitivity increased as the sessions progressed only in the group in which AX was never reinforced, Group 0. In the rest of the groups, sensitivity was quite stable in a low level, being similarly low in the groups that in which AX had a contingency of reinforcement of 1 and .66, and slightly higher in the group in which AX had a contingency of reinforcement of .33.

Figure 21

Sensitivity indexes d' for Experiment 1



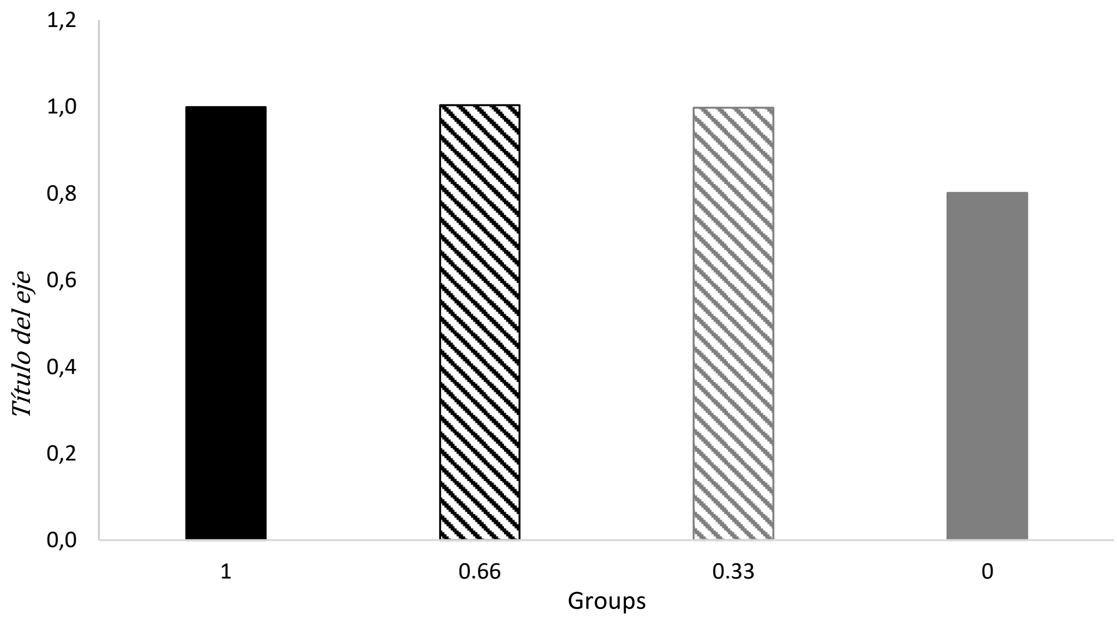
Note. Sensitivity indexes *d'* for the groups in Experiment 1. The indexes were calculated for blocks of 5 sessions. The black continuous line represents Group 1, which was trained with 18 A+ and 6 AX+ presentations per session in conditioning. The black discontinuous line represents Group 0.66, which was trained with 18 A+, 4 AX+ and 2 AX- presentations per session in conditioning. The grey discontinuous line represents Group 0.33, which was trained with 18 A+, 2 AX+ and 4 AX- presentations per session in conditioning. The grey continuous line represents Group 0, which was trained with 18 A+ and 6 AX- presentations per session in conditioning.

The sensitivity indexes indicate that in those Groups in which AX was reinforced, even if it was only in the 33% of the trials, sensitivity did not improve with greater experience, that is, more sessions. Also, it is worth noting that sensitivity was slightly better in the group in which AX was less reinforced, that is, Group 0.33. However, when AX was never reinforced, sensitivity did improve with experience, reaching a much higher level than when AX had any positive contingency of reinforcement.

The response criterion for each group is depicted in Figure 22. Groups 1, 0.66 and 0.33 had a similar criterion (β = .999, β = 1.004, and β = .997, respectively), and Group 0 showed a lower criterion than the rest (β = .801).

Figure 22

Response criterion indexes β for Experiment 1



Note. Response criterion indexes β for the groups in Experiment 1. The full black bar represents Group 1, which was trained with 18 A+ and 6 AX+ presentations per session in conditioning. The striped black bar represents Group 0.66, which was trained with 18 A+,4 AX+ and 2 AX-presentations per session in conditioning. The striped grey bar represents Group 0.33, which was trained with 18 A+, 2 AX+ and 4 AX- presentations per session in conditioning. The full grey bar represents Group 0, which was trained with 18 A+ and 6 AX- presentations per session in conditioning.

The predictions of the formula of β_{opt} (Equation 2) do not fully address the results of these analyses. It does predict that the criterion in Group 0 would be the lowest, but the differences in criterion that are predicted between Groups 1, 0.66 and 0.33 are not evident in this analysis. Also, the differences in sensitivity along sessions cannot account for the transition from an initial high responding to a lower responding in the last sessions of the Experiment in Groups 1, 0.66 and 0.33 found in Experiment 1 (Figure 3), as they did not show an increase in sensitivity, although is consistent with the increase in sensitivity found in Group 0. The different level of responding in the Groups might be a result of the combination of response criterion a sensitivity: Groups 1, 0.66 and 0.33 had a similar criterion but Group 0.33 had a higher sensitivity. This is consistent with the result showing that Group 0.33 had an intermediate level of responding between Groups 1 and 0.66 and Group 0. In addition, Group 0, that showed the lowest criterion and the highest sensitivity, showed the lowest responding in this Experiment (Figure 3).

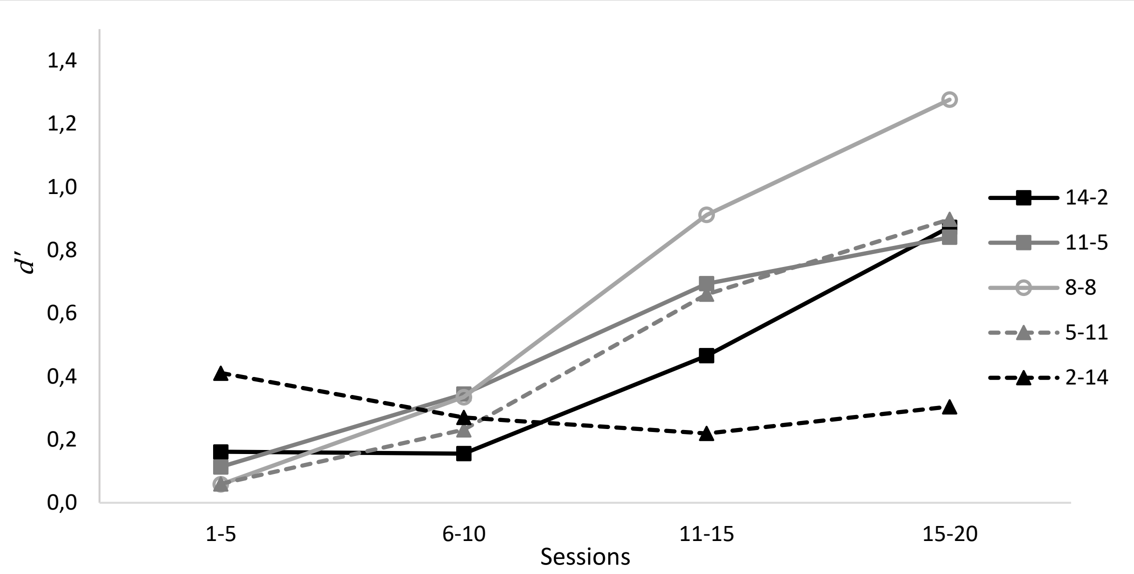
Experiments 4 to 9

The analysis was performed on the data from Experiments 4 to 9, collapsing together those subjects that received the same training, that is: in Group 14-2, the subjects trained with 14 A+, 2 AX–, 12 F-, and 2 X– presentations per session in conditioning; in Group 11-5 the subjects that were trained 11 A+, 5 AX–, 9 F–, 3 F+, and 2 X– presentations per session in conditioning; in Group 8-8, the subjects that were trained 8 A+, 8 AX–, 6 F–, 6 F+, and 2 X– presentations per session in conditioning; in Group 5-11 the subjects that were trained 5 A+, 11 AX–, 3 F–, 9 F+ and 2 X– presentations per session in conditioning; and in Group 2-14, the subjects that were trained with 2 A+, 14 AX–, 12 F+, and 2 X– presentations per session in conditioning. The mean responding of all subjects was 4.611. So, CRs that were equal or lower than 4 were considered “not responding”, and CRs that were equal or higher than 5 were considered “responding”.

Sensitivity was measured as d' for all groups in blocks of 5 sessions, as can be seen in Figure 23. Sensitivity increased in all groups as the sessions progressed except for Group 2-14. Group 2-14 showed a higher sensitivity in the first 5 sessions than the rest of the groups, equating with them in sessions 6 to 10 and then remaining lower than the rest of the groups for the final part of the sessions. Groups 14-2, 11-5 and 5-11 showed a similar increase in sensitivity with the progression of sessions, starting in a low value lower than 0.2 and finishing in a value of around 0.8. Group 8-8 had a similar increase in the first 10 sessions, and then had a higher increase than Groups 14-2, 11-5 and 5-11, reaching a sensitivity of around 1.2 in the last sessions.

Figure 23

Sensitivity indexes d' for Experiments 4 to 9

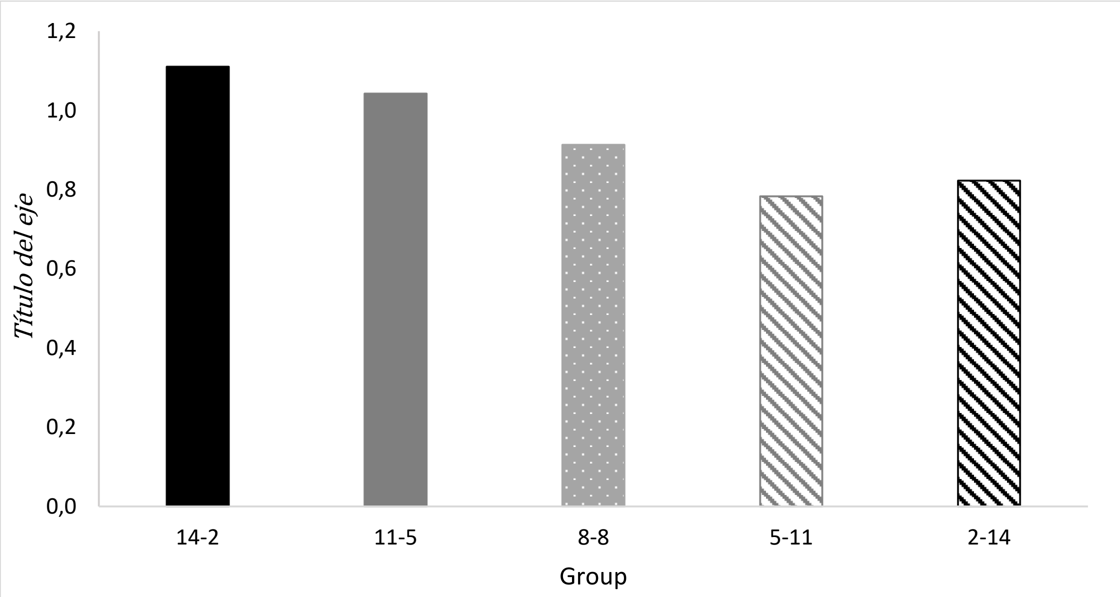


Note. Sensitivity indexes *d'* for the experimental groups in Experiments 4 to 9. The indexes were calculated for blocks of 5 sessions. The black continuous line represents the subjects that were trained with 14 A+ and 2 AX– presentations per session in conditioning. The dark grey continuous line represents the subjects that were trained 11 A+ and 5 AX– presentations per session in conditioning. The light grey continuous line represents the subjects that were trained 8 A+ and 8 AX– presentations per session in conditioning. The dark grey discontinuous line represents the subjects that were trained 5 A+ and 11 AX– presentations per session in conditioning. The black discontinuous line represents the subjects that were trained with 2 A+ and 14 AX– presentations per session in conditioning.

The response criterion for each group is depicted in Figure 24. Group 14-2 showed the highest criterion (β = 1.111), followed by Group 11-5 (β = 1.043), then Group 8-8 (β = 0.914) and then Group 5-11 (β = 0.783). Group 2-14 showed a criterion in-between Group 8-8 and Group 5-11 ((β =0.823).

Figure 24

Response criterion indexes β for Experiments 4 to 9



Note. Response criterion indexes β for the experimental groups in Experiments 4 to 9. The full black bar represents the subjects that were trained with 14 A+ and 2 AX– presentations per session in conditioning. The full dark grey bar represents the subjects that were trained 11 A+ and 5 AX–presentations per session in conditioning. The dotted light grey bar represents the subjects that were trained 8 A+ and 8 AX–presentations per session in conditioning. The striped dark grey bar represents the subjects that were trained 5 A+ and 11 AX–presentations per session in conditioning. The striped black bar represents the subjects that were trained with 2 A+ and 14 AX–presentations per session in conditioning.

As predicted by the formula of β_{opt} (Equation 2), the response criterion varied as the proportion of A+/AX- trials varied, finding a higher criterion when there were many A+ and few AX- trials, and a lower criterion when there were few A+ trials and many AX- trials. This is consistent with the differences in responding observed in Experiment

9 (Figures 19 and 20), as the highest was the A+/AX- proportion, highest was responding. An exception to this rule is the group 2-14, which did not show neither SOC nor CI at any point of the experiment, probably due to the low sensitivity that this group showed throughout the experiment. The transition from positive to negative mediation depends on both the response criterion and the increase in sensitivity. In the first sessions of the experiment, when sensitivity is low in all groups, the Groups 14-2, 11-5 and 8-8 showed a higher responding that was consistent with SOC (Figures 9, 11 and 13). In these groups, the criterion was higher than in those that did not showed SOC. In the last sessions, when sensitivity had increased, the Groups 8-8 and 5-11 showed CI (Figures 14 and 16), Group 11-5 showed a non-significant tendency towards CI (Figure 12), and Group 14-2 showed no CI (Figure 10). So, lower response criterion favoured the appearance of CI when sensitivity was higher, and even in conditions of high sensitivity but high criterion, such as in Group 14-2, CI did not develop.

APPENDIX II: Simulations

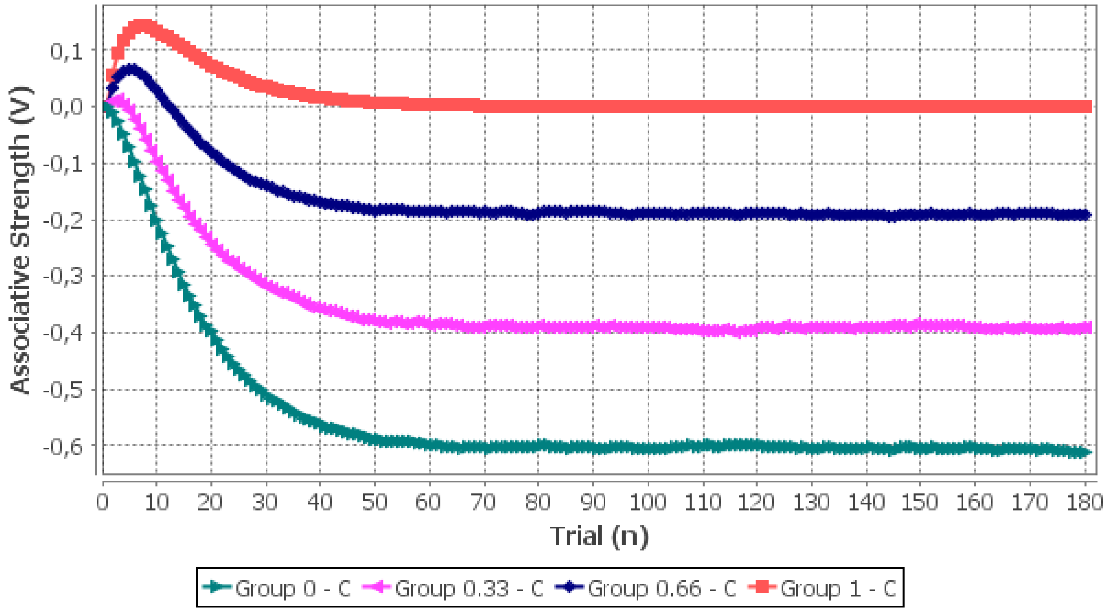
In this appendix, simulations of some of the most influential associative learning models are presented, and their predictions are contrasted with the main findings reported in this thesis. The models simulated are Rescorla and Wagner (1972), Pearce & Hall (1980), Wagner's SOP (1981) and Pearce's configural model (1994).

Rescorla and Wagner model (1972)

Simulations were carried with the Rescorla and Wagner simulator by Mondragón et al. (2012). The following simulations were carried with $\alpha = .2$ for all stimuli, $\beta+ = .5$, $\beta- = .45$, $\lambda+ = 1$ and $\lambda- = 0$. The simulation for Experiment 1 is depicted in Figure 25, according to the design in Table 5. The model predicts a small increment in the associative strength in Groups 1, 0.66 and 0.33, but not in Group 0. This increment was higher the higher was the contingency of reinforcement for AX. However, in the results from Experiment 1, all Groups showed an increase in responding in the first sessions (Figure 3), so the model can only predict the results for those Groups that received AX+ presentations but not for the Group that received only received AX- presentations. Also, the simulation is consistent with the results from Experiment 2, as no inhibitory properties were developed for the group trained a contingency of reinforcement of AX of 1, but were developed for the group trained with a contingency of reinforcement of AX of 0 (Figures 6 and 7).

Figure 25

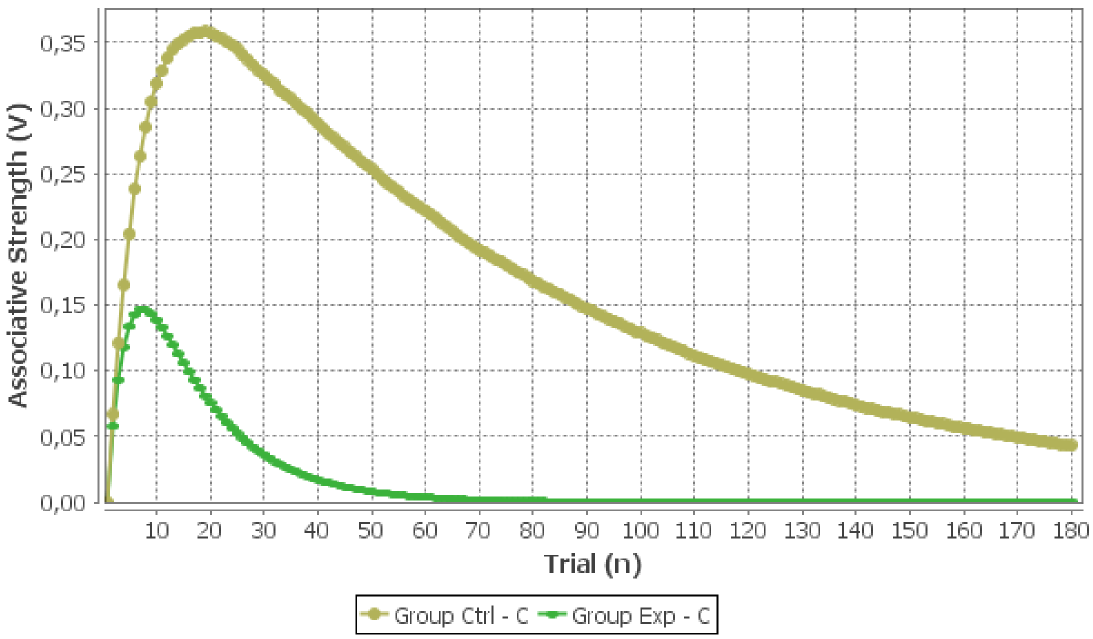
Simulation of the Rescorla and Wagner model for Experiment 1



Simulation of Experiment 3 is depicted in Figure 26, according to the design in Table 7. The model predicts an increase in the associative strength in both groups, being this increase higher in the Control than in the Experimental Group. Therefore, the model cannot predict the results from Experiment 3, as Augmentation was assessed by a higher responding in the Experimental Group compared with the Control (Figure 8).

Figure 26

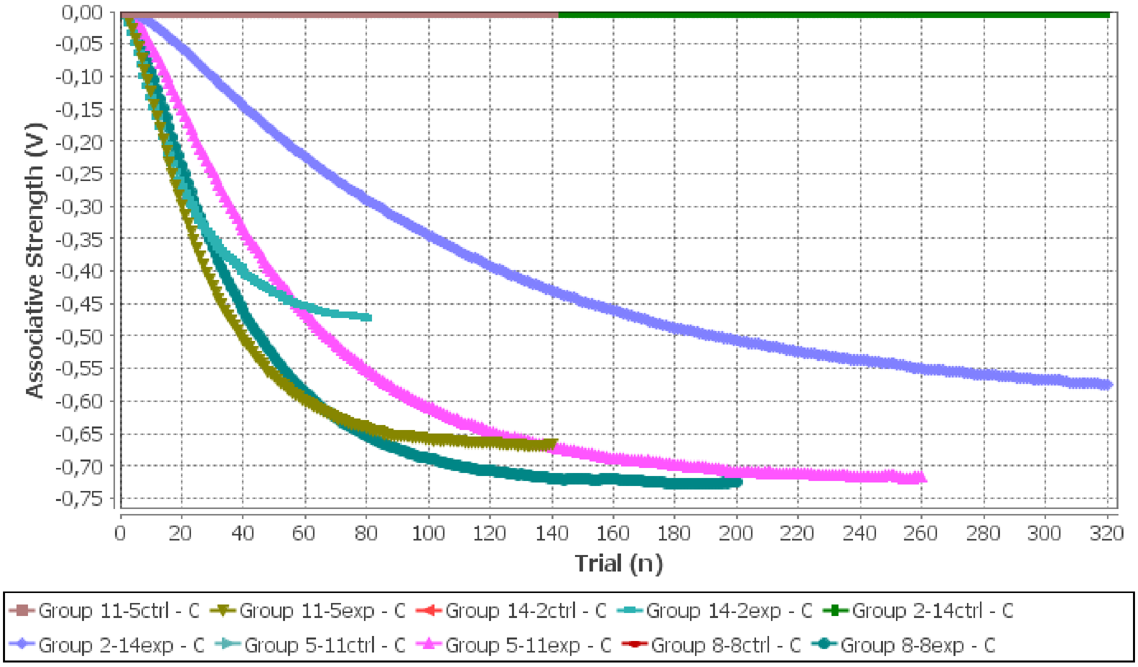
Simulation of the Rescorla and Wagner model for Experiment 3



Simulation of Experiments 4 to 9 is depicted in Figure 27, according to the design depicted in Table 8. The model predicts that all Control Groups would not gain associative strength, neither positive nor negative. For Experimental Groups, it predicts negative associative strength. The final negative associative strength was the lowest in Group 8-8, followed by Group 5-11, then Group 5-11, higher in Group 2-14 and the highest in the Group 14-2. Thus, the model cannot predict the results from Experiments 4 to 9. These experiments showed that Groups 14-2, 11-5 and 8-8 showed an increase in responding in the first sessions that was consistent with SOC (Figures 9, 11 and 13). Also, Group 14-2 did not develop inhibitory properties in Experiment 4 (Figure 10). Furthermore, responding in the retardation test in Experiment 9 indicated that the Group 8-8 had a higher responding than Groups 5-11 and 2-14, contrary to what the model predicts (Figure 20).

Figure 27

Simulation of the Rescorla and Wagner model for Experiments 4 to 9

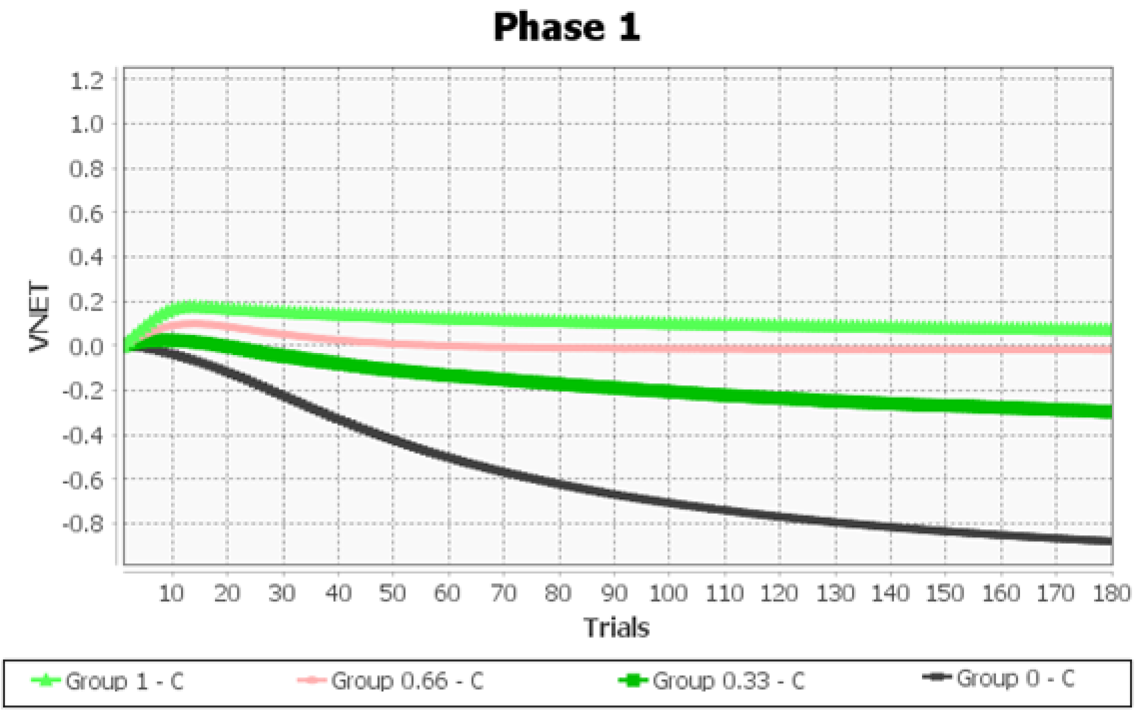


Pearce and Hall model (1980)

Simulations were carried with the Pearce and Hall simulator by Grikietis et al. (2016). These simulations were carried with $\alpha 1 = .7$ for all stimuli, $\gamma = .1$, $\beta I = .04$, $\beta E = .05$, and $\lambda = 1$. The simulation for Experiment 1 is depicted in Figure 28, according to the design in Table 5. The model predicts a small increment in the associative strength in Groups 1, 0.66 and 0.33, but not in Group 0. This increment was higher the higher was the contingency of reinforcement for AX. However, in the results from Experiment 1, all Groups showed an increase in responding in the first sessions, so the model can only predict the results for those Groups that received AX+ presentations but not for the Group that received only received AX- presentations (Figure 3). Also, the simulation is consistent with the results from Experiment 2, as no inhibitory properties were developed for the group trained a contingency of reinforcement of AX of 1, but were developed for the group trained with a contingency of reinforcement of AX of 0 (Figures 6 and 7).

Figure 28

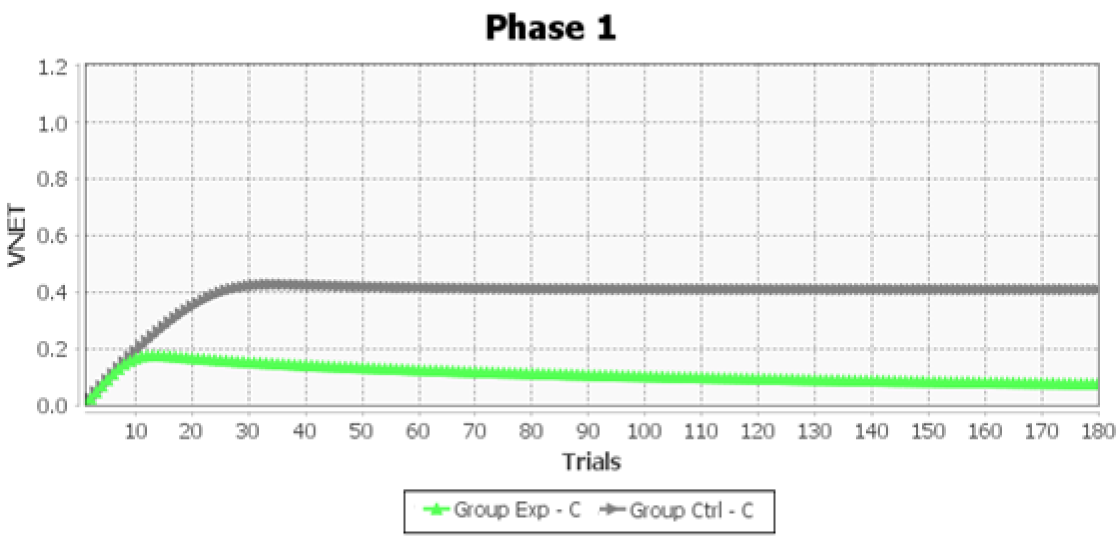
Simulation of the Pearce and Hall model for Experiment 1



The simulation for Experiment 3 was carried with the design in Table 7, and the results can be seen in Figure 29. The model predicts that both Groups would show an increase in the associative strength, however, the increase is higher in the Control Group, thus not predicting Augmentation. Therefore, the model cannot predict the results in Experiment 3 in which Augmentation was found as responding was higher in the Experimental than in the Control Group (Figure 8).

Figure 29

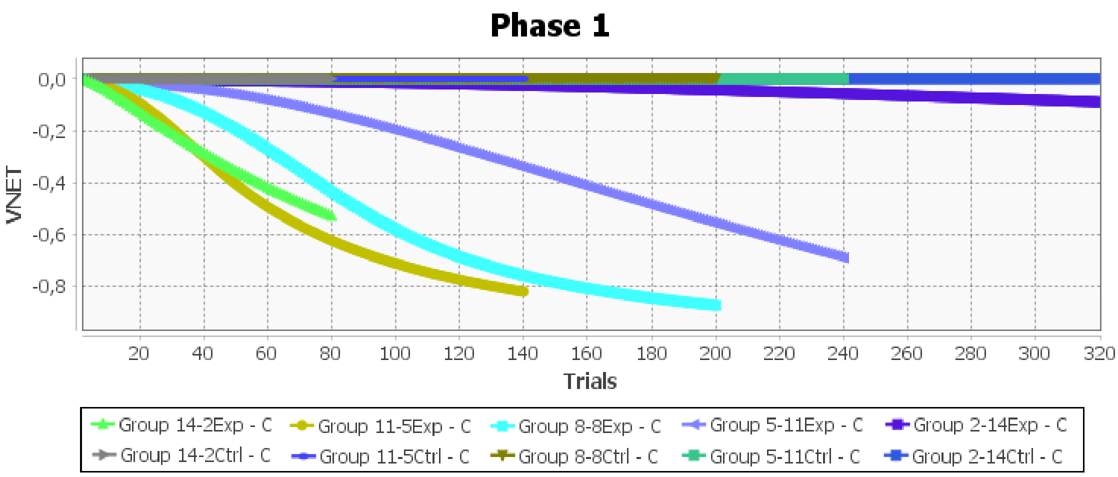
Simulation of the Pearce and Hall model for Experiment 3



Experiments 4 to 9 were simulated according to Table 8, and the result of the simulation is depicted in Figure 30. The model predicts that Control Groups would not gain neither excitatory nor inhibitory associative strength. For Experimental Groups, only inhibitory strength is predicted, which cannot predict the results from Experiments 4 to 9, as in Groups 14-2, 11-5 and 8-8 there is an increase in responding consistent with SOC (Figure 9, 11 and 13). Also, the final inhibitory strength predicted by the model for each group is different, from Group 8-8 that shows the most inhibitory strength, Group 11-5, Group 5-11, Group 14-2 and Group 2-14, that shows the less inhibitory strength. However, results from Experiment 4 showed that Group 14-2 did not develop inhibitory strength (Figure 10), and results from Experiment 9 showed that Group 8-8 developed significantly less inhibitory properties than Groups 5-11 and 2-14 (Figure 20).

Figure 30

Simulation of the Pearce and Hall model for Experiments 4 to 9



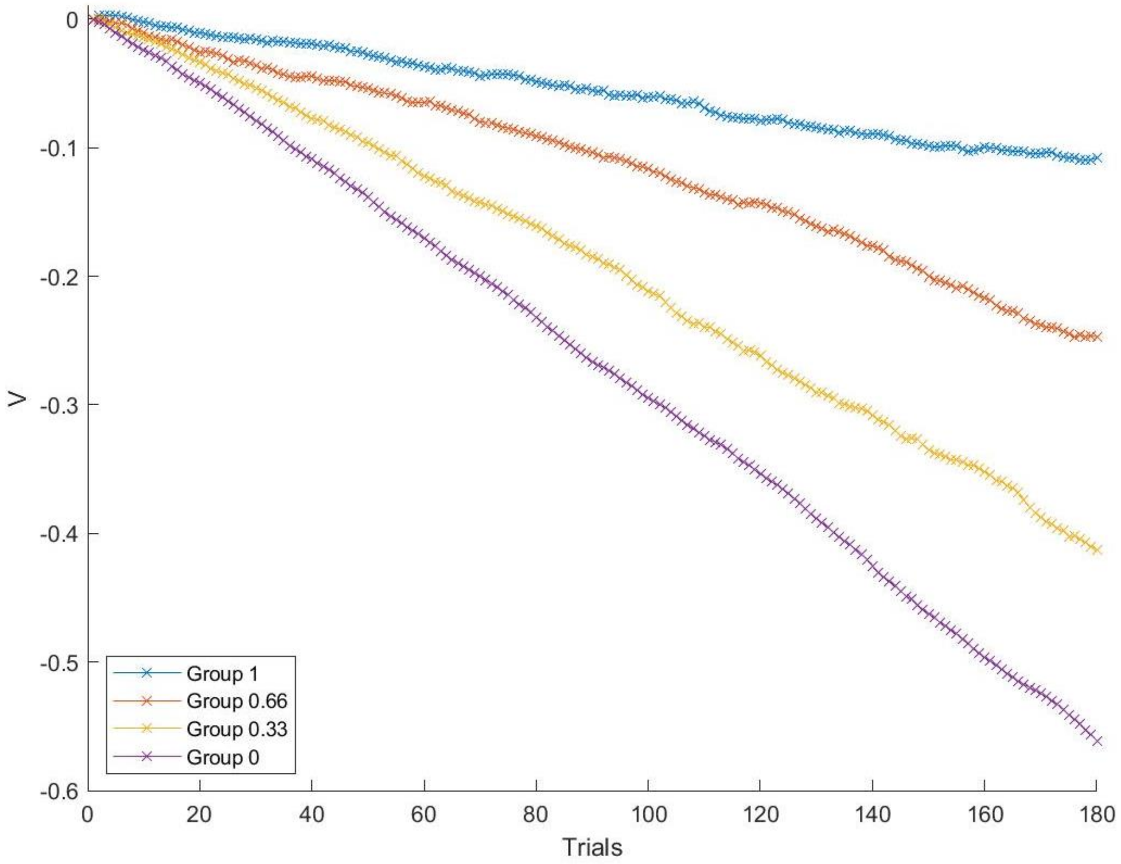
Wagner's SOP model (1981)

Simulations of Wagner's SOP model were carried with the SOP model simulator by Byers et al. (2017). The parameters of the simulations were $pA1 = .1$, $pD1 = .1$, $pD1/pD2 = 5$, $r1 = 1$, and $r2 = .01$, for all stimuli except for the context, for which $pA1 = .5$ and $pD1 = .1$. For all stimuli $L^+ = .05$ and $L^+/L^- = 5$, except for the US, which had $L^+ = .75$ and $L^+/L^- = 5$, and the context, for which $L^+ = .005$ and $L^+/L^- = 25$.

The simulation of Experiment 1 is depicted in Figure 31. The simulation was carried following the design specified in Table 5. Simulations predict that all Groups would display a decrease in the associative strength, acquiring inhibitory associative strength, and the intensity of the inhibitory strength would be different depending on the contingency of reinforcement of AX, in such a way that the less reinforced AX is (as in Group 0, in which AX was never reinforced), the steeper the acquisition of inhibitory associative strength is. The results of Experiment 1 suggest otherwise, as there is an increase in responding in the first sessions in all Groups that suggest the acquisition of excitatory properties in the first sessions (Figure 3). Furthermore, in Experiment 2, the Group in which AX had a contingency of reinforcement of 1 showed no inhibitory properties in the summation and retardation tests (Figures 6 and 7), contrary to what the model predicts.

Figure 31

Simulations of Wagner's SOP model for Experiment 1

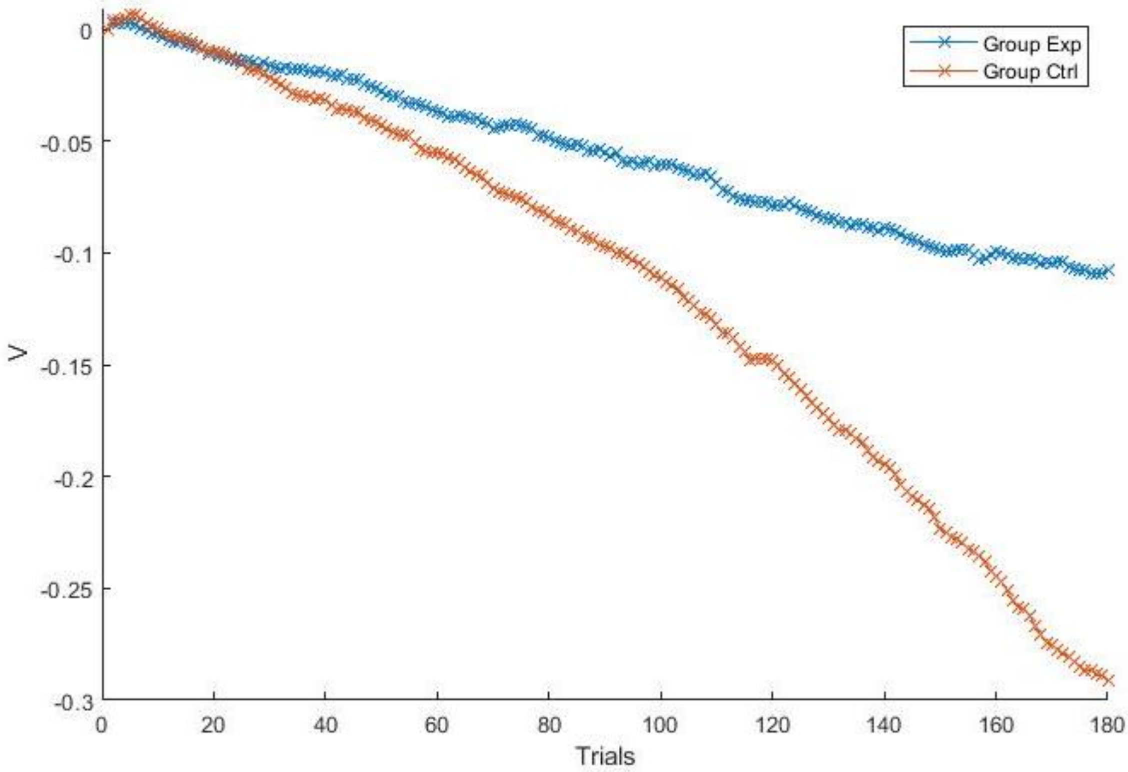


Following the design in Table 7, Experiment 3 was simulated. As can be seen in Figure 32, a very small increase in responding in the first trials is predicted for the Control Group, but not for the Experimental Group. Also, the model predicts that both groups would acquire inhibitory associative strength, being this acquisition faster in the Control Group than in the Experimental Group. The predictions of the model do not meet the results from Experiment 3, as Experimental Group showed an increase in responding bigger than Control Group in the first trial that was consistent with

Augmentation. Furthermore, Blocking was also evident in Experiment 3, given that in the final sessions responding in the Experimental Group was lower than in the Control Group (Figure 8).

Figure 32

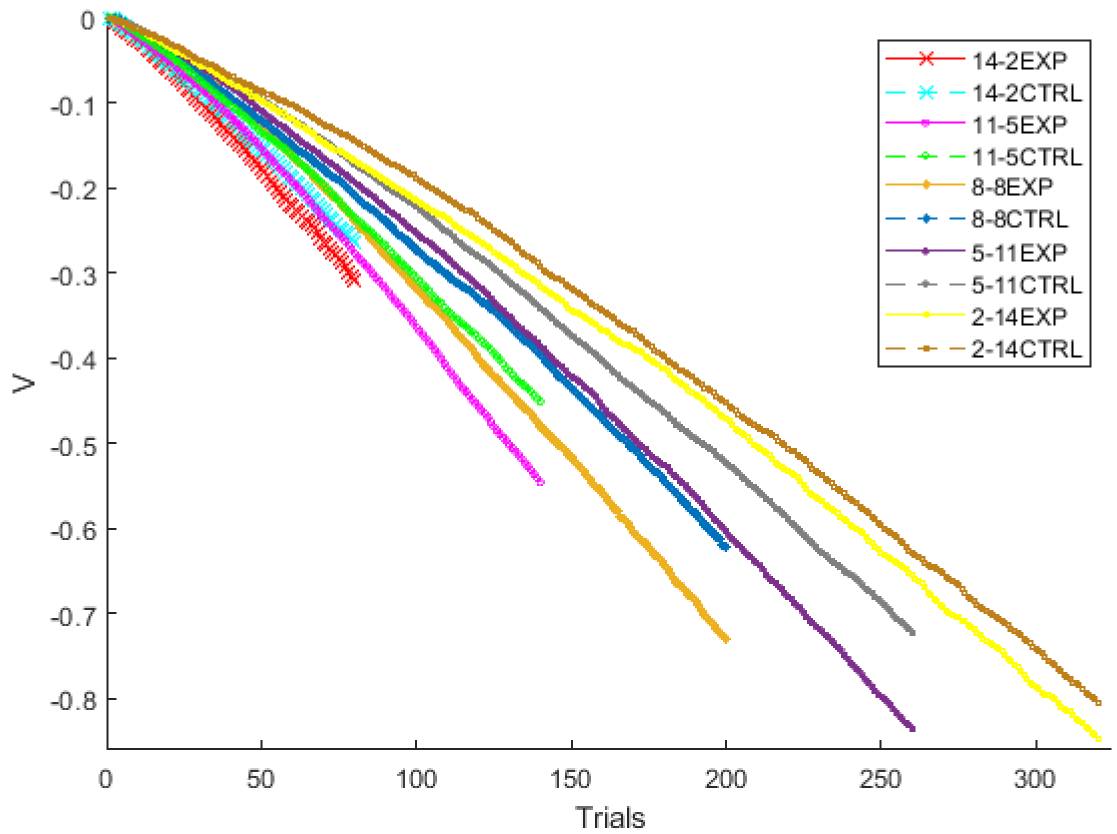
Simulation of Wagner's SOP model for Experiment 3



Simulations of Experiments 4 to 9, carried according to the design depicted in Table 8, can be seen in Figure 33. The model predicts that all Groups would acquire inhibitory strength from the first trial. This inhibitory strength is predicted to be smaller in the Control Groups than in the Experimental Groups for all A+/AX- trial number combination. Further, the inhibitory strength in the last trial is predicted to be smaller in the more A+ and less AX- trials are presented per session in training. Thus, the model cannot predict the results in Groups 14-2, 11-5 and 8-8, in which there was more responding in the Experimental Group than in the Control Group, consistent with SOC (Figures 9, 11 and 13). Also, it cannot predict the absence of CI found in Group 14-2 (Figure 10).

Figure 33

Simulation of Wagner's SOP model for Experiments 4 to 9



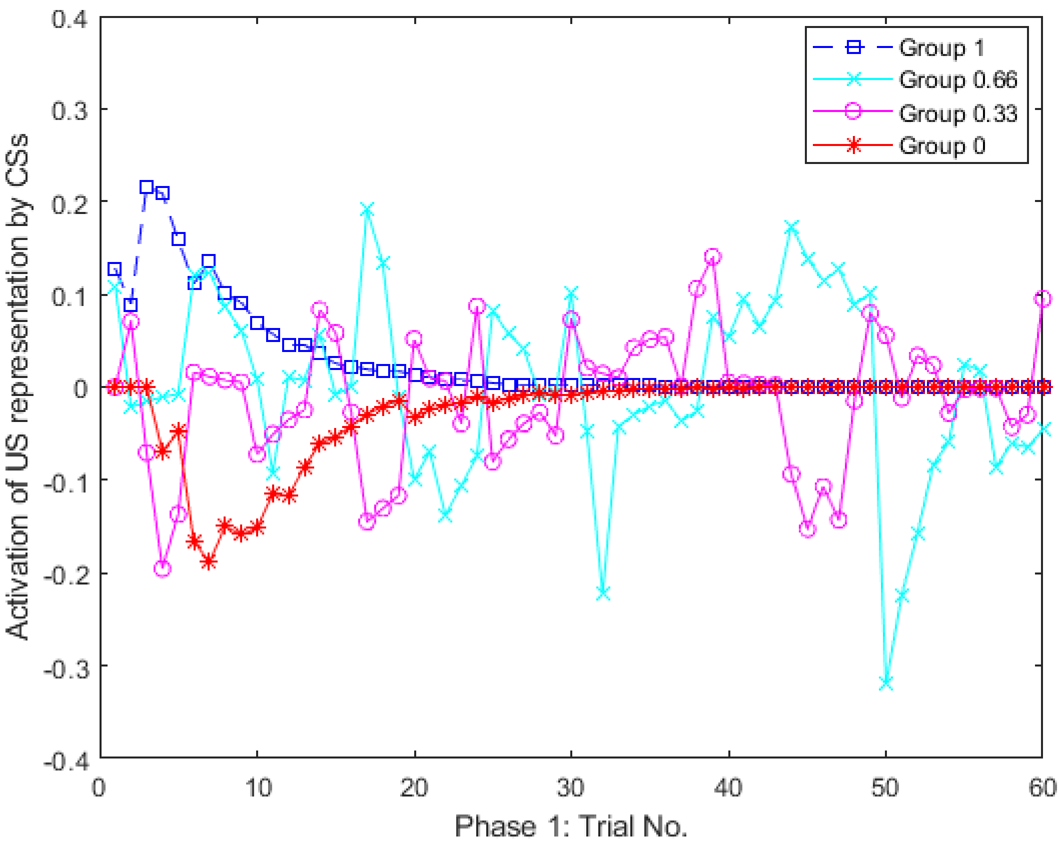
Pearce's configural model (1994)

Simulations of Pearce's configural model were carried with the ALTSim by Thorwart et al. (2009). The following simulations were carried with $\alpha = .6$ for all stimuli and configural units, $\beta+ = .5$, $\beta- = .5$, $\lambda+ = 1$ and $\lambda- = 0$.

The simulation of Experiment 1 is depicted in Figure 34. The simulation was carried following the design specified in Table 5. Simulations predict that Group 1 would show an increase in responding in the first trials, that is no longer evident in the latter trials. For Groups 0.66 and 0.33, the model predicts a high variability in the associative strength, being positive in some trails and negative in other trials. For Group 0, the model predicts an initial inhibitory strength that extinguishes in the last trials. The predictions of the model are inconsistent with the results from Experiment 1, except for the prediction for Group 1, in which responding increased in the first trials, and then decreased to a low level. However, contrary to what is predicted by the model, Groups 0.66, 0.33 and 0 also showed an initial increase that was no longer evident in the latter trials (Figure 3). Also, results from Experiment 2 suggested that Group 0 had developed inhibitory properties at the end of the conditioning phase, whereas the model predicts an absence of any associative strength (Figures 6 and 7).

Figure 34

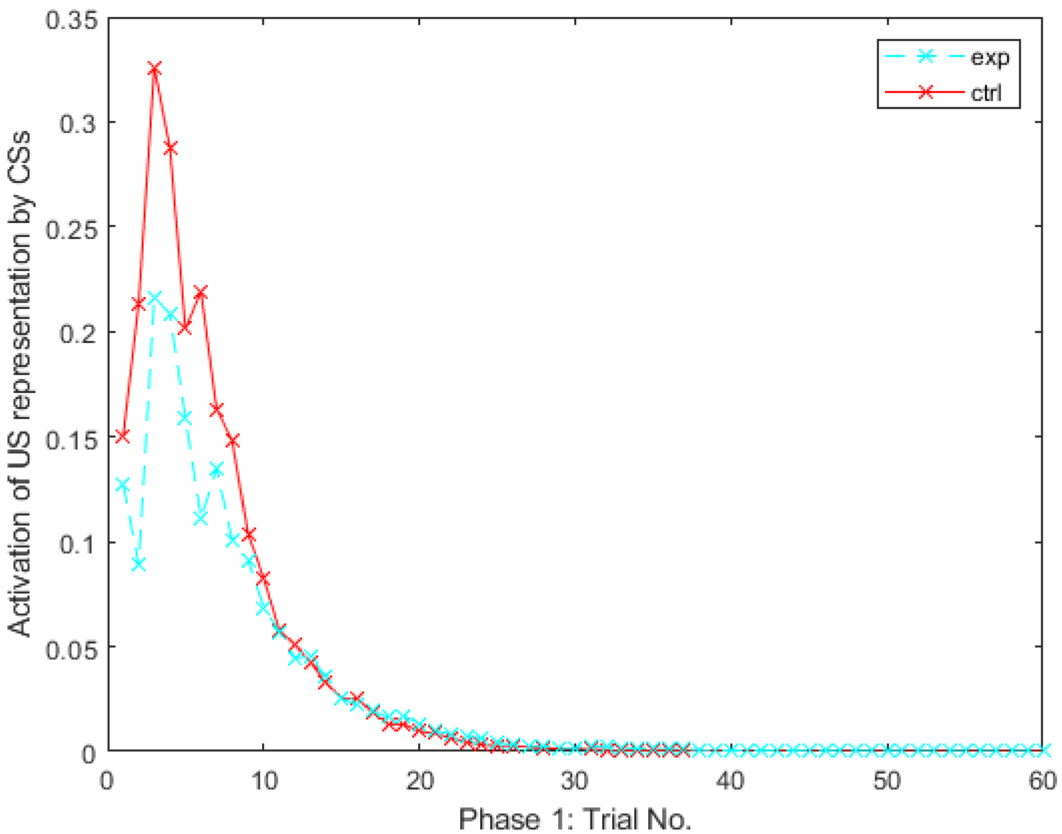
Simulations of Pearce's configural model for Experiment 1



Experiment 3 was also simulated, according to the design in Table 7. As can be seen in Figure 35, an increase in responding in both Groups is predicted. However, contrary to the results consistent with the phenomenon of Augmentation found in Experiment 3 (Figure 8), this increase is predicted to be bigger in the Control Group than in the Experimental Group.

Figure 35

Simulation of Pearce's configural model for Experiment 3



Simulations of Experiments 4 to 9, carried according to the design depicted in Table 8, can be seen in Figure 36. The model predicts that none of the Control Groups would gain any associative strength, neither excitatory nor inhibitory. On the other hand, in all Experimental Groups, the model predicts the development of inhibitory associative strength in the first trials, that extinguishes in the last ones. These predictions contrast with the results found in Experiments 4 to 9. Groups 14-2, 11-5 and 8-8 showed an increase in responding in the first sessions that was consistent with the development of SOC (Figures 9, 11 and 13), contrary to the inhibitory properties predicted by the model. Also, in Groups 8-8 and 5-11, the retardation test showed that CI was developed at the end of training (Figures 14 and 16), whereas the model predicts an absence of associative strength at that point of training. Furthermore, the model predicts a stronger inhibitory strength in the first sessions for the Group 8-8, followed by the Group 2-14, Group 5-11, Group 11-5, and finally Group 14-2. Again, this is inconsistent with the results from the experiments, as in the first sessions there is an increase in responding in all groups, being this increase higher with a higher number of A+ trials and a lower number of AX- trials (Figure 19).

Figure 36

Simulation of Pearce's configural model for Experiments 4 to 9