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Avoiding math on a rapid timescale: Emotional responsivity and anxious attention in math anxiety

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ABSTRACT

Math anxiety (MA) is characterized by negative feelings towards mathematics, resulting in avoidance of math classes and of careers that rely on mathematical skills. Focused on a long timescale, this research may miss important cognitive and affective processes that operate moment-to-moment, changing rapid reactions even when a student simply sees a math problem. Here, using fMRI with an attentional deployment paradigm, we show that MA influences rapid spontaneous emotional and attentional responses to mathematical stimuli upon brief presentation. Critically, participants viewed but did not attempt to solve the problems. Indicating increased threat reactivity to even brief presentations of math problems, increased MA was associated with increased amygdala response during math viewing trials. Functionally and anatomically defined amygdala ROIs yielded similar results, indicating robustness of the finding. Similar to the pattern of vigilance and avoidance observed in specific phobia, behavioral results of the attentional paradigm demonstrated that MA is associated with attentional disengagement for mathematical symbols. This attentional avoidance is specific to math stimuli; when viewing negatively-valenced images, MA is correlated with attentional engagement, similar to other forms of anxiety. These results indicate that even brief exposure to mathematics triggers a neural response related to threat avoidance in highly MA individuals.

1. Introduction

A major challenge to students' interest and success in STEM courses is math anxiety, or negative and anxious emotion associated with anticipation and performance of mathematics (Ashcraft, 2002; Hembree, 1990). While much research has focused on the long-term outcomes of math anxiety, less work has examined the low-level rapid or automatic responses that occur each time a highly math anxious (HMA) individual encounters math stimuli. This is an important consideration for understanding the neural, cognitive, and affective mechanisms underlying math anxiety, and ultimately, for treating these negative outcomes. For instance, suppose math anxiety is associated with an initial, rapid aversion to seeing a problem on a math test, even before beginning to solve the problem at hand. This type of reaction represents an obstacle in terms of the resources required for a HMA student to even begin the process of computing the solution to the problem. Prior to engaging the neural and cognitive resources that are typically brought to the task, a math anxious student must first respond to – and effectively inhibit – the threat signal that his or her emotional response system is generating. In the present fMRI experiment, we begin to examine the dynamics of how this process unfolds over a rapid timescale – on both a behavioral and a neural level – which will inform our understanding of how math anxiety influences cognition.

Neuroimaging presents a valuable tool to better understand how negative affect can alter initial neural reactivity to math, and how this emotion ultimately alters mathematical computation in the brains of HMA individuals. The amygdala responds to a myriad of affective cues, implying that this area of the brain is not just selective for fearful facial expressions (Whalen, 1998, 2004b), but instead provides a structure to integrate attentional mechanisms for uncertainty and resulting in cortical vigilance (Davis & Whalen, 2001). Indeed, due to its broad connectivity with cortical and subcortical regions, here we examine amygdala activity as a proxy for a broader network of regions associated with processing of negative affect, motivational salience, and vigilance (Kim, Gee, Loucks, Davis, & Whalen, 2011; Pessoa & Adolphs, 2010; Whalen, 2004a). We examine patterns of neural reactivity in the amygdala because math anxiety may be a result of learned negative responses, much like fear conditioning, such that mathematics may be thought of as a negatively conditioned stimulus. In generating affective responses in learning and fear conditioning (Davis & Whalen, 2001; Holland & Gallagher, 1999), the amygdala associates information linking a conditioned stimulus to positive or negative outcomes,

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signaling this value to the nucleus accumbens (NAcc) in the ventral striatum. In turn, dopaminergic projections from the NAcc back to the amygdala amplify this signal in a feedback loop. Additionally, the amygdala is responsible for lowering neuronal thresholds in sensory systems, through activation of basal forebrain cholinergic neurons, serotonergic systems and catecholamnergic systems, thereby increasing vigilance in order to facilitate a response during uncertain or potentially threatening situations (Davis & Whalen, 2001). Here we examine amygdala activity as a measure of broader network activity signaling vigilance, identifying mathematics as a particularly salient cue for math anxious individuals to potentially be approached or avoided, resulting in increased amygdala activity for math anxious individuals as a result of this orienting behavior.

This link between increased amygdala reactivity and a lowered threshold for responding to potentially threatening cues is a hallmark of many types of anxiety and phobia. Anxious individuals show increased amygdala reactivity to negative information and increased attentional bias for negative cues, as this threshold for attending and reacting to negative information is lowered (Bishop, 2007, 2008). Similarly, individuals with specific phobia show increased amygdala reactivity when viewing phobic stimuli (Schienle, Schäfer, Walter, Stark, & Vaitl, 2005), illustrating increased vigilance for a stimulus associated with a specific learned fearful reaction. However, unlike the increased attentional engagement observed for anxious individuals, phobia is associated with behavioral avoidance of phobic stimuli (Pflugshaupt et al., 2005). Indeed, though many people would not consider mathematics to be a particularly emotionally evocative stimulus, the subjective experience of negative emotion in math anxiety is consistent with prominent theories of affect (e.g., the constructionist model), that emphasize that emotional experience occurs as an integration of awareness of physiological sensations, and cognitive attributions based on previous experience and situational context, all of which are processed by a variety of brain regions and neural networks (Lange & James, 1922; Lindquist & Barrett, 2008, 2012; Lindquist, Wager, Kober, Bliss-Moreau, & Barrett, 2012). These sensations and attributions result in patterns of behavior (e.g., approach, avoidance) and changes in cognition that in turn result in altered attention and working memory (Ashcraft & Krause, 2007). In this way, HMA individuals may have developed these anxious and negative responses to mathematics as a result of repeated physiological arousal and negative cognitive attributions associated with mathematics, much in the way that someone learns to respond to a conditioned stimulus. This threat system may be triggered just by viewing a math problem, before other regions of the brain associated with mathematical processing (e.g., the intraparietal sulcus, IPS; Dehaene, Spelke, Pinel, Stanescu, & Tsivkin, 1999) are engaged to complete these computations. In other words, the negative affective response in math anxiety may begin very rapidly, even with mere exposure to a math problem, and thus alter subsequent attention, and further downstream, could alter the neural basis of mathematical cognition when individuals are asked to complete mathematical computations. In the present fMRI experiment, we test whether math anxiety is associated with initial hypervigilance and negative reactivity in the amygdala, illustrating that math anxiety alters even early responsivity to mathematical information, even before one begins the process of computation.

In line with the description of math anxiety as a tradeoff in neural resources between negative emotion processing and cognitive operations pertaining to math, previous research indicates HMA individuals show increased amygdala reactivity while performing math computations, and decreased activity in regions associated with math computation (Young, Wu, & Menon, 2012). However, it is possible that – even without requiring completion of math computations – increased affective processing for HMA participants results in specific arousal-related amygdala reactivity. This possibility has been left unexplored by previous work, which has focused either on periods of math computation (Young et al., 2012), or anxious anticipation of math computation (Lyons & Beilock, 2012a, 2012b). In contrast, here we examine responsivity to brief presentation of math stimuli absent any computation or instruction to evaluate numerical values. Therefore, if the results of this experiment demonstrate that amygdala responsivity while attending to math stimuli varies as a function of math anxiety, we can conclude that this response is not due to anticipating or engaging in an unpleasant mathematical task, but simply to seeing a math problem. In this way, due to repeated negative experiences, math problems may become a negative conditioned stimulus, and even brief exposure to these stimuli may evoke a rapid negative reaction. In other words, these results would suggest that negative amygdala reactivity in math anxiety cannot be wholly attributed to directly experiencing or anxiously awaiting a subjectively negative task. Instead, this increased emotional arousal and vigilance in response to a negatively-valenced stimulus occurs on a very rapid timescale, shaping initial attention and perhaps altering deployment of cognitive resources that could affect later working memory and mathematical computation.

In the present fMRI study, we explored how math anxiety influences neural and behavioral indices of anxious emotion and rapid orienting responses to math stimuli, illustrating heightened negative reactivity even without solving math problems. We utilized a dot probe task in an fMRI experiment examining how math anxiety influences attentional responses to briefly-presented mathematical expressions, as a means of measuring rapid emotional and attentional responsivity. By establishing the attentional changes and neural patterns that are associated with brief exposure to mathematical stimuli, we aim to develop a greater understanding of how negative emotion manifests in math anxiety and influences mathematical cognition and understanding.

2. Method

2.1. Power analyses

Using the effect size from a previous dot probe study with anxious participants, (Cohen's $d = 0.79$, $r^2 = 0.135$, $f = 0.391$; Bradley, Mogg, Falla, & Hamilton, 1998), for 80% power at $\alpha = 0.05$, we would require $N = 36$ participants, so 40 participants were recruited.

2.2. Participants

Forty undergraduate students completed a dot probe attentional paradigm in the fMRI scanner. Undergraduate students in the subject pool completed a 30-question version of the Math Anxiety Rating Scale (MARS; Suinn & Winston, 2003), which gauges anxiety across a variety of math-related scenarios, for example, "Taking an examination (final) in a mathematics course," "Studying for a mathematics test," and "Studying for a driver's license test and memorizing the figures involved, such as the distances it takes to stop a car going at different speeds." Participants were recruited on the basis of their extreme scores on the MARS ($N = 488$, 62% female, $M_{age} = 19.45$ years, $M_{MARS} = 2.26$, $SD_{MARS} = 0.56$, MARS Range: 1–5, Extreme scores were ± 0.7 SD away from mean, *LMA Range* = 1.00–1.84, *HMA Range* = 2.66–4.67). The resulting sample included 20 high math anxious individuals (HMA, $M_{MARS} = 2.98$, $SD_{MARS} = 0.21$, $M_{age} = 19.30$ years, 70% female) and 20 low math anxious individuals (LMA, $M_{MARS} = 1.60$, $SD_{MARS} = 0.21$, $M_{age} = 19.65$ years, 55% female).

2.3. Task

This fMRI task was designed to assess attentional deployment to traditionally negative stimuli (IAPS pictures; Lang, Bradley, & Cuthbert, 2008), as well as mathematical expressions. In the dot probe paradigm, attention to a stimulus of interest is compared to a neutral stimulus by measuring the speed and accuracy of responses to a subsequent stimulus in the same or different spatial location (MacLeod & Mathews, 1988). If participants are comparatively faster to detect the appearance