# Neural systems for fear generalization

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The ability to generalize information across different emotional experiences is paramount to adaptive behavior. For instance, it is important to generalize learning in threatening contexts beyond instances for which stimulus encounters directly led to aversive outcomes. Through mechanisms of stimulus and context generalization, one can effectively navigate the environment to avoid harm in the future. Here, we present results from functional neuroimaging experiments in healthy adults designed to examine the neural systems that mediate fear generalization on the basis of both perceptual and conceptual similarity to conditioned stimuli. First, we examined generalization of conditioned fear among stimuli that perceptually resembled a learned threat. During fear learning, a face expressing a moderate amount of fear (conditioned stimulus, CS+) signaled delivery of a mildly aversive electric shock (unconditioned stimulus, US), whereas the same face with a neutral expression was unreinforced. In a subsequent generalization test, subjects were presented with faces expressing more or less fear intensity than the CS+. Behaviorally, subjects retrospectively misidentified a learned threat as expressing more intense fear than its actual value and generated greater skin conductance responses (SCR) to generalized stimuli expressing higher fear intensity. Brain activity related to intensity-based generalization was observed in the striatum, insula, and thalamus. Generalized SCRs were correlated with activity in the amygdala, and task-induced functional connectivity changes between the amygdala and fusiform gyrus were correlated with trait anxiety levels. In a separate experiment, we examined fear generalization across exemplars of conceptually related objects. A select sample of objects from one natural object category (e.g. animals) were paired with a shock US whereas those from another category (e.g. tools) were unreinforced. Fear learning modulated activity in category-selective brain regions in the occipital-temporal cortex, as well areas commonly associated with fear conditioning (e.g. the amygdala and insula). We discovered a mechanistic account for the spread of conceptual fear across object exemplars based on hippocampal signaling of object typicality, which was reflected in greater functional coupling with the amygdala early in learning. Moreover, multivariate analysis revealed alterations in the representational architecture of the reinforced object categories in occipitotemporal cortex and amygdala. In sum, these studies provide human neuroimaging evidence for perceptual and conceptual factors supporting fear learning and generalization. While generalizing abilities are usually adaptive, overgeneralization of fear can prove maladaptive if acquired knowledge is applied too broadly, as in some anxiety disorders. These results thus add potentially new insights into neurobiologically-based models of anxiety disorders that go beyond basic conditioning processes.