Exploring the Relationship Between Gamma-band Activity and Maths Anxiety

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Abstract

Previous research has outlined high anxiety in connection with gamma modulation, identifying that gamma-band activity (40-100 Hz) correlates with processing of threat perception, attention and anxiety. Maths anxiety research has also noted the involvement of these aspects, yet this has not been investigated from a neurophysiological standpoint. Electroencephalography (EEG) was used to research gamma-band activity in relation to maths anxiety over two studies. The first measured gamma differences during the processing of complex addition and multiplication stimuli. Results identified differences between high and low maths anxious individuals; significantly greater gamma power was observed in those with high maths anxiety than those with low maths anxiety. As a control condition was not used, the second study replicated the design, but also applied a non-numerical control condition amongst the other stimuli sets. This showed significantly greater gamma activity in high maths anxious individuals across numerical conditions, but not in the non-numerical condition. High maths anxious individuals likely show attentional bias and threat perception to numerical-based stimuli, as indexed by gamma power. This study provides the first evidence of greater gamma-band activity in high maths anxious individuals and serves as a foundation for the exploration of gamma activity in high maths anxious individuals.

Keywords: maths anxiety, maths, gamma band, frequency analysis, EEG

Introduction

Maths anxiety is defined as "feelings of apprehension and tension concerning manipulation of numbers and completion of mathematical problems in various contexts" (Richardson & Suinn, 1972, p.551). There is a large amount of behavioural research concerned with how maths is processed, typically identifying that those with high maths anxiety have an increased reaction time and decreased accuracy during maths based tasks, than those with low maths anxiety (Ashcraft, 2002; Ashcraft & Kirk, 2001; Ashcraft & Krause, 2007; Faust, Ashcraft, & Fleck, 1996). More recently, the research focus has shifted to neurophysiological processing resulting in predictions that as cognitive neuroscience becomes more prominent in maths anxiety research, it is likely that the neural activity will bear a resemblance to other negative phobic states, affecting the same regions evoked during working memory activity (Ashcraft, 2002). Indeed, researchers have examined Event Related Potentials (ERPs) components and their relation to the processing of maths in high maths anxious individuals (Jones, Childers, & Jiang, 2012; Sheffield & Hunt, 2006; Suárez-Pellicioni, Núñez-Peña, & Colomé, 2013; Macarena Suárez-Pellicioni, Núñez-Peña, & Colomé, 2014). However, whilst ERP analyses typically include lower bands of activity (between .5-30Hz), EEG research has recently begun to include higher frequency bands, for example, the gamma band (30-100Hz). This band of activity has been shown to play a large role in key cognitive processes, such as working memory and attention (Jensen, Kaiser, & Lachaux, 2007; Keil et al., 2001; Müller, Keil, Gruber, & Elbert, 1999; Oya, Kawasaki, Howard, & Adolphs, 2002; Tallon-Baudry, Bertrand, Hénaff, Isnard, & Fischer, 2005; Taylor, Liberzon, & Koeppe, 2000), as well as corresponding to processing in the amygdala (Garcia-Garcia, Yordanova, Kolev, Domínguez-Borràs, & Escera, 2010; Luo, Holroyd, Jones, Hendler, & Blair, 2007; Maratos, Senior, Mogg, Bradley, & Rippon, 2012; Oathes et al., 2008). This makes it extremely relevant for the study of maths anxiety as it has been associated with the processing of negative emotions (Brunyé et al., 2013), hyperactivity in the amygdala (Young, Wu, & Menon, 2012) and attentional bias (Suárez-Pellicioni et al., 2014).

Research has shown that there are evolutionary advantages to attending to negative stimuli over neutral stimuli (see Davis & Whalen, 2001 for a review), which may explain the tendency of anxious individuals to exhibit a bias towards threat-related stimuli to a greater extent than non-anxious individuals (Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & van IJzendoorn, 2007). A meta-analysis of threat-related attentional bias found this to be consistent across anxious populations and concluded that this bias is not evident in non-anxious individuals (Bar-Haim et al., 2007). To further understand the relevance of threat and attentional bias in high maths anxious individuals, investigation into the gamma frequency band is necessary.

Gamma-band activity has been shown to mark higher cortical arousal, with high frequency oscillations elicited more in individuals with greater arousal ability, such as those with high levels of anxiety (Knyazev, Savostyanov, & Levin, 2005). For example, Knyazev, Savostyanov, & Levin (2004) investigated EEG power measures across a range of anxious individuals and whilst the primary objective was to investigate alpha oscillations as a correlate of trait anxiety, they also noted that the power of high frequency oscillations were consistently greater in high anxious individuals. This research suggests that high frequency bands, play a significant role in high anxious individuals and moreover, even when confronted with the possibility of performing well, high anxious individuals will remain vigilant, as if presented with a threat. This has also been identified within maths anxiety research, explaining that this vigilance and avoidance is likely due to the fear of pain caused by the anticipation of maths processing in high maths anxious individuals (Lyons & Beilock, 2012). Based on this research it would be of use to understand how the high frequency gamma band relates to maths processing in high maths anxious individuals.

Whilst there is a clear gap linking gamma-band activity to maths anxiety, there has been research associating general anxiety to gamma-band activity. For example, Oathes et al. (2008) presented worry inducing stimuli to participants diagnosed with general anxiety disorder (GAD) as well as a control group and found that EEG gamma band activity (35-70Hz) was exhibited in GAD participants in comparison to control groups, particularly at posterior electrodes. They further identified that following psychotherapy for treatment, GAD participants exhibited lower levels of gamma activity. In contrast, Maratos et al. (2012) identified a reduction of gamma-band activity when participants were exposed to threat related versus neutral facial expressions. However, they note this difference due to their methodological variance of the task; for example, threatening stimuli were task irrelevant whereas previous research uses threatening stimuli as the primary focus (e.g. Luo et al., 2009). Although this research provides evidence for the use of the EEG gamma band in monitoring anxiety and worry and further identifies it as an appropriate method for monitoring treatment, to date, no research has focused on gamma oscillations as a correlate of maths anxiety.

The previous research supports the association between gamma activity and the amygdala and suggests that increased gamma activity may play a role in regulating negative emotions associated with the perception of threat. Neurophysiological research also suggests that this brain region is responsible for processing fear, threat and negative emotions (Cisler & Koster, 2010; Davis, 1992; Davis & Whalen, 2001; LeDoux, 2003; Ohman, 2005; Oya et al., 2002) with some recent research focusing on maths anxiety (Young et al., 2012). It is clear that those with high maths anxiety appraise maths as negative and whilst it may be seen as neutral among those with low maths anxiety, high maths anxious individuals observe maths as a difficult task or an obstacle (Ashcraft & Kirk, 2001; Eysenck et al., 2007). However, the link between gamma-band activity and maths anxiety specifically, remains unexplored. It is proposed that the processing of maths in high maths anxious populations will be associated with increased gamma activity. This study seeks to explore this possibility within maths anxious populations. As a first step, the following study will aim to identify whether gamma activity differs across maths anxious populations in response to (perceived) threatening stimuli. It is hypothesised that there will be differences in gamma activity, between high and low maths anxious individuals when conducting addition and multiplication, due to this frequency band's involvement in threat processing, anxiety and attention. Based on *a priori* assumptions, it is thought that complex addition will be seen as more difficult due to the carry-over used (Ashcraft, 2002), resulting in higher levels of gamma-band activity for this operation.

Methods

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 (Keil et al., 2001; Müller, Gruber, & Keil, 2000; Oathes et al., 2008; Tallon-Baudry & Bertrand, 1999) therefore, the electrodes across these sites were used for analysis (T3/T7, C3, C4, T4/T8, T5/P7, P3, P4, T6/P8). Electrodes were allocated to groups based on their horizontal and vertical layout (see table 1).

[Table 1 near here]

Participant Selection

Two hundred and three participants were recruited from the University of Derby, and were asked to complete the MAS-UK (Hunt, Clark-Carter, & Sheffield, 2011) which consisted of 23 statements answered by a five point Likert-scale about how anxious participants would feel in certain maths-based situations. A total maths anxiety score was calculated by assigning a value, 1 to 5, for every item (1 being 'not at all' to 5 being 'very much anxious'), with the sum of these values providing the total maths anxiety score. High scores indicate high levels of maths anxiety and lower scores indicate low levels of maths anxiety. Experimental procedures were in accordance with BPS ethics and was approved by the University of Derby research ethics committee

Cluster Analysis

A cluster analysis was run on MAS-UK data to identify clusters of participants that possessed similar characteristics (Aldenderfer & Blashfield, 1984; Everitt, Landau, & Leese, 2001). This provided a statistical representation of groups rather than using more arbitrary methods, such as a median split or quartile cut-off points. A hierarchical cluster analysis indicated two clusters. The first cluster had 52.2% of cases (N=106) and contained those who scored low on the MAS-UK indicating a low maths anxiety cluster. The second had 47.8% of the total sample (N=97) and contained those who scored higher on the MAS-UK indicating a high maths anxiety cluster. To distinctly recruit those with the highest and lowest levels of maths anxiety, participants were systematically selected (low maths anxiety with a maximum score of 40 and high maths anxiety with a minimum score of 65) for the EEG phase of the study.

Thirty participants were invited back for the EEG research. Participants consisted of 15 high maths anxious and 15 low maths anxious individuals, 14 males and 16 females (Mean age = 25.17 SD = 8.60) and were all right handed. Participants reported normal or corrected to normal vision and had not been diagnosed with dyslexia.

Materials and Equipment

In order to compare neurophysiological and behavioural data, stimuli similar to those used in previous maths anxiety research were presented to participants (e.g. Ashcraft & Kirk, 2001). This included both complex addition and multiplication problems with 1 correct and 3 incorrect answers. This was chosen due to the quantity of maths anxiety research concerning addition and multiplication over subtraction, division and algebra (Ashcraft & Kirk, 2001; Ashcraft & Krause, 2007; Faust et al., 1996).

One-hundred and twenty maths problems, 60 complex, two-digit addition, e.g. 19+54= (answers displayed as: 73 67 79 68) and 60 complex 2x1 digit multiplication, e.g. 19x5= (answers displayed as: 86 103 95 91), were presented to participants. Complex addition was defined by using double digit addition and the need to implement a carry operation (Faust et al., 1996; Wu, Amin, Barth, Malcarne, & Menon, 2012) and complex multiplication was defined by using a one digit by two digit equation (Tronsky, 2005). Multiplication problems with 0 and 1 as operands were not used because they act as simple rule-based problems (LeFevre et al., 1996). Each stimulus was presented for 8000ms with a response window of 8000ms followed by a fixation with a duration of 500ms. Inter trial intervals were pseudo randomised between 500ms and 2500ms to avoid habituation.

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 (16.065cd/m^2) room whilst white stimuli were presented on a black background and were sat in a comfortable chair at eye height to the centre of the screen. They were asked to sit comfortably in the chair and relax as much as possible. Participants were asked to note the correct answer to the equations by pressing the corresponding button on a button box. Sampling rate was 1000Hz and impedances were kept below 15 kiloohms (kΩ) but were typically less than 5kΩ.

To analyse gamma-band activity, data were first corrected for ocular artefacts. These were reduced from the data using a regression procedure to average out artefacts. A positive trigger threshold for ocular artefacts was set to 10% from the maximum artefact voltage with the minimum number of sweeps (estimate of a blink or VEOG artefact) required to construct an averaged VEOG artefact being 30. The duration of the average artefacts was 400ms. To rule out movement artefacts in the gamma band, the earliest response time across the study was taken. This was found to be at 2400ms so data were epoched to 2400ms and splined to 2048 points to fit with the frequency analysis parameters. Trials were also manually inspected if any other artefacts were found. 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, then averaged for addition and multiplication 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), decision making (~40Hz) and visual processing (~60Hz; Castelhano, Duarte, Wibral, Rodriguez, & Castelo-Branco, 2014).

Results

Behavioural Results

Two 2 (High/Low maths anxiety) × 2 (Stimulus type) mixed factorial ANOVAs were conducted to identify any interactions between accuracy and reaction time for responses. There was no significant main effect of maths anxiety on accuracy, $F(1,28) = .54$, $p=.47$, $\eta^2 = .02$. However, there was a significant main effect of stimulus type, $F(1,28) = 10.31$, $p=.003$, $\eta^2 = .27$, such that accuracy was significantly higher for multiplication, Mean = 31.47, SD = 15.13, than for addition, Mean = 27.20, SD = 17.60. There was no significant interaction between maths anxiety group and stimulus type, $F(1,28) = .43$, $p=.52$, $\eta^2 = .01$. There was a significant main effect of stimulus type, $F(1,28) = 8.94$, $p=.006$, $\eta^2 = .23$, such that reaction time was quicker overall for addition, Mean = 4740ms, SD = 969ms, than multiplication, Mean = 5016ms, SD = 935ms. There was also a significant main effect of maths anxiety, $F(1,28) = 11.59$, $p=.001$, $\eta^2 = .03$, such that those with low maths anxiety had a quicker reaction time than those with high maths anxiety. There was no significant interaction between maths anxiety and stimulus type, $F(1,28) = .003$, $p=.95$, $\eta^2 = .04$.

Gamma-Band Activity Results

A 2 (Maths anxiety) × 2 (Stimulus type) × 2 (Horizontal electrodes) × 4 (Vertical electrodes) mixed measures ANOVA was conducted to identify any interactions and main effects. For Gamma analyses, the Greenhouse-Geisser correction was 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 maths anxiety and horizontal electrodes, $F(1,28) = 5.09$, $p=.03$, $\eta^2=.05$, such that higher gamma activity was experienced at anterior regions but was larger for high maths anxious individuals (see Table 2). There were no other two-way interactions. There was a significant main effect of horizontal electrodes, $F(1,29) = 6.34$ $p=.01$, $\eta^2=.08$, such that there were higher levels of gamma activity in temporal and central regions, Mean = .047, SD = .082, than parietal, Mean = .018, SD = .022.

Finally, there was a significant main effect of maths anxiety group, $F(1,28) = 4.77$, $p=.04$, $\eta^2=.15$, such that those with high maths anxiety showed higher gamma activity, Mean = .052, SD = .068, than those with low maths anxiety, Mean = .013, SD = .013. This shows high maths anxious individuals experienced higher levels of gamma activity than low maths anxious individuals throughout the study. There were no other significant main effects.

[Table 2 near here]

Study 1 Discussion

This research aimed to observe differences in gamma activity between high and low maths anxious groups, associated with the typical decrease in accuracy and increase in reaction time experienced by high maths anxious individuals. It was predicted that there would be differences in gamma activity between high and low maths anxious individuals due to its involvement in threat and anxiety processing, something that has not previously been investigated within this anxious population.

Behavioural Measures

There was no significant difference in maths anxiety groups for accuracy; however, the significant main effect of stimulus type shows there were more correct answers given for multiplication than addition. This could be due to an artefact whereby participants may have developed a technique to respond to a multiple-choice task more quickly. Multiplication complexity tends to be increased in research when a larger amount of digits are used (Zago et al., 2001) for example, 35×15= would be more difficult than 18×9=. Participants may have applied a technique multiplying only the last digits to choose the correct answer more easily. Addition is made more difficult by increasing digits as well as ensuring that the correct answer requires a carry-over (Geary, Hoard, Byrd-Craven, & Catherine DeSoto, 2004) for example, 25+37= would be considered more difficult than 13+24=, which places a larger demand on attentional resources as calculating the last digit becomes more challenging. In support of previous research (Ashcraft, 2002) the higher working memory demand of a carry-over explains why addition was seen as more complex and higher accuracy scores were present for multiplication.

In contrast, reaction time was shown to be quicker for addition overall. If addition was seen to be more difficult, a slower reaction time would have been expected. Previous research has shown that when faced with a difficult maths problems individuals will often guess to avoid threat or anxiety (Ashcraft, 2002; Ashcraft & Faust, 1994) which may explain the quicker reaction time and poorer accuracy for addition. Overall, low maths anxious individuals had quicker reaction time than high maths anxious individuals. This result concurs with the many previous behavioural studies showing that high maths anxious individuals struggle more with math based tasks and will, on average, take longer to problem solve in these situations (Ashcraft & Kirk, 2001).

Electrophysiological measures

The significant main effect of maths anxiety showed greater gamma-band activity in individuals with high maths anxiety. Research suggests that those with high maths anxiety experience threat detection towards maths anticipation (Lyons & Beilock, 2012) and therefore, would have higher gamma-band activity. The significant interaction between horizontal electrodes and maths anxiety also identified increased gamma-band activity for high maths anxious individuals, at anterior temporal sites. This higher gamma-band activity in temporal regions has been previously shown when individuals are presented with threat-related faces (Luo et al., 2007). Research also verifies this interaction noting higher levels of gamma-band activity at temporal than at parietal sites during worry (Oathes et al., 2008), supported by the close link between temporal lobes and the amygdala (Swanson & Petrovich, 1998).

The results of the current study, consistent with previous research, supports that the perception of maths processing induces a threat response, where those with high maths anxiety experience significantly higher gamma-band activity due to a perceived threat of maths stimuli. Higher gamma-band activity was shown regardless of perceived difficulty of the task in high maths anxious individuals, suggesting that the difficulty between the mathematical operations might not have been great enough to exhibit gamma-band differences. However, as this was an initial study, only numerical tasks were implemented indicating that high maths anxious individuals may perceive other non-numerical stimuli as threatening and could be just anxious in evaluation situations. As evaluation anxiety is a contributing factor to maths anxiety (Bessant, 1995; Hunt et al., 2011; Resnick, Viehe, & Segal, 1982), study 2 includes both numerical and non-numerical stimuli to identify whether this is also shown for non-numerical stimuli.

Study 2:

Introduction:

Study one suggested that high maths anxious individuals experience higher levels of gamma activity in response to threatening stimuli; however, the stimuli used were all maths-based and lacked a valid non-numerical comparison. The aim of study two is to replicate the previous design but compare using control stimuli as well as maths-based tasks, achieved by observing gamma activity differences between word-based and maths-based tasks.

In this study, a total of four stimuli sets are used; compound words, complex addition, simple addition and compound numbers. Compound words are used as a non-numerical control condition. The majority of research involving visual word tasks in EEG formats typically consist of reading words or sentences (for example, Barber, Otten, Kousta, & Vigliocco, 2013; Nie et al., 2014; Sereno & Rayner, 2003) or involve an emotional stroop task (Thomas, Johnstone, & Gonsalvez, 2007); however, these are either unchallenging or provide unnecessary semantic context. With this in mind, this condition is created to provide a similar challenge that would be expected from a maths sum: using compound words provides a problem-solving condition in a non-numerical format that has been used in previous neurophysiological research (Chee, Tan, & Thiel, 1999; Vergara-Martínez, Duñabeitia, Laka, & Carreiras, 2009). In a similar procedure to the previous study, a question will be visually presented (THUNDER+STORM= or STORM+THUNDER=) and four answers will follow, one being correct true word (THUNDERSTORM) and three incorrect (CLOUDTHUNDER, STORMTHUNDER, THUNDERCLOUD). The researchers acknowledge that there is unlikely to be an adequate word task comparison to maths tasks therefore, compound numbers are used to provide the closest equivalent, usable within an EEG paradigm.

The previous study had used complex addition as one of the conditions, so will also use as a condition in this study to compare results. As compound words are considered a simpler task and therefore, not equal to complex addition, simple addition (e.g. 4+5=) is also used as a condition. Finally, to ensure the complexity of the compound words condition was matched within a numerical task, compound numbers is included as the last condition. Like compound words, it contains a (maths-based) question (90+3= or 3+90=) with four answers, one correct (93) and three incorrect (89, 93, 98).

Previous research has noted that emotionally negative words are associated with sustained amygdala activity (Maloney & Beilock, 2012) therefore, to ensure that semantic responses to certain words are minimised, stimuli with emotional context will not be used in this sample. Those who are diagnosed with dyslexia will not be included in the EEG study, due to potential anxiety effects experienced during word tasks presentation.

It is predicted that there will be an increase in accuracy and decreased reaction time for simple addition, compound numbers and compound words, when compared to complex addition. However, it should be noted that there is a possibility of all stimuli types being disrupted by the anticipation of maths tasks (Lyons & Beilock, 2012) in high maths anxious individuals. This may contribute to a heightened level of gamma activity across all conditions, including compound words. It is hypothesised that gamma power will be lower for word tasks as these stimuli should be perceived as less threatening to those with high maths anxiety.

Methods:

Participants:

One hundred and eighty seven participants were recruited from the University of Derby and asked to complete the MAS-UK (Hunt et al., 2011) and were told that they may be selected for the second part of the study which involved EEG.

Cluster analysis:

Nine participants were removed due to missing data. A hierarchical cluster analysis indicated two clusters. The first cluster had 42.7% of cases (N=76) and contained those who scored low on the MAS-UK indicating a low maths 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 maths anxiety cluster. To distinctly recruit those with the highest and lowest levels of maths anxiety, participants were systematically selected (low maths anxiety with a maximum score of 40 and high maths anxiety with a minimum score of 65) for the EEG phase of the study.

Thirty participants were invited to participate in the EEG phase of the research. Individuals consisted of 15 high and 15 low maths anxious, 13 males and 17 females (Mean age = 27.73, SD = 7.60) and were all right handed. Participants reported normal or corrected to normal vision.

Materials:

Two hundred and forty maths and word tasks were presented to participants, including 60 complex two-digit addition (e.g. 19+54=), 60 simple 1x1 digit addition (e.g. 7+3=), 60 compound numbers (e.g. 90+3=) and 60 compound words. Using the MRC Psycholinguistic Database (n.d.) compound words were selected and the amount of letters (6-14), phonemes (4-13), syllables (2-4) and Thorndike-Lorge written frequency (0-3679) were recorded and emotionally triggering words removed.

Results:

Behavioural Results

Two 2 (High/Low maths anxiety) x 2 (Stimulus type) mixed factorial ANOVAs were run to identify any interactions between accuracy and reaction time for responses to stimuli.

[Table 3 near here]

Mauchly's test of sphericity was found to be significant therefore, the Greenhouse-Geisser was applied to reduce type I error rate. There was a significant interaction between maths anxiety group and stimulus type $F(3,35.12) = 6.18$, $p=.013$, $\eta^2 = .07$, such that accuracy was higher in low maths anxious individuals, particularly during complex addition (see table 3). There was also a significant main effect of stimulus type $F(1.25,35.12) = 59.90$, $p<.001$, $\eta^2 = .63$, such that lower accuracy was identified during complex addition. However, there was no significant main effect of MA $F(1,28) = 3.49$, $p=.07$, $\eta^2 = .11$, showing that whilst those with high maths anxiety performed worse than those with low maths anxiety overall, the difference was minimal.

There was a significant interaction between maths anxiety and condition $F(1.837,51.448) = .15.450$, $p<.001$, $\eta^2 = .05$, such that high maths anxious individuals took significantly longer to respond to stimuli particularly during complex addition (see table 3). There was also a significant main effect of condition $F(1.837,51.448) = 278.210$, $p<.001$, $\eta^2 = .86$ such that reaction time was significantly longer for complex addition than during other conditions. Finally, there was a significant main effect of maths anxiety $F(1,28) = 13.956$, $p=.001$, $\eta^2 = .33$, such that those with low maths anxiety had a quicker reaction time than those with high maths anxiety.

Gamma-band Activity

EEG data processing and analysis procedure was replicated from the previous study with the exception of additional conditions. A 2 (Maths anxiety group) × 4 (Stimulus type) × 2 (Horizontal electrodes) × 4 (Vertical electrodes) mixed measures ANOVA was conducted to identify any interactions and main effects.

There were no significant four, three or two-way interactions. There was a significant main effect of horizontal electrodes $F(1,29) = 12.32$, $p = .001$, $\eta^2 = .05$, such that there were higher levels of gamma activity in temporal and central regions, Mean = .23, SD = .44 than parietal, Mean = .09, SD = .25.

There was a significant main effect of maths anxiety groups $F(1,28) = 4.92$, $p = .03$, $\eta^2 = .15$, such that those with high maths anxiety showed higher gamma activity, Mean = .05, SD = .07, than those with low maths anxiety, Mean = .01, SD = .01. This shows high maths anxious individuals elicited higher levels of gamma activity (.24) than low maths anxious individuals

(.08) throughout the study, suggesting that those with high maths anxiety experienced higher anxiety and threat levels overall.

It was identified that there was no significant interaction between stimulus type and maths anxiety; however, this may have not shown due to the larger amount of maths-based conditions. Therefore, it was of value to ascertain whether maths anxiety groups were affected by each individual condition. Post-hoc analyses were conducted to identify maths anxiety differences at each individual condition. Table 6.17 outlines the individual 2 (Maths anxiety group) x 2 (Horizontal electrodes) x 4 (Vertical electrodes) mixed factorial ANOVA results for each condition.

[Table 4 near here]

The analysis identified that all maths-based condition produced significant gamma differences between high and low maths anxious individuals; however, compound words showed a no significant difference.

Study 2 Discussion

Behavioural measures

Accuracy scores showed complex addition to be the poorest which is expected based on its complexity over other tasks. This was also seen in the interaction between maths anxiety group and condition, whereby high maths anxious individuals had particularly poorer accuracy in this condition than in others, compared to low maths anxious individuals. This was previously identified as the condition that high maths anxious individuals would struggle with most. This was also reflected in the reaction time analysis whereby; reaction time was higher for complex addition overall and was higher in high maths anxious individuals than low maths anxious individuals. With this being the most complex condition, this can be expected. Overall it was found that those with high maths anxiety took significantly longer than those with low maths anxiety supporting previous behavioural research (Ashcraft & Kirk, 2001; Faust et al., 1996).

Electrophysiological Measures

One of the main findings of the gamma analysis was the significant main effect of maths anxiety groups. Overall, those with high maths anxiety experienced significantly higher levels of gamma activity than low maths anxious individuals. This is to be expected during the presentation of maths stimuli, based on the previous studies results. Originally, it was hypothesised that the compound words condition would produce lower levels of gamma activity for high maths anxious individuals or at least more equal levels to those with low maths anxiety. However, the lack of an interaction between stimulus type and maths anxiety group indicated that this was not the case. This was explored further to assess how and if both maths anxiety groups were affected by each condition.

The post-hoc analyses identified that those with high maths anxiety had significantly higher levels of gamma activity across all maths based conditions (complex addition, simple addition and compound numbers) but a non-significant interaction was found for compound words. Complex maths and compound numbers produced similar levels of gamma activity in high maths anxious participants; however, slightly decreased levels were found in high maths anxious participants for simple addition, similar to the compound words condition. It could be argued that high maths anxious individuals display higher levels of gamma activity in response to an increased level of perceived threat. For example, 90+3= (compound numbers) would typically be considered simple over a sum that requires more manipulation of number such as

9+7= (simple addition). Yet, at first, the perception of larger sums (containing at least one 2-digit addend) can be seen to produce higher levels of gamma activity. This suggests that it may be the initial observation of maths stimuli that generates this increase in gamma activity and therefore, heightened anxiety and threat perception.

Nevertheless, high maths anxious individuals still experienced higher levels of gamma activity overall, albeit with a non-significant difference to low maths anxious individuals during the compound words condition. Observing the results, it could be argued that it is the initial perception, or even anticipation, of maths stimuli that generates larger levels of gamma activity in high maths anxious individuals. It may be of interest to particularly focus on early gamma band activity pre and post-stimulus onset. This could identify support for previous anticipation research (Lyons & Beilock, 2011) whereby high maths anxious individuals may experience higher levels of gamma activity in response to more anxiety inducing or (perceived) threatening stimuli. This could account for the delay in accuracy and reaction time experienced in high maths anxious individuals as they try to combat anxious and threatening thoughts as well as the primary task.

Overall Discussion

Both studies have shown that those with high maths anxiety experience greater gamma activity when exposed to numerical stimuli. This is theorised to occur due to the anticipation of the (threatening) maths stimuli and could be argued that until recognition of the stimulus occurs, high maths anxious individuals are in a perpetual state of anxiety unless the stimulus is perceived as less threatening, providing a slight relief. It can be seen from accuracy and reaction time data that the levels of gamma activity, for each condition, are not reflected in the score or time taken which again points more towards an anticipatory effect. It may be that the anticipation of the task explains a portion of the poorer accuracy and delay but does not explain all of the behavioural response, perhaps because participants are constantly fearful of the appearance of maths stimuli, so become more vigilant.

Through the analysis it could be argued that there is a need for improvement, in the method. Whilst the control condition was useful it cannot be considered a legitimate equivalent to a maths-based problem. Nevertheless, it is extremely difficult to achieve this without using a form of number in an EEG paradigm. Furthermore, the use of three maths-based and one word-based condition may have influenced gamma band activity levels. If this is theorised to represent anticipatory effects, then it is possible that this could have increased levels by 25% in high maths anxious participants than if there was an equal amount of word and maths conditions. However, to bridge results from the previous study and introduce an equivalent word condition, the use of all conditions was necessary.

Nevertheless, the results still have large implications for maths anxiety research. It could be argued that those with high maths anxiety have a deficit in working memory when maths processing is involved (Maloney, Ansari, & Fugelsang, 2011), which is why poorer accuracy and higher vigilance is identified. Alternatively, it may just be that higher levels of gamma activity begin the process which inevitably reduces accuracy and increases reaction time through consuming working memory resources for anxious thoughts (Ashcraft & Moore, 2009). Considering maths anxiety is hypothesised to begin in early years and that number anxiety is theorised to begin the journey to maths anxiety (Kazelskis, 1998), it would be of use to identify whether the threatening response, observed here in high maths anxious individuals, is visible through the observation of number. This would hopefully support or refute the working memory deficit suggested by Maloney et al. (2011), as little working memory resources are needed when purely observing number, as well as shedding light on the effect of observing number within a high maths anxious population.

In summary, this study has shown interesting gamma band activity results, which subscribe to previous theories concerning feelings of anticipation and threat perception. Both studies have shown that gamma-band activity analyses have provided a strong foundation for identifying the role of this band in numerical processing for those with high maths anxiety. Identifying whether this theory applies to numbers within maths anxious populations could provide an extensive contribution to the current body of knowledge concerning the neurophysiological correlates of maths anxiety.

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Table 1. Layout of Horizontal and vertical electrodes for gamma analysis:

		Vertical			
		Left	Midline Left	Midline Right	Right
Horizontal	Anterior	T7	C3	C4	T8
	Posterior	P7	P3	P4	P8

Table 2. Mean power (μV²) and standard deviation depicting the interaction between horizontal electrodes and maths anxiety group.

	Maths Anxiety	
Horizontal Electrodes	**Low**	**High**
Anterior	.02 (.03)	.08 (.13)
Posterior	.01 (.01)	.03 (.03)

Table 3: Mean (SD) accuracy and reaction time scores between high and low MA during conditions.

		Maths Anxiety Group		
	Stimulus Type	**High**	**Low**	**Total**
Accuracy	Complex Addition	45.73 (7.67)	51.93 (6.03)	48.83 (7.47)
	Simple Addition	54.00 (2.67)	55.33 (1.76)	54.67 (2.32)
	Compound Numbers	58.53 (3.39)	59.40 (2.20)	58.97 (2.37)
	Compound Words	54.67 (3.83)	55.13 (2.36)	54.90 (3.13)
Reaction Time (ms)	Complex Addition	4947.80 (514.62)	3711.18 (567.28)	4329.49 (823.83)
	Simple Addition	2513.61 (622.30)	1993.65 (414.58)	2253.63 (582.97)
	Compound Numbers	2345.88 (556.00)	2047.60 (277.11)	2196.74 (457.52)
	Compound Words	3037.31 (589.76)	2835.50 (354.82)	2936.41 (489.11)

Table 4: Post-hoc gamma activity ANOVA F values, degrees of freedom, significance levels and effect size for between subject effects.

Stimulus Type	**ANOVA**			
	F	**df**	**p**	**η^2**
Complex Addition	4.49	1,28	.04	.14
Simple Addition	5.64	1,28	.03	.17
Compound Numbers	4.33	1,28	.047	.13
Compound Words	1.26	1,28	.27	.04