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Rule-based generalisation in single-cue and differential fear conditioning in humans

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ABSTRACT

Fear generalisation refers to the spread of conditioned fear to stimuli similar but distinct from the original conditioned stimulus. In this study, participants were presented with repeated pairings of a conditioned stimulus with a shock, in either a single-cue or differential conditioning paradigm. Generalisation of fear was then tested by presenting stimuli that were novel, but similar to the conditioned stimulus along a spatial stimulus dimension. Dependent measures were online shock expectancy ratings and skin conductance level. A diverse range of generalisation gradients was observed, and the shape of the gradients for both expectancy ratings and skin conductance responses corresponded with participants' verbally reported rules. The findings point to an important role for cognitively controlled processes in human fear generalisation, and provide support for a single-system learning model. They also highlight the potential importance of cognitive reappraisal in clinical treatments for over-generalised fear.

1. Introduction

Associative learning refers to a learning process which associates two elements – for example, the conditioned stimulus (CS) and the unconditioned stimulus (US) in the case of Pavlovian conditioning (Pavlov, 1927). Interestingly, the conditioned response (CR) also spreads to novel stimuli which are similar but distinct from the original CS, a phenomenon referred to as generalisation (Pavlov, 1927). Generalisation is considered to be adaptive as it allows rapid adaptation to new situations and extends the benefits of learning. However, it has been claimed that anxiety patients shown overgeneralisation of fear, which suggests that excessive generalisation can be maladaptive (Lissek et al., 2010; Lissek & Grillon, 2010; Lissek et al., 2014). The present study investigates the mechanisms that underlie generalisation of fear learning in humans, guided by data and theory from both the associative learning and cognitive literatures.

Generalisation of associative learning has been extensively studied in animals using an operant conditioning paradigm (e.g., Guttman & Kalish, 1956; Jenkins & Harrison, 1960). After learning to respond to a single reinforced stimulus (S+), animals showed maximum responses to S+, and a gradual decrement in response to stimuli more dissimilar to S+ along the stimulus dimension, forming a peaked generalisation gradient. This generalisation pattern has been replicated in numerous animal studies (see Honig & Urcuioli 1981 for a review). Interestingly, after discrimination training between S+ and a non-reinforced stimulus (S-) lying on the same stimulus dimension, a sharper peaked gradient is observed, with the highest responding shifted to the stimulus adjacent to S+ (Hanson, 1959). This phenomenon has been coined 'peak shift', as the response peak shifts beyond S+ in the direction away from S-.

Different theoretical accounts have been put forward to account for the generalisation process, with the dominant ones being similarity-based associative accounts. These accounts emphasize similarity between stimuli, with the recent ones drawing attention to shared perceptual elements (Blough, 1975; McLaren and Mackintosh, 2002). These theories suggest that each stimulus is made up of individual elements (e.g., shape, colour, orientation). Stimuli that are perceptually more dissimilar share fewer common elements along the stimulus dimension and hence acquire less associative strength and automatically trigger weaker responses (Hull, 1934a, 1934b). This mechanism can account for the peaked generalisation gradient with the highest responding to the trained value and a gradual decrease in responding to stimuli along the dimension, as commonly found in the animal literature. It can also explain the occurrence of peak shift, in terms of the optimal balance between excitatory elements shared with CS+ and inhibitory elements shared with CS-. Hence, a stimulus beyond CS+ in the direction opposite of CS- would gain the highest net excitatory elements, as it shares similar numbers of excitatory elements with CS+ but fewer inhibitory elements with CS-, resulting in peak shift.

However, the findings in human generalisation studies do not

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completely align with animal studies. A few studies have found the expected generalisation decrement to stimuli that are more dissimilar to the trained value, and some have shown peak shift, supporting the idea that generalisation in humans can be similarity-based (e.g., Wills and Mackintosh, 1998; Livesey and McLaren, 2009). However, the majority of human studies show a linear gradient with the highest responding at the extreme end in the direction opposite to CS- after discrimination training (e.g., LaBerge, 1961; Dunsmoor, Mitrogg, & LaBar, 2009). These increasing linear gradients (and lack of peak shift) cannot be readily predicted and explained by similarity-based associative accounts, suggesting that human generalisation is influenced by additional factors such as relational rules (see Dymond, Dunsmoor, Vervliet, Roche, and Hermans, 2015 for factors that affect fear generalisation in humans). The mixed results in the literature therefore suggest that human generalisation can be either associatively-driven or cognitively driven, or potentially both.

Given the mixed findings in human generalisation studies, the current study sought to examine the potential contribution of associative and cognitive processes to generalisation in humans. Recently, Ahmed and Lovibond (submitted [a]) investigated how cognitively inferred rules may affect fear generalisation in humans. In their study, participants first learnt to discriminate the causal status of two circles with different sizes (CS+ and CS-). They were then presented with selected test stimuli along the same stimulus dimension, and expectancy ratings to each stimulus were recorded. An increasing monotonic generalisation gradient was observed, in line with most previous human generalisation studies (e.g., LaBerge, 1961; Dunsmoor et al., 2009). According to the post-experimental questionnaire, a majority of participants reported inferring a linear rule, such as 'the larger the circle (smaller in the counterbalancing group), the more likely electric shock would be delivered', which corresponded to the resulting linear generalisation gradient. The results also directly support the idea that the linear gradients obtained in previous human studies (e.g., LaBerge, 1961; Dunsmoor et al., 2009) could be a result of participants entertaining a linear rule. However, most studies that found linear generalisation patterns used an asymmetrical stimulus dimension, which means the magnitude or intensity of one end of the dimension is higher than the other end. For example, Dunsmoor et al. (2009) used facial stimuli with increasing intensity of fear expression; Ahmed and Lovibond (submitted [a]) used circles with increasing size. These asymmetrical stimulus dimensions could potentially induce intensity bias, which encourage the formation and usage of a linear rule. This may limit any potential contribution of associatively-driven generalisation.

Hence, in order to minimize the effect of intensity bias, the current study used a symmetrical stimulus dimension developed by Ahmed and Lovibond (submitted [b]). The current study used a differential fear conditioning paradigm, and measured both US expectancy ratings and physiological skin conductance responses. Skin conductance response is a sensitive measure of anticipatory anxiety responses and has been claimed to reflect any underlying associative processes in conditioning tasks (e.g., Esteves, Dimberg, & Öhman, 1994; Tabbert, Stark, Kirsch, & Vatil, 2006; Schultz & Helmstetter, 2010; but see Lovibond & Shanks, 2002). If rule-based generalisation patterns are found in skin conductance that are consistent with participants' reported rules, it would suggest that fear generalisation in humans is likely to be cognitively-driven. Alternatively, if a similarity-based gradient is observed in skin conductance despite participants reporting coming up with a different rule or no rule, this would instead suggest that fear generalisation in humans is associatively-driven. Expectancy ratings were expected to follow participants' reported rules as in Ahmed and Lovibond's studies (submitted [a], submitted [b]).

The current study also sought to compare generalisation after differential conditioning with a single-cue conditioning procedure that involves only a single CS+ during training. Only a few studies have previously employed a single-cue paradigm (e.g., Baron, 1973; Wheeler, Anubdson, & Miller, 2006); and to our knowledge, no studies have tested a single-cue conditioning design in fear generalisation studies. Therefore, it would be beneficial to further our understanding of the contribution of associatively- and cognitively-driven generalisation by using a single-cue conditioning paradigm. The associative approach would always predict a peaked generalisation gradient, while the cognitive approach would be more flexible, predicting various gradients depending on participants' inferred rules. Additionally, the single-cue conditioning paradigm arguably provides greater clinical relevance, as it mimics the pathogenesis of anxiety disorders in real world scenarios that involve a single traumatic experience.

2. Methods

2.1. Participants

Undergraduate students were recruited as participants who received either course credit or AUD $15 for participation. A total of 139 participants (86 females) were recruited, with a mean age of 19.3 years (SD = 3.7).

2.2. Apparatus and materials

Participants were tested individually in an experimental room. A 43-cm computer monitor was used to present the experimental instructions and stimuli. A computer equipped with MatLab software was located outside the experimental room, which generated the stimuli presented to the participants and recorded the expectancy ratings, while another computer controlled AD Instruments equipment to record the skin conductance data at a sampling rate of 1000/s throughout the experiment.

The stimuli were yellow squares [5.5 × 5.5 cms] with black outline containing a black dot varying horizontally from left to right (Fig. 1). The location of the dot was manipulated by an equal distance of 0.5 cm from one stimulus to the next. The stimulus with the black dot in the middle of the square (Stimulus E) always served as the CS+, while Stimulus C served as CS- in the differential conditioning group. Note that the position of CS- was not counterbalanced, since the stimulus dimension was symmetrical and intensity bias was minimized. A red lightning bolt served as the symbolic US. All stimuli and the symbolic US were presented in the centre of a white background on the computer screen.

A 0.5-s electric shock (sinusoidal pulse stimulation, 80 Hz) was delivered through electrodes attached to the distal and middle segments of the index finger of participants' non-dominant hand. Skin conductance electrodes were attached to the distal and proximal segments of the third finger of the same hand. A semicircular dial with a rotary pointer was attached to the table in front of the participants. The dial was labelled *Expectancy of SHOCK after figure*, with the left position labelled *Certain NO SHOCK* and the right position labelled *Certain*

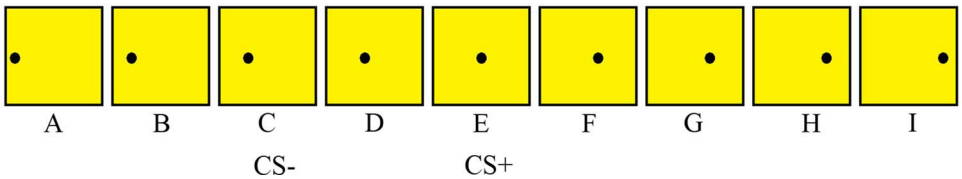

Fig. 1. Stimulus dimension. Note that only the differential conditioning group received non-reinforced trials with stimulus C (CS-) during the acquisition phases.