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CUE-COMPETITION IN FEAR POTENTIATED STARTLE CONDITIONING IN HUMANS

COMPETENCIA DE ESTÍMULOS EN EL CONDICIONAMIENTO DEL SOBRESALTO POTENCIADO POR EL MIEDO EN HUMANOS

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Abstract

In two experiments of fear-potentiated startle, human participants were trained in a discrimination task, in which a stimulus A was paired with a wrist shock, while another stimulus, B, was not (A+B-). In a test, participants were assessed for startle by presenting an air-puff either alone or in the presence of the trained stimulus. In Experiment 1, evidence of discriminative learning was found in the form of a reliably greater startle to the air-puff in the presence of A than in the presence of B, and in the absence of any cue. In Experiment 2, after A+B- training (counterbalanced visual and vibrotactile cues), cues A and B were compounded with novel auditory cues X and Y and reinforced (AX+BY+), which is the standard design for cue-competition. In test, there was evidence of cue competition only in those participants in which A and B were the visual and vibrotactile cues, respectively. In this subgroup, responding in the presence of the redundant cue X was reliably lower

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than in the presence of Y, and not different from responding to the air-puff alone, indicating that X was blocked by A. We speculate that the absence of such an effect in the subgroup in which A was vibrotactile and B was visual might be due to some unexpected generalization between vibrotactile and auditory cues.

Keywords: Blocking, cue competition, selective learning, fear potentiated startle, fear conditioning.

Resumen

En dos experimentos de sobresalto potenciado por el miedo, los participantes fueron entrenados en una tarea de discriminación, en la que un estímulo A se emparejó con un choque eléctrico en la muñeca, mientras que otro estímulo, B, no (A+ B-). En una prueba, la respuesta de sobresalto fue evaluada al presentar un soplo de aire solo o en presencia del estímulo entrenado. En el Experimento 1, se encontró evidencia de aprendizaje discriminativo en la forma de un sobresalto significativamente mayor al soplo de aire en presencia de A que en presencia de B, y en ausencia de cualquier estímulo. En el Experimento 2, después del entrenamiento A+ B- (estímulos visuales y vibrotactiles contrabalanceadas), los estímulos A y B se emparejaron con nuevos estímulos auditivos X e Y y se reforzaron (AX+ BY+), lo cual es un diseño estándar de competencia de estímulos. En la prueba, hubo evidencia de competencia de estímulos solo en aquellos participantes en los que A y B fueron estímulos visuales y vibrotáctiles, respectivamente. En este subgrupo, la respuesta en presencia del estímulo redundante X fue significativamente más baja que en presencia de Y, y no fue diferente de la respuesta al soplo de aire solo, lo que indica que X fue bloqueado por A. Especulamos que la ausencia de tal efecto en el subgrupo en el que A era vibrotáctil y B era visual podría deberse a una generalización inesperada entre las señales vibrotáctiles y auditivas.

Palabras clave: Bloqueo, competencia de estímulos, aprendizaje selectivo, sobresalto potenciado por el miedo, condicionamiento del miedo.

Emotional responses are critical for the survival of any animal. The majority of these responses are innately modulated by specific stimuli, but importantly, they can also be learned. The conditioning of fear is an example of this, where an emotionally neutral or conditioned stimulus (CS) is paired with a fearful unconditioned stimulus (US). As a result, CS is able to provoke a central state of fear, which is inferred from several indicators, such as pupil dilation (e.g., Reinhard et al., 2006), freezing (e.g., Blanchard & Blanchard, 1969), changes in heart rate (e.g., Smith et al., 2005) and variation of skin conductance (e.g., Haesen et al., 2017). Apart from these direct measures, researchers have also developed a number of procedures to indirectly measure conditioned fear. Two of these paradigms have dominated research in the field: conditioned suppression and fear-potentiated startle.

The conditioned suppression procedure was initially described by Estes and Skinner (1941) who observed that rats, that have been trained to press a lever for food, showed a marked decrease in the rate of lever-pressing when a light that had been previously paired with a footshock was presented. Based on these findings, Annau and Kamin (1961) proposed an index of conditioned fear, known as suppression ratio, which is computed as the number of lever presses occurring during the CS divided by the sum of lever presses during the CS and during a prior baseline period. This method has also been profusely applied to other behaviors, such as licking a water dispenser (rats and mice; e.g. Mackintosh, 1975a), pecking a key for food (pigeons; Schwartz,1976), or playing a video game (humans; e.g., Arcediano et al., 1996).

On the other hand, the fear-potentiated startle paradigm was introduced by Brown et al. (1951), who reported that the pairing of a light CS with a foot-shock US in rats resulted in an increase in the amplitude of the startle reflex to a noise burst when the probe was conducted in the presence of the light, relative to when the noise was presented alone. Subsequent variations in the procedure included auditory CSs and an air-puff as the startle evoking stimulus (see Davis, 1990). One of the greatest advantages of this method is that conditioned fear can be investigated with very similar protocols in both nonhumans and humans (see, Grillon & Bass, 2003).

Conditioned suppression and fear-potentiated startle have become major models for understanding the behavioral and neurological basis of conditioned fear in nonhuman animals. At the behavioral level, it has been shown that fear conditioning conforms with most of the regularities of Pavlovian conditioning, such as acquisition (e.g., Bouton & Bolles, 1980), extinction (e.g., Myers & Davis, 2002), generalization (e.g., Armony et al., 1997), discrimination (e.g., Myers & Davis, 2004), inhibition (e.g., Rescorla, 1969), and selective learning (e.g., Kamin, 1968, 1969), among others. At the neurobiological level, it is already a well-established fact that the amygdala and its underlying molecular and pharmacological processes are directly involved in the acquisition and expression of conditioned fear (e.g., LeDoux, 2000).

The applicability of this knowledge to humans has been growing systematically due to the acknowledgment that conditioned fear shares many similarities with the symptoms that are used to diagnose anxiety disorders in clinical populations (e.g., Ballard et al., 2014). The predominant choice in this incipient corpus of research with humans has been the use of the fear-potentiated startle procedure and very simple training protocols involving single cues. Thus, in this initial stage, researchers have directed their attention to examine those conditions under which conditioned fear is acquired (e.g., Ameli & Grillon, 2001), extinguished (e.g., Kindt & Soeter, 2013) and generalized to other stimuli (e.g., Lissek et al., 2008). Although doubtless these findings are of translational value, it has been recognized that more complex designs, involving training with several rather than single cues, are needed to progress in the understanding of the hypothetical links between fear conditioning and anxiety disorders (Beckers et al., 2013; Boddez et al., 2012, 2013). In this regard, one type of phenomenon that has been extensively studied in nonhumans is the so-called selective learning.

The term “selective learning”, also known as “cue-competition”, is used to refer to observations that in conditioning involving some compound of cues, what is learned to one of the cues appears to depend upon the associative value from other cues (Wagner, 1969). One example is the blocking effect, where prior reinforcements of a cue, by itself, prevents or reduces learning of a second cue when it is reinforced in compound with the first (Kamin, 1968).

Blocking and other cue competition effects, like overshadowing and supernormal conditioning, are robust in fear conditioning in non-humans (Fam et al., 2017; Mackintosh, 1975a; Wagner et al., 1968; but see Maes et al., 2016). Little research has been done, however, on fear conditioning in humans (Grillon & Ameli, 2001; Jovanovic et al., 2005, 2006). Moreover, as it will be discussed later, the evidence of selective learning in strict Pavlovian conditioning procedures, even beyond fear conditioning, is almost nil in humans.

On the basis of this rather limited corpus of evidence, we deemed useful to initiate a program of research on selective learning in human fear conditioning. Therefore, the two experiments reported here were motivated by purely empirical considerations. We have a laboratory for human conditioning with the availability of several cues from different sensory modalities (tactile, visual, and auditory) which can be especially well-suited for examining the effects of stimulus competition. To the best of our knowledge, there are no studies of human fear-potentiated startle using cues from different sensory modalities, consequently in Experiment 1 we provided evidence of intermodal discriminative learning (visual versus auditory). In Experiment 2, we examined intermodal cue competition.

Experiment 1

The purpose of this study was to establish the conditions to observe fear-potentiated startle in a differential learning procedure with cues belonging to different sensory modalities in our laboratory. For this, we employed an experimental situation similar to that of Grillon and Davis (1997) in which one CS, A, is paired with the US, while another CS, B, is not (A+B-). Fear conditioning is examined in a final test stage, in which the amplitude of the startle response to an air-puff, either alone or in the presence of the CSs is examined. Several studies have demonstrated differential learning with this procedure; that is, the startle response to the air-puff in presence of A is greater than both, to the air puff alone, and to the air-puff in the presence of B (Glenn et al., 2002; Lissek et al., 2008, 2010, 2014; Torrents-Rodas et al., 2014). All of these studies have used CSs belonging to the same sensory modality (predominantly visual). Furthermore, it has been observed in some of these studies that startling in the presence of B was also increased relative to the air-puff alone, especially in clinical populations (Grillon & Morgan, 1999; Lindner et al., 2015, Lissek et al., 2009), probably due to generalization from A. In order to reduce this factor, we use two CSs from different sensory modalities. The design of the experiment is summarized in Table 1.

Table 1
Design of experiment 1

Training	Test
A+(18), B-(18)	A+(9), B-(9), ITI(9)

Note. Letters A-B represent different CS that could be followed (+) or not followed (−) by the US. The numbers in parenthesis indicate the frequency of each trial type.

Method

Participants

A total of 24 undergraduate psychology students at University of Talca participated in the experiment for course credit (mean age= 22.0, *SD*= 2.1 years, 6 men). They all reported normal or corrected to normal vision, normal hearing, normal tactile sense, and no neurological problems. They were tested individually and had no previous experience in similar research. The content of the informed consent and the procedure of the experiment were approved by the Scientific Ethics Committee of University of Talca.

Apparatus

The experimental sessions were conducted in four identical 2.5×2.76×2.4 m sound attenuating isolation chambers, dimly illuminated by an 18-Watt white bulb located in the ceiling of the room. The stimulus presentation and data collection were under the control of a National Instruments PXIe-8135 Core i7-3610QE 2.3 GHz Controller located in an adjacent room.

There were two conditioned stimuli, 8-sec duration each. A visual CS was provided by a 50-watt light presented through a white bulb located approximately 2 meters in front and 50 cm above of the participant´s head. An auditory CS was provided by a 60-dB white noise delivered through PHILIPS SHS5200 earphones.

The US was a 200-µsec, 5-mA square-wave electric pulse produced by a constant-current generator (Digitimer 7a) and delivered to the anterior part of the right wrist through two disk electrodes. Participants in this study described this stimulus as "unpleasant but not painful". The startle-probe stimulus was a 40-msec, 15-psi puff of compressed air delivered to the center of the right zygomatic bone through a copper tube with a diameter of 2-mm connected to a plastic hose. The total length from the solenoid to the point of air delivery was 371-cm.

The eyeblink component of the startle response was measured by recording electromyographic activity (EMG) using three Ag-AgCl electrodes filled with a standard electrolyte gel. Two electrodes were placed on the orbicularis oculi muscle of the left eye, 1 cm below the pupil and 1.5 cm lateral. A third reference electrode was placed on the left mastoid (Blumenthal et al., 2005). The EMG signal was recorded at 512 Hz using a gTec USBAmp amplifier and transmitted to the embedded controller for event synchronization and storage. To score the magnitude of the startle eyeblinks, sampled data were imported offline into Matlab format (The Mathworks, Inc., Natick, MA, USA) using custom scripts, and EEGLAB (Delorme & Makeig, 2004) and ERPLAB (Lopez-Calderon & Luck, 2014) toolboxes. Continuous EMG data were then band-pass filtered from 0.1 to 30 Hz with a second order Butterworth filter, and epoched from 500 msec pre-stimulus to 235 msec post-stimulus (response window). A baseline period was quantified as the mean voltage within a pre-stimulus sub-window from -100 to 0 msec. The epochs were subtracted from the baseline period for baseline correction. This method ensures that the amplitude of the response during the response window is measured with respect to the mean baseline voltage and not in relation to zero voltage. Next, the ERPLAB toolbox was used to detect peak values during the response window for each epoch. This tool detects local peak, which was defined as a sampled value that is greater than the average of the three samples (6 msec) on the left and the right side of it. If more than one local peak were detected in the response window, the algorithm chooses the largest. If no local peak was found, then the epoch (trial) was excluded from the study. Furthermore, trials included in this analysis (valid trials) were those where the onset of the startle eyeblink fell within the response window (not earlier).

In addition to this automated procedure, the voltage during baseline and response windows of every trial (see below) was plotted as a function of time. The goal of this step was to visually detect additional trials due to noisy baseline, and/or artifacts caused by participant´s movements and exclude them from the analyses. The observer that performed this procedure was blind with respect to the experimental conditions assigned to each trial.

Procedure

The experiment occurred in a single session of two phases: training and test. In training, participants received 18 trials of CS A coterminated with the US (A+), interspersed with 18 trials with CS B nonreinforced (B-). Stimulus A and B were the light and the noise, counterbalanced. At the end of this training, the participants received a series of test trials in which the eyeblink response to the air-puff probe was examined when it was embedded in A or B, or when the air-puff was presented alone (ITI). Each test trial type (A, B, ITI) was repeated 9 times, totaling 27 test trials. Discriminative training continued during testing and the puff was presented at 2, 4 or 6 seconds after the onset of the conditioned stimulus in the case of A and B, or after the onset of an eight -seconds "blank trial" in the case of the puff-alone type. The inter-trial intervals were 20, 25 and 30 seconds presented pseudo-randomly throughout the experiment.

In test, the trial types A, B and ITI were presented in a pseudorandom order with the restrictions that each type occurred once in each block of three trials. The stimulus that was presented in the first trial was counterbalanced across participants. This resulted in the following counterbalances: A+, ITI, B-, B-, A+, ITI, ITI, A+, B-, B-, ITI, A+, A+, B-, ITI, ITI, B-, A+, A+, ITI, B-, B-, ITI, A+, A+, B-, ITI (sequence 1); ITI, A+, B-, B-, A+, ITI, A+, ITI, B-, B-, ITI, A+, A+, B-, ITI, ITI, B-, A+, A+, ITI, B-, B-, ITI, A+, A+, B-, ITI (sequence 2), B-, ITI, A+, A+, B-, ITI, ITI, B-, A+, A+, ITI, B-, B-, A+, ITI, ITI, A+, B-, B-, ITI, A+, A+, ITI, B-, B-, A+, ITI (sequence 3); and ITI, B-, A+, A+,B-, ITI, B-, ITI, A+, A+, ITI, B-, B-, A+, ITI, ITI, A+, B-, B-, ITI, A+, A+, ITI, B-, B-, A+, ITI (sequence 4). Sequences 1 and 3 were used twice as many as sequences 2 and 4.

Since there were 2 different stimulus assignments and 6 test sequences, there were 12 different participant conditions. The experiment was run in two replications, each consisting of 12 participants.

Statistical Analysis

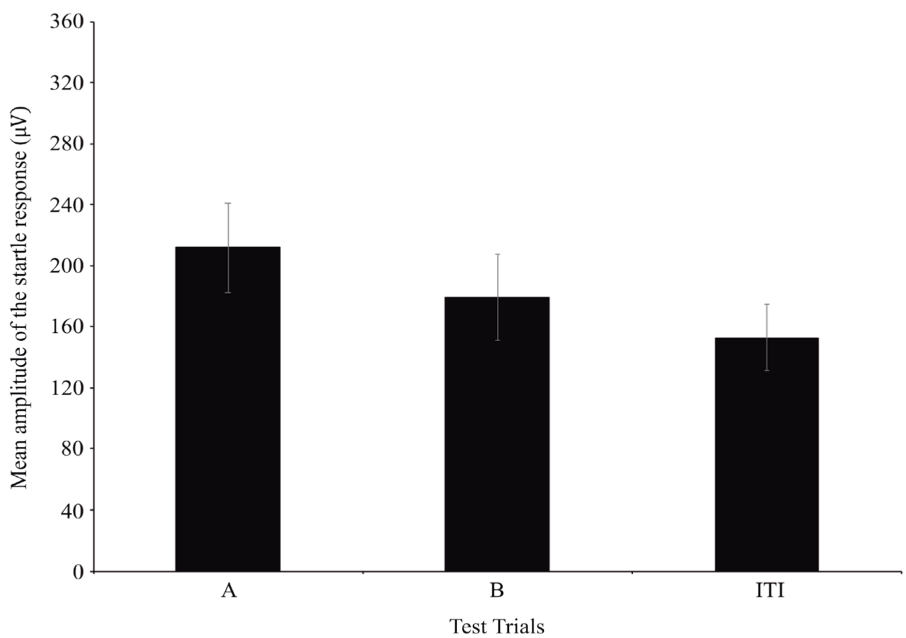
The statistical reliability of the effects was assessed by a 3 (trial type: A, B, ITI) x 2 (cue: light, noise) mixed-design analysis of variance (ANOVA) with the mean peak amplitude of startle as the dependent variable. For each experimental condition, the first trial was eliminated from this analysis to avoid novelty effect. We performed post-hoc pairwise comparisons using the least significance difference test (LSD).

Results and discussion

Figure 1 presents the mean startle response in trials 2-9 of each type. It is apparent that responding to the puff in the presence of the reinforced CS A (M =211.60, SEM =29.51) was larger than responding to the puff alone (M=152.82, SEM=21.86), indicating the development of fear conditioning, and greater than when the puff occurred in the presence of the nonreinforced CS, B (M =179.25, SEM =28.16), indicating discrimination. Some degree of generalized fear may have been carried out by B, since the mean startle in the presence of this cue was also superior to that of the puff alone. Consistent with these observations, the repeated measures ANOVA revealed a main effect of trial type, $F(2, 44) = 12.922$, $p < 0.001$, η^2partial= .370, 90% CIs [.166, .499], but not reliable effect of cue, $F(1,22)<1$ or trial type x cue interaction, $F(2,44)<1$. Post hoc comparisons revealed that responding to the puff in the presence of cue A was significantly larger than responding to the puff alone ($p<0.001$), and larger than startle in the presence of cue B ($p= 0.003$). The difference in responding to the puff alone and to the puff in the presence of B was also significant ($p= 0.035$).

Figure 1

Mean amplitude of the startle response in test trials from Experiment 1



Note. The error bars represent to standard error of the mean.

In summary, our findings reveal that there is an associative potentiation of the startle response with our intermodal differential conditioning procedure. Specifically, we demonstrate discriminative learning, in the form of a larger startle response in the presence of a stimulus from one sensory modality (i.e., visual or auditory), that was paired with the US (A), than in the presence of a stimulus from another sensory modality (i.e., auditory or visual), but that was not paired with the US (B). This adds to the existing literature in differential learning that mostly have focused in intra-modal discrimination with geometrical figures (e.g., Baas et al., 2014; Ballard et al., 2014; Borelli et al., 2015), lights (e.g., Ameli & Grillon, 2001; Baas et al., 2004; Grillon & Davis, 1997), and sounds (e.g., Asli et al., 2009; Asli & Flaten, 2012).

Experiment 2

As mentioned in the introduction, while there is considerable evidence of cue competition effects in nonhumans, it is less clear whether this is a robust phenomenon in humans. For instance, Martin and Levey (1991) conducted four experiments examining cue competition in human eyeblink conditioning with visuals CSs and an air puff US. In three of these experiments (1, 3 and 4), with similar methods and results, participants were trained first in a discrimination procedure in which CS A was reinforced and CS B was not (A+ B-). In a second stage, A and B were compounded with X and Y, respectively, and reinforced (AX+BY-). In test, conditioned eyeblink to X was reliably lower than to Y, indicating that learning to X was degraded by being reinforced in compound with the more valid cue, A, relative to Y that was reinforced in compound with the non-valid cue, B. In Experiment 2, however, in which the two conditions (i.e., A+/AX+ versus B-/BY+) were between-subjects, no differences between X and Y were found.

A few studies in electrodermal conditioning have directly assessed blocking by comparing the response to a blocking condition with the one to an overshadowing condition (i.e., X versus Y, after training A+ followed by AX+, BY+). Here, there are also mixed results: while some studies have provided reliable evidence of blocking (Hinchy et al., 1995; Kimmel & Bevil, 1996; Mitchell & Lovibond, 2002), others have failed in seen this effect (Davey & Singh, 1988; Lovibond et al., 1988). Recently, Eippert et al. (2012), Boddez et al. (2013), and Kausche and Schwabe (2020) reported null results of blocking when conditioning was measured through the electrodermal response, but positive results when the participant´s declarative expectation of an electric shock was used as measure of learning.

Furthermore, in our knowledge, no studies have been reported that evaluate cue competition in fear-potentiated startle. Therefore, we designed an experiment (Experiment 2) based on Martin and Levey's (1991) studies, involving an A+B- discrimination in the first stage followed by AX+BY+ compound training, to examine the possibility of observing cue competition in fear-potentiated startle. The design of the experiment is summarized in Table 2.

Table 2
Design of experiment 2

Phase 1	Phase 2	Test
A+(18), B-(18)	AX+(4), BY+(4)	Y(6), X(6), ITI(6)

Note. Letters A-Y represent different CS that could be followed (+) or not followed (–) by the US. The numbers in parenthesis indicate the frequency of each trial type.

Method

Participants

A total of 24 undergraduate psychology students at University of Talca participated in the experiment for course credit (mean age= 22.0, *SD*= 2.1 years, 9 men). They all reported normal or corrected to normal vision, normal hearing, normal tactile sense, and no neurological problems. They were tested individually and had no previous experience in similar research. The content of the informed consent and the procedure of the experiment were approved by the Scientific Ethics Committee of University of Talca.

Apparatus

The apparatus and stimuli were the same as those employed in Experiment 1, except than there were four conditioned stimuli. A visual CS was provided by a 50-watts light. A vibratory CS was produced by a small electric motor (5 Volt) which was applied on the index finger of the right hand. There were two 70-dB auditory stimuli CSs presented through PHILIPS SHS5200 earphones: a 1000-Hz pure tone and a white noise.

Procedure

The experiment occurred in a single session of three phases: In Phase 1, participants received 18 trials of a CS designated as "A" coterminated with the US (A+) interspersed with 18 trials which a CS designated as B was nonreinforced (B-). Stimuli A and B were the light and the vibrator (counterbalanced across participants). Likewise, stimuli X and Y were the tone and the noise (counterbalanced across participants). During Phase2, participants received 4 trials of each AX and BY compounds paired with the US. The inter-trial intervals of Phase1 and Phase2 were 20, 25 and 30 seconds presented pseudorandomly. For each participant, at the end of this training, the eyeblink response to the air-puff test stimulus was examined when the air-puff was preceded by X, Y, and when it was presented alone (ITI). Each type of test trial (Y, X, ITI) was repeated 6 times, totalizing 18 test trials. The puff was presented at 2, 4 or 6 seconds after the onset of the conditioned stimulus, with a fix inter-puff interval of 100 seconds.

The assignment of specific stimulus to CSs A-Y was partially counterbalanced across participants of each group by means of their different allocation in one of four subgroups, each with a different assignment of stimulus as A-Y. Specifically, in subgroup 1 the assignment for A, B, X, and Y was vibration, light, tone, and noise, correspondingly. Subgroup 2 was identical to subgroup 1, except that the stimuli used for X and Y were noise and tone, respectively. In subgroup 3 the assignment for A, B, X, and Y was light, vibration, tone, and noise, correspondingly. Subgroup 4 was identical to subgroup 3, except that the stimuli used for X and Y were noise and tone, respectively.

In test, stimulus X, Y and ITI were presented in a pseudorandom order with the restrictions that each stimulus occurred once in each block of three trials, and it was never followed by itself or by every other stimulus equally often. The stimulus that was presented in the first trial was counterbalanced across participants. This resulted in the following counterbalances: X, Y, ITI, Y, X, ITI, X, ITI, Y, ITI, X, Y, ITI, Y, X, Y, ITI, X (sequence 1), Y, X, ITI, X,Y, ITI, Y, ITI, X, ITI, Y, X, ITI, X, Y, X, ITI, Y (sequence 2), ITI, Y, X, Y, ITI, X, ITI, X, Y, X, ITI, Y, X, Y, ITI, Y, X, ITI (sequence 3). There was no reinforcement in the testing phase.

Since there were 4 different stimulus assignments, and 3 test sequences, there was a total of 12 different conditions. The experiment was run in two replications, each consisting of 12 participants.

Statistical Analysis

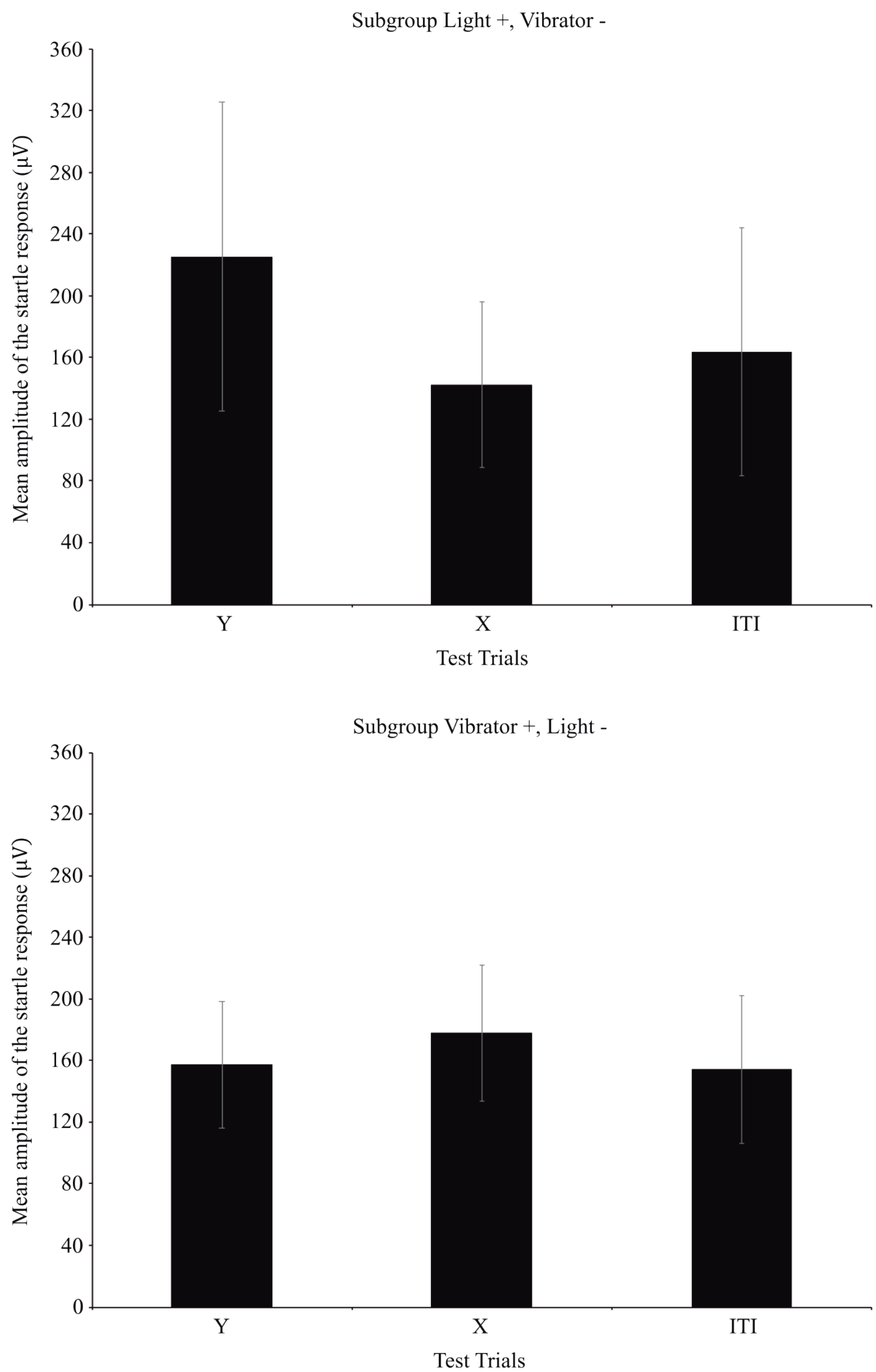
The statistical reliability of the effects was assessed by a 3 (trial type: Y, X, ITI) x 2 (reinforced cue: light, vibrator) mixed-design analysis of variance (ANOVA) with the mean peak amplitude of startle as the dependent variable. For each experimental condition, the first trial was eliminated from this analysis to avoid novelty effect. We performed post-hoc pairwise comparisons using the least significance difference test (LSD).

Results and discussion

Figure 2 shows the mean startle response across trials 2-6 of each trial type of each of two subgroups. We decided to display the results separately for two subgroups because there was a very different pattern of results for the participants that were trained with the light reinforced in Phase1 versus those trained with the vibrator reinforced in Phase1. When the reinforced cue was the light (top plot), fear conditioning to Y seems to have been developed over training, since the response to the puff, in its presence, is higher than the response to the puff alone. Furthermore, the data suggest a cue competition effect in the form of a larger response in the presence of cue Y than in the presence of cue X. On the contrary, in the subgroup in which the reinforced cue was the vibrator (bottom plot), the responses in the three types of tests trials were very similar.

Figure 2

Mean amplitude of the startle response in test trials from Experiment 2.



Note. Subgroup for which the light was reinforced in Phase 1 (top plot), and subgroup for which the vibrator was reinforced in Phase 1 (bottom plot). The error bars represent the standard error of the mean.

The reliability of this pattern was mainly confirmed by our statistical analysis. There was a reliable trial type x reinforced cue interaction, $F(2, 44) = 3.403$, $p = 0.042$, η^2 partial= .134, 90% CIs [.003, .270], but not reliable effect of trial type, $F(2,44) = 1.740$, $p = .187$, η^2 partial= .073, and of reinforced cue $F(1,22) < 1$. Simple effects of trial type in each subgroup revealed that when the reinforced cue was a light, the response to the puff in the presence of cue Y was significantly larger than responding to the puff alone ($p = 0.008$) and larger than startle in the presence of cue X ($p = 0.032$). The difference in responding to the puff alone and to the puff in the presence of X was not significant ($p = 0.386$). When the reinforced cue was the vibrator, there were no significant differences in the responses ($ps > 0.346$).

In summary, our results provided the first evidence of cue competition in fear-potentiated startle in humans in the subgroup in which cue A was the light and cue B the vibrator. The fact that responding in the presence of cue X was not reliably greater than responding to the puff alone, suggest that probably cue X was blocked by cue A. Nevertheless, it is also possible that cue Y had developed supernormal conditioning due to the fact that was trained in compound with a "safe" or "inhibitory" cue (B). In order to probe whether this effect was added to the blocking effect, it would be necessary to present a third compound comprising two entirely new CS in Phase 2, (i.e, CZ+).

On the other hand, our results suggest that cue competition may depend somehow on the stimulus modality. The fact that an auditory CS was blocked by a visual cue, but not by a vibrotactile cue might be due to greater generalization among vibrotactile and auditory stimuli. It is conceivable that our vibrotactile stimulus shares a common component with the auditory cues, X and Y (e.g., the sound generated by the small electric motor). It is possible, then, that the common auditory component of the vibrator acquired sufficient fear to block both X and Y equally. This is consistent with the lack of difference between X and Y in test and with the fact that responding to both is above than responding to the puff alone (although this difference was not reliable). Of course, this is merely speculative and further research must be conducted to clarify this issue.

General discussion

The demonstration of cue competition effects in Pavlovian conditioning is important for theoretical and empirical reasons. When these effects were initially observed in nonhumans, they suggested importantly that although the CS and the US are presented with an otherwise effective degree of coincidence, learning can fail if the informational or predictive value of the CS regarding the occurrence of the US is low. Thus, authors come to the conclusion that learning a CS-US association seems to depend on the associative value of other stimuli that were present during training. Thus, theoreticians faced the challenge of describing how animals develop associations between a CS and a US according to the degree that the CS occurrence acquires a predictive or informational value about the US occurrence. Theories designed to account for these findings use what is now known as "competitive learning rules" (e.g., Mackintosh, 1975b; Rescorla & Wagner, 1972; Vogel et al., 2019; Wagner, 1981).

Reciprocally, these theoretical models based on the findings with nonhumans, lead authors to propose that competitive mechanisms of this sort might underlie several other forms of learning in humans, beyond Pavlovian conditioning, such as predictive and casual learning (e.g., Dickinson et al., 1984; Wagner & Vogel, 2008). Although the studies on cue competition in casual and predictive learning are substantially larger in number than those on Pavlovian conditioning in humans, they are almost as inconclusive as the latter (Miller & Matute, 1996).

Moreover, recently, an empirical debate has emerged with respect to the reliability of some cue competition effects, not only in humans, but also in nonhumans (Maes et al., 2016, 2018; Soto, 2018; Urcelay, 2017). For instance, while Maes et al. (2016) reported several failures in demonstrating blocking in rats, Fam et al. (2017), with very similar procedures, found the opposite. Currently, researchers are reaching the consensus that cue competition effects are not guaranteed but instead their occurrence would depend on several variables, such as stimulus modality and generalization of the CSs in the compound (Haselgrove, 2010; Soto et al., 2015; Soto, 2018; Vogel & Wagner, 2017), relative salience of the elements in the compound (Sanderson et al., 2016), outcome additivity (Beckers et al., 2006), number of blocking cues (Witnauer et al., 2008), presence of generalized anxiety in the case of fear conditioning (Boddez et al., 2012), or just individual differences (Urcelay, 2017).

The current study is the initial part of a larger project intended to address stimulus competition in the context of fear conditioning in humans. Having established the conditions to observe this phenomenon, further studies may evaluate, for instance, whether or not cue competition depends on some of the variables mentioned above.

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