The Neurophysiological Relationship Between Number Anxiety and the EEG Gamma-Band

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Keywords: Math Anxiety, EEG, Number Anxiety, Gamma, Gamma-band

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Abstract

The development of math anxiety is thought to originate at a young age, as a form of number anxiety, but has not been investigated extensively. Research has shown greater levels of EEG gamma-band activity are experienced during threat perception and attentional bias. This has been identified in high math anxious individuals when confronted with math-based tasks, but has not yet been explored for number anxiety specifically. Single-digit numbers and letters were presented to 15 high and 15 low math anxious participants, who were required to observe the stimuli. High math anxious participants displayed significantly greater levels of gamma activity during number observation compared to letter observation. Findings suggest high math anxious individuals may have a threat-related response to observation of simple numerical stimuli. Further behavioural investigations are needed, but high math anxious individuals may display avoidance towards number and math due to a threat response associated with increased gamma activity.

Introduction

Those with high math anxiety have limited job and study prospects (Beilock & Ramirez, 2011), in part, due to an avoidance effect towards math-based tasks (Ashcraft, 2002). This has been researched extensively from cognitive and behavioural perspectives; for example, using eye-tracking methods, Hunt, Clark-Carter and Sheffield (2015) found that high math anxious individuals tended to look away from math problems compared to low math anxious individuals. To date, there is limited neurophysiological research of math anxiety (Suárez-Pellicioni et al., 2016) identifying if certain neurophysiological signatures are present during math processing, or even number observation, which is the focus of the present study.

Using an Event-Related Potential (ERP) paradigm, Jones, Childers, and Jiang (2012) measured math anxiety differences in a shopping decision making task. Nineteen low and 20 high math anxious individuals were asked to evaluate the prices presented to them and either buy or not buy an item depending on whether they thought the offered promotion would give them a 'better deal'. Fifty items were used and in promotion tasks, discounts (such as 20%) were applied. Results showed that under promotion situations high math anxious individuals rely on assumption rather than using a memory search to identify if the price or promotion is acceptable, in an effort to avoid doing math. Jones et al., (2012) note that the greater P3 component experienced by high math anxious individuals is likely representative of emotional and motivational factors due to the rapid response needed. However, for those with low math anxiety this is more like the typical P300, representing decision making in working out the correct answer. They conclude by identifying that high math anxious individuals deduce that mathematical processing, when no promotion is associated, means a bad price but a good price under promotional trials, showing the classic avoidance technique found in those with high math anxiety (Ashcraft & Faust, 1994).

Whilst this research provides an insight into the neurophysiological processing of math anxiety, it leaves some aspects untouched. Firstly, this work focuses solely on buying and price comparison and so fails to identify why math anxiety may occur. Secondly, buying is only one aspect that math anxious individuals struggle with; using simpler math-based stimuli to understand the origin of math anxiety would be more beneficial at this early stage of research. It is pertinent to focus on the basic underlying neurophysiological principles of math anxiety and the contributing factors towards it, as well as specific situations where it may be relevant.

Prior research has helped to understand the behavioural representations of EEG bands of activity. Examples of these are given below: Delta activity has been evidenced in decision making and attentional processes (Güntekin & Başar, 2016) and increases in theta band activity have been shown to improve memory performance (White et al., 2013). Alpha activity is typically representative of eyes-closed wakefulness/relaxation and associated multiple behavioural representations, for example, inhibitory control (Klimesch et al., 2007) whereas beta activity has been associated with attentional processes, including alertness (Kamiński et al., 2012).

Previous research has shown that the gamma band is responsible for the processing of threat-related stimuli (Garcia-Garcia et al., 2010; Maratos et al., 2012) and attentional bias in high anxious individuals (Bar-Haim et al., 2007). This has since been related to math anxiety, whereby high anxious individuals have been shown to display increased gamma power for math-related problems of varying complexities, but not for word-based tasks (Batashvili, Staples, Baker, & Sheffield, 2019).

Furthermore, studies have shown that task demand may not be responsible for these increasing effects. The mere anticipation of math-based stimuli is enough to activate pain pathways in those with high math anxiety (Lyons & Beilock, 2012) and therefore, the perception of a numerical task alone may increase gamma activity without the need for conducting a task. Consequently, it would be of interest to determine whether increased gamma-band activity, would also be observed during the simple observation of numbers, requiring no manipulation of number or math.

Number anxiety has not been studied in great depth but is a factor that could be a contributor to the formation of math anxiety. Kazelskis (1998) notes “the manipulation of numbers could be the *sine qua non* of math anxiety” (p.631), yet only recently have studies begun to identify number anxiety as a possible prerequisite to math anxiety. Maloney, Risko, Ansari, & Fugelsang (2010) used an enumeration task whereby a number of squares (between 1-9) were presented to high and low math anxious individuals. When 1-4 squares were presented, they found that both groups enumerated equally as quick. However, when 5-9 squares were presented, high math anxious individuals took significantly longer, supporting the theory that those with high math anxiety may also experience number anxiety. Maloney et al. (2010) further examined why number anxiety would have an effect on high math anxious individuals and whether it is through math anxiety impacting on working memory or through a numerical deficit. Participants were asked to state whether a number was higher or lower than 5. This study manipulated the numerical distance effect (NDE) stating that the further away the number is from 5 (e.g. 1 or 9 being the furthest) the easier it becomes to distinguish differences between it and the target number. Overall, they identified a slower reaction time for high math anxious individuals showing the NDE was more prominent in low math anxious individuals. This can be expected due to anxiety affecting working memory whilst it is in use, i.e. keeping the target number (5) active during the task.

Therefore, in order to rule out working memory's role in the study, Maloney et al. (2010) conducted a follow up using a modified version of the low/high 5 task. Participants were presented with two stimuli on screen and were asked to press either the left or right end on the keyboard to correspond to which number they identified as being the largest. This showed a replication of the previous NDE results without the need for a target number active in working memory. These findings raise issues concerning current theories of math anxiety. It has been assumed that working memory is impaired due to the amount of resources consumed by anxious responses and intrusive thoughts (Hunt et al., 2014), which creates delay and performance issues when attempting to solve math-based tasks. However, Maloney et al. (2010) note there is no research currently stating that numerical comparison is demanding of working memory resources. Therefore, it is theorised that those with high math anxiety may have a low-level deficit during numerical processing. This is contradictory to previous research which theorises low working memory capacity is not a consequence or precursor to math anxiety. If this was the case then cognitive performance in other areas would also be affected (Ashcraft & Kirk, 2001) and anxiety reduction would likely show no performance improvements for math anxiety interventions.

The above research has noted the prominent behavioural and cognitive effects of math anxiety on even the most basic numerical processes including counting and simple addition (Maloney et al., 2010). However, further research is necessary to identify whether those with high math anxiety have a deficit in working memory. There has been little research concerning the observation of number from a neurophysiological perspective, due to the absence of behavioural measures, i.e. observation of stimuli requires no participant response, which is why more simple manipulation of number tasks have been observed within math anxiety research (e.g. Maloney, Ansari, & Fugelsang, 2011). With more recent investigations focusing on the neurophysiological correlates of math anxiety, it makes more sense to study what could be the '*sine qau non'* to the development of math anxiety (Kazelskis, 1998) in order to understand why this may occur. Accordingly, examining neurophysiological responses to the mere observation of number, the first step in developing math skills, may provide clues as to why and how math anxiety develops. In the current EEG research, participants were presented with single digit numbers or letters and needed only to observe them. This eliminated the need for a task demand, therefore excluding the need for great amounts of working memory resources.

Research above has outlined that processing of math stimuli in high math anxious populations generates higher levels of gamma band activity (Batashvili et al., 2019). Studies also propose that it is the initial perception, rather than manipulating and calculating number, that causes this response (Lyons & Beilock, 2012). This indicates that the perception of numerical stimuli may also show these higher levels. Therefore, it is hypothesised that higher levels of gamma activity will be shown in response to number observation when compared to letter observation in high math anxious individuals, whereas low math anxious individuals will show no difference between stimuli sets.

Method:

Design

Relevant electrodes were selected based on a priori assumptions; previous research has outlined temporal and parietal activity for attention and visual information associated with gamma oscillations (Müller et al., 2000; Oathes et al., 2008) therefore, the electrodes across these sites were used for analysis (T3/T7, C3, C4, T4/T8 (anterior), T5/P7, P3, P4, T6/P8 (posterior)).

Participant Selection

One hundred and eighty seven participants were recruited from the University of Derby, and were asked to complete the MAS-UK (Hunt et al., 2011) which consists of 23 statements answered by a five point Likert-scale about how anxious participants would feel in certain math-based situations. High scores indicate high levels of math anxiety and lower scores indicate low levels of math anxiety. Experimental procedures were in accordance with BPS ethics and was approved by the University of Derby Research Ethics Committee

Cluster Analysis

Nine participants were removed due to missing data. A hierarchical cluster analysis identified two clusters of participants that possessed similar characteristics. The first cluster had 42.7% of cases (N=76) and contained those who scored low on the MAS-UK indicating a low math anxiety cluster. The second had 57.3% of the total sample (N=102) and contained those who scored higher on the MAS-UK indicating a high math anxiety cluster. In order to distinctly invite those who had very high and very low math anxiety and to avoid crossover between the clusters, participants with scores below 40 and above 65 on the MAS-UK were selected for the EEG phase of the study.

Thirty participants were invited to participate in the EEG phase of the research. All participants were enrolled on, or had completed, a degree in higher education. Individuals consisted of 15 high (9 males, Mean Age = 22.33, SD = 4.20) and 15 low (4 males, Mean Age

= 29.73, SD = 8.01) math anxious, and were all right-handed. Participants reported normal or corrected to normal vision.

Materials and Equipment

Each participant was presented with a random (with replacement) list of 80 letters, from A-Z and 80 single digit numbers, from 0-9 (presented one at a time). Stimuli were presented for 2000ms followed by a fixation with a duration of 500ms. Inter-trial intervals were pseudorandomised between 500ms and 2500ms to avoid complacency effects. NeuroScan SynAmps² was used to acquire and process EEG data (Neurosoft, Inc. Sterling, USA). EEG data were recorded from a 64 Silver-Chloride Sintered electrodes Quik-Cap using a linked mastoid reference. All electrodes in the cap were arranged according to the international 10-20 electrode placement standards.

EEG Recording and Analysis

Participants were seated in a dimly lit room and white stimuli were presented on a black background. They were sat at eye height to the centre of the screen, asked to sit comfortably in the chair and to concentrate on the stimuli presented. Impedances of all electrodes were kept below 15 kΩ.

To analyse gamma-band activity, data were first corrected for ocular artefacts. A positive trigger threshold for ocular artefacts was set to 10% from the maximum artefact voltage with the minimum number of sweeps required to construct an averaged VEOG artefact being 30. The duration of the average artefacts was 400ms. Trials were also manually inspected for any artefacts; no other artefacts from movement or HEOG electrodes were observed. A

100ms pre-stimulus baseline correction was applied and then Fast Fourier Transformed (cosine 10% taper) on each trial, which were then averaged for letters and numbers separately.

Data were averaged within a specific segment of the gamma frequency band (35-70 Hz), chosen based on previous research observing gamma activity and threat (30-50Hz; Luo et al., 2009, 2007), anxiety (35-70; Oathes et al., 2008) and math anxiety (35-70; Batashvili et al., 2019).

Results

High and low math anxiety group scores were tested for violation of normality using a Shapiro-Wilk test and were found to be normally distributed ($p = .06$ and .66, respectively). A 2 (Math anxiety) × 2 (Stimulus condition) × 2 (Horizontal electrodes) × 4 (Vertical electrodes) mixed measures ANOVA was conducted to identify any interactions and main effects. Greenhouse-Geisser corrections were included to ensure type I error rates were not inflated (Greenhouse & Geisser, 1959) as neurophysiological data is rarely homogenous.

There were no significant four-or three-way interactions. There was a significant two-way interaction between condition and math anxiety group, $F(1,28)=5.15$, $p=.031$, $\eta^2=.02$, such that higher gamma activity was experienced during number in high math anxious individuals than in low math anxious individuals (see Table 1). Simple effects showed a significant difference in gamma power between letter and number conditions for high math anxious participants ($p=.042$) and no significant difference for low math anxious participants ($p>.1$) The activity during letter observation did not differ between both groups ($p>.1$). There were no other two-way interactions. There was a significant main effect of horizontal electrodes

$F(1,29)=15.03$, $p=.001$, $\eta^2=.12$, such that there were higher levels of gamma activity in temporal and central regions (Mean = .02 μV^2, SD = .04) than parietal (Mean = .01μV^2, SD = .01). There were no other significant main or interaction effects.

[Table 1 near here]

Discussion

There was a significant main effect of horizontal electrodes showing higher gamma activity at anterior sites. This is similar to gamma activity results identifying increased attentional resources at these locations (Li et al., 2005). This main effect is likely due to the anterior sites including temporal electrodes, as research has noted gamma band activity's location, in reference to attention, to the fusiform gyrus found at temporal sites (Tallon-Baudry & Bertrand, 1999) .

The main finding of this study was the significant interaction between condition and math anxiety group. Overall, it was found that equal levels of gamma activity were experienced by both high and low math anxious participants in this study during the observation of letters. Low math anxious individuals also experienced similar levels during the observation of numbers, however, high math anxious individuals showed significantly greater gamma activity during number observation, supporting our prediction. The results suggest that high math anxious individuals may show increased levels of threat and anxiety towards viewing number and that this potential effect happens regardless of task or high working memory demand.

These findings suggest that there may be other contributing factors to poor math performance than a working memory deficit. As the current study used no performance measures, the theory that a deficit (causing a lack of working memory resources) is responsible for the math anxiety effects seems weak when little working memory resources are in demand during mere observation. It could be argued that instead, the processing of threatening stimuli may explain the reduction in accuracy in response to behavioural tasks. However, as there were no behavioural responses used in this study, it should be followed up in future research to provide further support for this.

Alternatively, in line with Lyons and Beilock's (2012) research, it could be argued that anticipation plays a role. Participants may experience activity stimulating pain pathways in response to anticipating math or numerical-based task as reported by Lyons and Beilock (2012). Future analysis of this type of data would be useful to identify points of gamma activity change over time. This could then reveal whether anticipation of task or viewing of number (prior to stimulus presentation) produces higher levels of gamma activity than post recognition.

The results from this study has implications for those suffering with math anxiety and provides some possible explanation as to why high math anxious individuals avoid math related situations. If the increased gamma-band activity is seen in a study, such as the current one, that requires no manipulation of number within the task, then anxiety towards manipulating math outside of a lab-based setting are likely to increase greatly. This again has important implications for future math anxiety research and supports Lyons & Beilock's (2012) study such that, if pain pathways are activated at anticipatory stages during the processing of math, it could also occur when viewing it in raw form, i.e. numbers. If it is the case that pain pathways activate at the simple sight of number, it is clear why high math anxious individuals consistently avoid math-based situations.

In conclusion, previous research has defined math anxiety as a “feeling of tension, apprehension, or fear that interferes with math performance” (Ashcraft, 2002, p.1). However, this does not mention simple observation of number or viewing math without the need for a response. It may be that this definition needs to include the processing of math as well as performance. Similarly, based on previous assumptions that number anxiety is the *sine qua non* to math anxiety (Kazelskis, 1998), and the results of the current research, an aspect of number anxiety may need to be included in an updated definition (or recognised separately). The interesting findings concerning mere observation of number from this study showed greater levels of gamma-band activity in high math anxious individuals only when observing numerical-based stimuli. Future research should consider the measurement of gamma activity level pre- and post-stimulus onset to identify fluctuations in gamma band activity and how this may relate to emotional and behavioural responses alongside performance. Further research investigating the observation of number should also aim to include a behavioural task (e.g. the modified low/high 5 task used by Maloney et al. (2010)) or psychophysiological paradigm (e.g. an electrodermal activity measure) to corroborate the accompanying neurophysiological effects.

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Table 1: Mean (SD) gamma power between stimulus condition and math anxiety group.

	Math Anxiety Group	
Stimulus Condition	**Low**	**High**
Number	.012 (.02)	.025 (.05)
Letter	.014 (.02)	.014 (.02)