Emotional Processing of Math-related Words in People with Math Anxiety

Rocío Linares[a], Santiago Pelegrina[a], Rafael Delgado-Rodríguez[a1]

[a] Department of Psychology (University of Jaén), Campus Las Lagunillas, 23009, Jaén, España. E-mail addresses: rlinares@ujaen.es, spelegri@ujaen.es, rfdelgad@ujaen.es.

[1] Corresponding author. Department of Psychology (University of Jaén), Campus Las Lagunillas, 23009, Jaén, España. E-mail address: rfdelgad@ujaen.es.

ORCID

Rocío Linares: https://orcid.org/0000-0002-9031-2176

Santiago Pelegrina: https://orcid.org/0000-0002-4441-8965

Rafael Delgado-Rodríguez: https://orcid.org/0000-0003-4971-6643

Abstract

Background: Research exploring emotional responses to math-related words in individuals with math anxiety (MA) is scarce. Here, we examined MA participants' subjective emotional processing of math-related cues within Lang's bioinformational model of emotion to further understand the role of those cues in MA.

Methods: In total, 41 high-MA and 32 low-MA undergraduates rated math-related words, along with neutral, pleasant, and unpleasant words, from the Affective Norms for English Words. The Self-Assessment Manikin was used to calculate valence, arousal, and dominance scores for each word.

Results: The low-MA group rated math-related words as neutral on the three emotional scales, however, the high-MA group rated them lower and higher for valence and dominance than neutral and unpleasant words, respectively. Moreover, math-related words were rated as more and less activating than neutral and unpleasant words, respectively. The two groups significantly differed in scores on the three scales only for the math-related words.

Conclusions: These results provide evidence that individuals with high MA show altered emotional processing of math-related words, experiencing them as moderately aversive and moderately activating. The findings emphasize that the altered emotional processing of words associated with math should be considered a symptom of MA.

Keywords: math anxiety, emotional words, math words, emotional processing, Self-Assessment Manikin

Introduction

Math-related stimuli may evoke negative emotional responses in people who suffer from math anxiety (MA). MA is defined as a feeling of tension, apprehension, and anxiety that interferes with the manipulation of numbers (Ashcraft & Faust, 1994; Richardson & Suinn, 1972) and affects various domains, such as academic (e.g., mathematical) performance and ordinary life situations (e.g., handling money or evaluating sales prices) (Richardson & Suinn, 1972). This decrease in performance in cognitive tasks is thought to be mediated by the negative effect of anxiety on executive functioning. Attentional control theory (Eysenck et al., 2007, 2011), a theoretical approach to explaining the negative impact of anxiety on cognition, proposes that anxiety negatively affects attentional control. Anxiety is associated with a greater influence of the stimulus-driven attention system, which would lead anxious individuals to pay more attention to threatening information and to be more easily distracted. The debilitating effect of anxiety on executive functioning may be particularly evident in complex tasks such as those often encountered in academic situations.

Although MA is not recognized as a clinical condition, features of various types of anxiety disorders are also present in MA. Specifically, math-related cues attentionally and emotionally affect individuals with high MA differently compared with less anxious students (e.g., Pizzie & Kraemer, 2017; Qu et al., 2020; Rubinsten et al., 2015). MA has been specifically studied in relation to numeric stimuli, such as numbers and quantities (Ashcraft & Kirk, 2001; Beilock & Maloney, 2015; Kucian et al., 2018), however, mathematics also involves words that are frequently used in both academic (e.g., "Solve the following *equation*") and ordinary life (e.g., "Let's *divide* the bill among all diners") situations. The present study examines how individuals emotionally assess math-related words.

Research on math-related words has mainly focused on assessing attention (e.g., by using an emotional Stroop or dot probe task). In this field, authors have concluded that, similar to anxious individuals displaying an attentional bias towards threatening information (which is considered a cognitive marker of anxiety; Beck et al., 1985), the attention of individuals with MA is selectively captured by math-related words (Rubinsten et al., 2015; Suárez-Pellicioni et al., 2015). These results highlight the threatening nature of math-related words for individuals with MA, in line with studies examining physiological arousal (an indicator of state anxiety; Spielberger 1972; Strohmaier et al., 2020) in response to math cues. Specifically, Eidlin-Levy and Rubinsten, (2021) explored differences in the skin conductance response (a physiological measure of emotional arousal; Dawson et al., 2007) between high- and low-MA participants performing a dot probe task. Their results showed that, whereas MA levels were related to increased physiological arousal during the performance of complex numeric tasks, mixed results were found with math-related words; they concluded that MA has physiological manifestations, especially during the processing of complex numerical information.

Although the above-mentioned research shows that math cues can induce attentional biases and specific physiological responses, less is known about the subjective emotional processing of these words in individuals with MA. Daches-Cohen et al. (2021) asked a sample of adults (without a diagnosis of MA) to rate the degree to which a series of math-related words were related to the field of mathematics (i.e., math loading), and how threatening they perceived them to be. They found a positive association between math loading and threat assessments. Thus, certain math-related words can appear threatening even in normal populations. Suárez-Pellicioni et al. (2015) provided data supporting the threatening nature of math-related words specifically in MA individuals; a high MA group reported higher levels of anxiety in response to math-related than neutral words (vs. a low-MA group, in which responses did not differ between word categories). Therefore, their study provides initial evidence that individuals differ in their emotional evaluations of these stimuli depending on the level of MA. We aim to gather additional evidence and obtain a more complete understanding of the emotional processing of math-related words in individuals with MA. More specifically, our goal is to study the emotional reactions of individuals with and without MA to words related and unrelated to math, in order to compare these reactions across various emotional dimensions that have been extensively studied and are well understood in terms of their psychophysiological and behavioral correlates (e.g., Bradley et al., 2001; Lang & McTeague., 2009). Following this approach, response patterns of individuals with MA could be interpreted within a sound theoretical framework for understanding emotions.

An influential theoretical framework explaining the emotional processing of emotional stimuli is Lang’s bioinformational model of emotion (Bradley & Lang, 2007; Lang, 1995). This approach could be useful to deeply examine the emotional processing of math-related words in individuals with MA. According to Lang, emotion is a predisposing factor for action that is organized around two motivational systems: appetitive and defensive (Lang, 1995; Lang et al., 1997). These systems are activated by contexts that promote survival and involve threat, respectively. From this perspective, three basic parameters of emotion are proposed to organize emotional stimuli: valence, arousal, and dominance. Valence (unpleasant vs. pleasant) indicates which motivational system is activated: unpleasant cues activate the defensive system (which involves a basic repertoire of responses, including withdrawal, escape, and attack) and pleasant cues activate the appetitive system (involving ingestion, copulation, and caregiving behaviors). Arousal (calm vs. activated) reflects the degree of motivational activation (i.e., the level of energy required to carry out a behavior). Valence and arousal exert the largest influence on the hierarchical organization of emotions. When stimuli (words, pictures, or sounds; Bradley & Lang, 2000) are represented in a Cartesian bidimensional space defined by valence (vertical axis) and arousal (horizontal axis), they show a global boomerang-shaped distribution that is consistent with the two motivational systems: an upper arm that extends from a calm, intermediate-valence (i.e., neutral) space toward a high arousal-valence (appetitive system) space, and a lower arm that extends from a neutral space toward a high arousal-low valence space (defensive system) (Bradley et al., 2001; Lang et al., 1997). The correlation between valence and arousal ratings, which is calculated separately for pleasant and unpleasant stimuli, is represented by regression lines that can be considered as “motivational vectors” indicating the degree to which the brain’s motivational systems are engaged by stimuli (Bradley et al., 2001). The third dimension of emotion (dominance) is related to the sense of control over emotions (ranging from feeling dominated vs. dominant) and reflects the experience of control over a given situation or stimulus (Bradley & Lang, 1994).

Human fear and anxiety disorders have been widely studied within this theoretical framework using the affective image visualization paradigm (Bradley et al., 1993), in which participants passively view cues related to their specific fear while psychophysiological responses (e.g., startle blink responses and heart rate) and subjective ratings (i.e., valence, arousal, and dominance) are recorded. In this model, fear reactions to threat are thought to be mediated by the defense system (Konorski, 1967; Lang & McTeague, 2009); in particular, participants with fear or anxiety disorders rate cues depicting their specific fear as unpleasant (e.g., spider-phobic individuals provided ratings for spider cues reflecting lower valence and higher arousal than neutral cues; Kindt & Brosschot, 1997, 1999), highlighting activation of the defensive system. When comparing groups (i.e., controls vs. groups with fear or anxiety disorders), individuals provided ratings for cues depicting their specific fear reflecting lower valence and higher arousal than the control group (e.g., for spider- [Michalowski et al., 2015], snake- [Miltner et al., 2005] and social phobia-related cues [McTeague et al., 2009]). Finally, although dominance has been less studied using Lang’s theoretical model and explains less of the variance in affective judgments than valence and arousal (Bradley & Lang, 2007), it seems important to anxiety given that anxious people (who tend to underestimate their capacity to manage threatening events; Chorpita, 2001) perceive that they have low control over anxiety-related events. Consequently, some authors have stressed that perceived control may be a defining characteristic of anxiety psychopathology (Rapee et al., 1996; Russell & Mehrabian, 1974). Thus, similar to other types of anxiety, studying the emotional processing of math-related words using this robust theoretical model and a strict methodology consistent with that model could improve our understanding of the "emotional" role of those cues in individuals with symptoms of MA. This, in turn, would allow parallels to be drawn between math anxiety and other types of anxiety.

The Present Study

The current study aims to examine the emotional processing of math-related cues in people with MA using Lang's theoretical model. To this end, in this study, participants with low and high MA (classified using the Abbreviated Math Anxiety Rating Scale; Alexander & Martray, 1989) passively viewed math-related words along with pleasant, neutral, and unpleasant words from the Spanish version of the Affective Norms for English Words (ANEW; Bradley & Lang, 1999; Redondo et al., 2007). Participants assessed each word in terms of valence, arousal, and dominance using the Self-Assessment Manikin (SAM; Bradley & Lang, 1994), a pictographic scale that has been extensively used to assess emotional reactivity to cues (e.g., (Bradley, 1994; Delgado-Rodríguez et al., 2019; Gantiva et al., 2015; Miccoli et al., 2018; Morris et al., 1992). This design allowed us to perform two types of relevant comparisons. Math-related words were compared with other stimuli with normative valence, arousal, and dominance scores, which allowed them to be situated within two-dimensional space along with numerous other words. In addition, the responses given to each type of stimulus by individuals differing in terms of MA severity could be contrasted. Based on previous literature on fear and anxiety disorders, we expected that individuals with high MA would perceive math-related words as unpleasant; i.e., they will be placed within the lower arm (defensive system). However, low-MA individuals should experience math-related words as neutral. We expected to find group differences only in the math-related word category.

Method

Participants

A total of 293 students (239 females, 53 men, and 1 nonbinary) were screened for MA and general anxiety during regular classes. Of those 293 participants, 30 who failed to respond correctly to the control questions were excluded from the analysis. The nonbinary participant was also excluded since it was not possible to apply a matching procedure based on gender (because there was only one subject in that gender category). Two groups of participants in the lower and upper quartiles of MA scores were identified. Individuals from the upper quartile mainly consisted of women (60 women and 5 men), primarily because a larger number of women were screened and because, in line with the literature, there are higher prevalence rates of MA symptoms among females than males (e.g., Baloğlu & Koçak, 2006; Else-Quest et al., 2010; Ma & Cartwright, 2003). Given that MA is moderately related to general anxiety and gender (Devine et al., 2012; Hembree, 1990), the two groups were matched in terms of general anxiety and gender to reduce the bias arising from these confounding variables. We performed a propensity score matching procedure using the MatchIt R package (Ho et al., 2011) in R (version 1.3.1093; R Development Core Team, Vienna, Austria) with the exact matching option applied. Exact matching involves crossing covariates (i.e., gender and general anxiety) to create subclasses defined based on their combination. Any subclass that does not include participants from the low- and high-MA groups is eliminated, leaving only subclasses that contain participants from both groups with the same values for the covariates. Of the 131 participants initially classified into the lower and upper quartiles, 78 (34 in the lower quartile and 44 in the upper quartile) were invited to take part in the next phase of the study. As gender was included as a matching variable, the small number of men in the upper quartile led to the selection of a small number of men in the lower quartile. Ultimately, 73 participants completed the task and were included in the analyses; they all had normal or corrected-to-normal vision. Descriptive statistics for the MA and general anxiety measures for each group are shown in Table 1. The two groups differed in the Abbreviated Math Anxiety Rating Scale, $t(71) = 24.68$, $p < .001$, $d = 5.69$, but not State-Trait Anxiety Inventory-Trait version, scores, $t(71) = .95$, $p = .346$, $d = 0.22$.

Table 1

Means (standard deviations) of the STAI and SMARS scores as a function of MA group

Group	*n*	STAI	SMARS
High math anxiety	41 (3 males)	25.4 (8.33)	84.1 (5.31)
Low math anxiety	32 (2 males)	23.5 (8.89)	46.7 (7.6)

Note. STAI, State-Trait Anxiety Inventory-Trait version; SMARS, Abbreviated Math Anxiety Rating Scale.

Stimuli

The participants viewed 60 words belonging to four different categories: pleasant (n = 15), neutral (n = 15), and unpleasant (n = 15) and math-related (n = 15). Pleasant, neutral, and unpleasant words were selected for the Spanish adaptation of the ANEW (Bradley & Lang, 1999; adapted from Redondo et al., 2007). The three ANEW categories selected differed significantly in valence (all *p*s < .001): pleasant > neutral > unpleasant (see Table 2). In the arousal dimension, the emotional word categories (i.e., pleasant and unpleasant), which did not differ from each other, differed from neutral words (both *p*s < .001).

We used the following procedure to select math-related words (n = 15): first, we created an initial pool of math-related words (n = 68) using those included in previous studies (Daches-Cohen et al., 2021; Eidlin-Levy & Rubinsten, 2021; Rubinsten et al., 2015; Suárez-Pellicioni et al., 2015). After discarding polysemic (e.g., root; see Eidlin-Levy & Rubinsten, 2021), uncommon math-related words in the Spanish culture (e.g., gematria), and those for which information about frequency, familiarity, imageability, and/or concreteness was lacking in a repository of the properties of Spanish words (Espal; Duchon et al., 2013), 15 math-related words remained. Words from each category, as well as their ratings in emotional scales (i.e., valence, arousal, and dominance) and characteristics, can be found in the supplementary material. As Table 2 shows, word categories did not differ in terms of the number of letters, number of syllables, frequency, familiarity, imageability, or concreteness.

Table 2

Mean (standard error of the mean) scores for characteristics of words in different categories

	Pleasant (n = 15)	Neutral (n = 15)	Unpleasant (n = 15)	Math (n = 15)	ANOVA
N of letters[1]	8.00 (1.85)	6.73 (1.79)	8.00 (1.92)	8.00 (2.03)	$F(3,59)= 1.66$, $p = .186$, $\eta_p^2= .08$
N of syllables[1]	3.53 (0.83)	2.87 (0.64)	3.53 (0.91)	3.40 (1.12)	$F(3,59)= 1.88$, $p = .142$, $\eta_p^2= .09$
Frequency[1]	48.56 (60.15)	42.14 (38.12)	50.35 (111.89)	56.40 (88.14)	$F(3,59)= 0.08$, $p = .970$, $\eta_p^2= .00$
Familiarity[1]	5.84 (0.61)	5.49 (0.72)	5.41 (0.69)	5.35 (0.75)	$F(3,59)= 1.44$, $p = .241$, $\eta_p^2= .07$
Imageability[1]	5.18 (0.95)	5.06 (1.18)	4.94 (0.67)	4.36 (0.92)	$F(3,59)= 2.14$, $p = .104$, $\eta_p^2= .10$
Concreteness[1]	4.43 (0.97)	4.57 (1.04)	4.82 (0.90)	4.65 (0.62)	$F(3,59)= 0.49$, $p = .688$, $\eta_p^2= .02$
Valence[2]	7.84 (0.42)[a]	4.65 (0.25)[b]	1.78 (0.53)[c]	-	$F(2,44)= 790.08$, $p < .001$, $\eta_p^2= .97$
Arousal[2]	6.79 (0.90)[a]	4.80 (0.49)[b]	6.64 (0.66)[a]	-	$F(2,44)= 36.56$, $p < .001$, $\eta_p^2= .63$

Note. N, number. Separate analyses of variance were run using different criteria, with category (pleasant, neutral, unpleasant, and math) as the between-subjects factor. Superscript letters for the valence and arousal dimensions might be interpreted in rows: means in the same row with the same superscript letter do not significantly differ).

[1] Data obtained from the EsPal repository (Duchon et al., 2013).

[2] Ratings obtained from the Spanish adaptation of ANEW by Redondo et al. (2007).

Measures

The Abbreviated Math Anxiety Rating Scale (Alexander & Martray, 1989) is a 25-item version of the Math Anxiety Rating Scale (Richardson & Suinn, 1972), which presents participants with 25 situations that may cause MA. Respondents indicate their level of anxiety on a 5-point Likert-type scale ranging from 1 (*no anxiety*) to 5 (*high anxiety*). Scores range from 25 to 125; higher scores indicate higher MA. We used the Spanish version of the Abbreviated Math Anxiety Rating Scale, which shows sound psychometric properties (Núñez-Peña et al., 2013). The Cronbach's α for this scale was .94 in the current study.

The State-Trait Anxiety Inventory-Trait version (Spielberger et al., 1983) is a self-report measure of general anxiety that consists of 20 items scored on a 4-point Likert scale. Respondents rate their responses from 0 (*almost never*) to 3 (*almost always*) according to how they feel "in general". Scores range from 0 to 60, where higher scores indicate higher trait anxiety. The Spanish version of the State-Trait Anxiety Inventory-Trait version (Spielberger et al., 2008) was used in the current study; it has shown good psychometric properties in Spanish college students (Fonseca-Pedreiro et al., 2012). The Cronbach's α for this inventory was .92 in the current study.

The SAM (Bradley & Lang, 1994) is a non-verbal pictorial rating scale with nine levels of intensity (from 1 [lower end] to 9 [upper end]), which are represented by five humanoid figures and the spaces between them. The SAM represents three general emotional dimensions; valence (pleasant vs. unpleasant), arousal (relaxed vs. activated), and dominance (dominated vs. dominant). SAM ratings represent how participants feel while viewing the projected image. We used a computerized version of the SAM, which was created with Psychopy 3.2.3 (Peirce et al., 2019); participants responded on a computer screen, using the mouse to click on the appropriate point of the scale.

Plan of Analysis

We performed separate mixed analyses of variance (ANOVA) for each affective dimension (valence, arousal, and dominance), using group (low vs. high) as the between-participants factor and word category (pleasant, neutral, unpleasant, and math) as the within-participants factor. The level of significance was set to 0.05, Greenhouse-Geisser adjustments were applied when necessary, and partial η^2 was used to report effect sizes. Significant main and interaction effects were further examined using post-hoc contrasts, with Bonferroni correction applied for multiple comparisons. All data were analyzed with SPSS (version 21.0; SPSS Inc., Chicago, IL, USA).

Procedure

This study was approved by the University of Jaén Ethics Committee (ABR.22/9.PRY). The experimental task took place approximately 2 weeks after screening the participants in groups of approximately seven individuals. After collecting the informed consent forms, participants were provided with standardized instructions on the use of the SAM (Lang et al., 2008). The ANEW/math-related words were displayed (in black uppercase letters with a height of 2.5 cm [on a white background]) on the screen; each participant used a desktop computer with a 19’’ flat screen, which was situated approximately 60 cm from the participant. Word presentation and assessment (via the SAM scales) were conducted using Pavlovia (https://pavlovia.org/), with the programming done in Psychopy 3.2.3 (Peirce et al., 2019). After the experimenters had provided the SAM instructions, four practice trials (three words from the ANEW [one pleasant, one neutral, and one unpleasant] and one math-related word[1]) were displayed to familiarize participants with the word presentation and scale usage.

[1] Pleasant word: belleza (*beauty*); neutral word: lavabo (*bathroom*); unpleasant word: hospital (*hospital*); and math-related word: coseno (*cosine*).

Words were presented for 6 s. The scales appeared immediately (one by one) after the word presentation and remained on the screen until the participants clicked on them. There was a delay of 0.5 s between scales, and 2 s between the last scale and next word. Four pseudorandomized word orders were used across participants. Each order involved 4 trial words, 30 emotional words (15 pleasant and 15 unpleasant), 15 neutral words, and 15 math-related words. Each order started with a different word category, and there were no more than two repetitions of the same category. At the end of the experiment, participants were debriefed and thanked.

Results

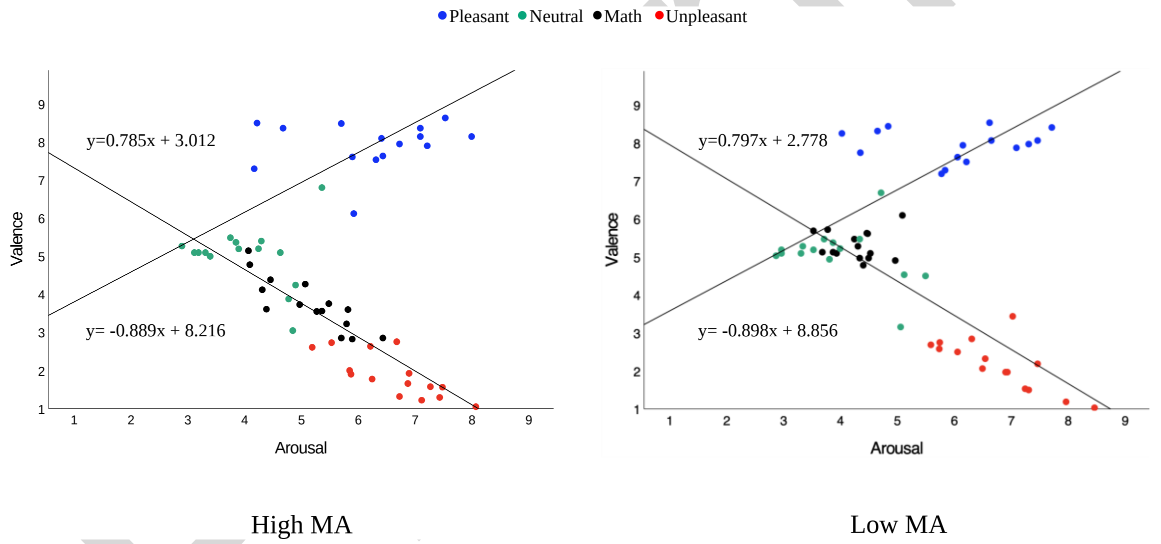
Affective Space for ANEW and Math-related Words

Figure 1 shows the distribution of the 60 words in the bidimensional space of valence and arousal for the high (left panel) and low (right panel) MA groups. For each group, affective ratings of valence and arousal were linearly independent (high: $r = -.139$, $p = .288$; low: $r = -.239$, $p = .066$), consistent with previous literature (Redondo et al., 2007). Further, while neutral words were situated in the left-center (i.e., neutral space), pleasant and unpleasant words were situated in the upper (i.e., appetitive) and lower (i.e., defensive) arms in each group, respectively; this distribution fits the typical boomerang shape found previously in normative studies (Bradley & Lang, 1999; Redondo et al., 2007). Regarding math-related words, the between-group differences were remarkable; for individuals scoring high in MA, math-related words were situated in the lower arm, spreading out from the neutral to the aversive space. Conversely, math-related words were situated in the neutral space for individuals in the low-MA group. Regression analyses yielded a positive slope between valence and arousal for appetitive cues (i.e., those with valence > 5) (high: $\beta = .785$;

R^2 = .60; t = 6.337; p < .001; low: β = .797; R^2 = .63; t = 7.805; p<.001), and a negative slope between valence and arousal for aversive cues (i.e., those with valence < 5) (high: β = -.889; R^2 = .78; t = -10.634; p < .001; low: β = -.898; R^2 = .80; t = -9.347; p < .001) in both groups. In additional regression analyses of math-related words only, the standardized regression coefficient between valence and arousal was significantly negative for the high-MA group (β = -.857; R^2 = .71; t = -5.995; p < .001), however, this regression coefficient was not significant for the low-MA group (p = .965). Scatter plots with labels (i.e., word names) for both groups can be found in the supplementary material.

Figure 1

Affective space



Bidimensional plot of each ANEW and math-related word as a function of its mean valence and arousal ratings. Each point in the plot represents the valence and arousal ratings for an ANEW (blue, green, and red) or math-related (black) word. Regression lines are plotted separately for appetitive (valence ratings > 5) and defensive contents (valence ratings < 5). **Left panel** is a bidimensional plot for the high-MA group and **right panel** is a plot the low-MA group.

As Figure 1 (left panel) shows, math-related words are spread along the lower arm for the high MA group, indicating variability in emotional reactions among those words. With the aim of identifying the characteristics of the most aversive math-related cues, we performed k-means cluster analysis. For each math-related word, valence and arousal responses (of the high-MA group) were entered into k-means cluster analyses performed using SPSS (version 21.0). Two groups/clusters that differed in valence and arousal were distinguished: Cluster 1 (i.e., arithmetic, calculus, division, equation, statistics, formula, geometry, and mathematics) was characterized by lower valence and higher arousal than Cluster 2 (i.e., quantity, diameter, fraction, number, percentage, subtraction, and addition). Subsequent analyses yielded between-cluster differences in the number of syllables ($t(13) = 2.65$, $p < .05$), but not in any other word characteristics (i.e., number of letters [$p = .073$], frequency [$p = .268$], familiarity [$p = .196$], imageability [$p = .697$], and concreteness [$p = .983$]). Words from Cluster 1 had more syllables than words from Cluster 2.

Valence Ratings

The ANOVA yielded a main effect of word category, $F(3, 213) = 657.23$, $p < .001$, partial $\eta^2 = .903$, and a main effect of the group, $F(1, 71) = 28.34$, $p < .001$, partial $\eta^2 = .285$. The main effect of word category reflected the expected pattern for ANEW words: pleasant words had the highest valence, followed by neutral, math-related, and, finally, unpleasant words (all *p*s < .001). As shown in **Figure 2A**, the ANOVA also revealed a significant group × word category interaction, $F(3, 213) = 14.49$, $p < .001$, partial $\eta^2 = .169$: the high-MA group had lower valence ratings for math-related than neutral words (math < neutral; $p < .001$). In contrast, the low-MA group had similar valence ratings for math and neutral words (math = neutral; $p = .81$). In both groups, the valence ratings for math-related words were lower and higher to pleasant and unpleasant words (all *ps* <. 001), respectively. When comparing groups in each word category, group differences were found only for math-related words ($p < .001$).

Arousal Ratings

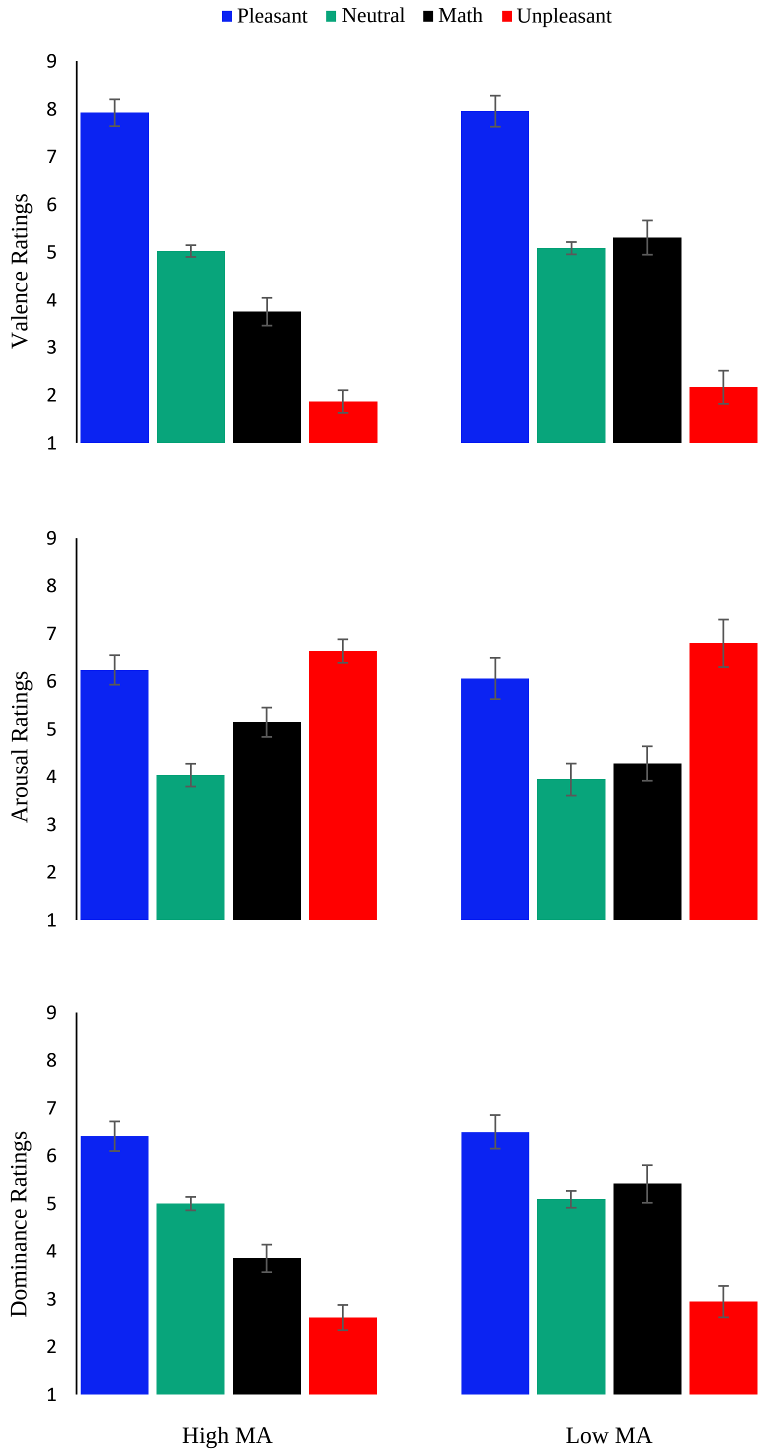
The ANOVA revealed a main effect of word category, $F(3, 213) = 114.05$, $p < .001$, partial $\eta^2 = .616$; as expected based on previous literature on ANEW words, unpleasant words were associated with higher activation, followed by the pleasant, math-related, and, finally, neutral words (all *p*s < .001, except for the pleasant – unpleasant comparison; *p* <. 05). Importantly, as shown in **Figure 2B**, the ANOVA also yielded a significant group × word category interaction, $F(3, 213) = 3.45$, $p < .05$, partial $\eta^2 = .046$: the high-MA group showed greater activation in response to math-related than neutral words (math > neutral; $p <. 001$). In contrast, the low-MA group showed similar reactions to math-related and neutral words (math = neutral; $p = .53$). In both groups, arousal in response to math-related words was lower than in response to pleasant and unpleasant words (all *p*s <. 001). When comparing the high- and low-MA groups in each word category, they only differed in the arousal ratings for math-related words ($p < .05$).

Dominance Ratings

The ANOVA indicated a main effect of word category, $F(3, 213) = 226.27$, $p < .001$, partial $\eta^2 = .761$, and a main effect of group, $F(1, 71) = 20.77$, $p < .001$, partial $\eta^2 = .226$. Consistent with previous work on ANEW words, pleasant words had the highest dominance ratings, followed by neutral, math-related, and, finally, unpleasant words (all *p*s < .001, except for the neutral – math comparison; $p < .05$). More importantly, as shown in **Figure 2C**, the ANOVA also yielded a significant group × word category interaction, $F(3, 213) = 12.13$, $p < .001$, partial $\eta^2 = .146$: the high-MA group had lower dominance ratings for math-related than neutral words (math < neutral; $p < .001$), whereas the low-MA group had similar dominance ratings for math-related and neutral words (math = neutral; $p = .47$). In both groups, dominance ratings for math-related words were lower to and higher to pleasant and unpleasant words (all *ps* < .001), respectively. When comparing the high- and low-MA groups in each word category, they only differed in math-related words ($p < .001$).

Figure 2

Subjective ratings across word categories



Note. A shows the mean valence ratings for ANEW and math-related words, B shows the mean arousal ratings for ANEW and math-related words, and C shows the mean dominance ratings for ANEW and math-related words. Considering that the main comparisons are within-group, error bars represent within-subjects 95% confidence intervals calculated using the Cousineau-Morey-O'Brien method (Cousineau & O'Brien, 2014), which prevents making between-subjects comparisons (Cousineau & O'Brien, 2014). For between-groups comparisons, see Results section.

Discussion

This study aimed to explore potentially altered patterns of subjective emotional reactivity to math-related words in individuals with high MA. Following Lang's bioinformational model of emotion (Bradley & Lang, 2007; Lang, 1995), participants with low and high MA assessed pleasant, neutral, unpleasant, and math-related words in terms of valence, arousal, and dominance. The low-MA group perceived math-related words as neutral (i.e., math and neutral words did not differ in the three dimensions). Conversely, for the high-MA group math-related words were moderately unpleasant; compared with neutral words, participants scoring higher in MA felt worse, more activated, and more dominated when viewing math-related words. However, they had higher valence and dominance ratings for math-related words, and lower arousal ratings, compared with unpleasant words. When comparing both groups, high-MA individuals had lower valence and dominance ratings for math-related words, and higher arousal ratings, but there were no between-groups differences for the emotional and neutral categories. These results indicate that math-related words are heightened emotional cues for individuals with MA, and activate the defensive emotional system in this population. These findings are consistent with the attentional bias to math-related words found previously in individuals with MA (Rubinsten et al., 2015; Suárez-Pellicioni et al., 2015), and enhance our understanding of the mechanisms underlying this phenomenon.

We found that high-MA persons experienced math-related words as more unpleasant and activating than neutral words (vs. the control group, for which math-related words were neutral). Accordingly, math-related words were situated in the lower arm (defensive system) within the bidimensional space, as also observed in some anxiety disorders (e.g., simple phobic disorder; Kindt & Brosschot, 1997, 1999; Lang & McTeague, 2009). Other remarkable result supporting the aversiveness of math-related words in MA participants was the negative correlation between valence and arousal for such words, which was not seen in the control group. A similar negative relationship has been observed for unpleasant cues in patients with anxiety (Bradley & Lang, 1994). Because math-related words are unpleasant cues for individuals with MA, they may facilitate retrieval of information and associations from memory that are related to those words; e.g., a distressing situation in a mathematics class. Emotion theories posit that linguistic expressions are stored in semantic networks that include links to different linguistic and pragmatic usages (Bower, 1981; Kissler et al., 2006; Lang, 1979). For example, the word "arithmetic" may not only represent the stimulus, but also encompass links to its usage, situations in which it is involved, or emotional evaluations thereof (Bower, 1981). Thus, retrieval of associated information may lead to avoidance of math-related events, and promote withdrawal or escape behaviors. In the academic domain, avoidance behaviors can include students not taking math classes, or even eschewing math-related career paths; this sort of behavior is typically seen in individuals who fear mathematics (Ahmed, 2018; Brown et al., 2008; Chipman et al., 1992; Lyons & Beilock, 2012a). People may also show these avoiding behaviors in everyday situations; for example, they may engage in problematic behaviors such as not checking whether a bill is accurate, or whether they are carrying the cash necessary to pay for their purchases.

Despite the aversiveness of the math-related words in our high-MA group, they were rated as less negative and arousing than unpleasant words, which indicates that math-related words are moderately unpleasant and activating for individuals with more severe symptoms of MA. This moderate aversion may be attributable to math-related words not posing an imminent threat to human survival, unlike the most aversive stimuli, i.e., those that strongly engage the defensive system (e.g., attack and mutilation cues) (Bradley et al., 2001). To better understand the extent to which persons with high MA process/experience math-related words as aversive, we searched the Spanish version of ANEW (Redondo et al., 2007) for words with similar normative ratings–in terms of valence and arousal–to those observed in our study of math-related words. In the high-MA group, math-related words had similar ratings to words from the illness (e.g., crutch, scar, surgery), cutting/sharp tool (e.g., knife, scissors, cut), and social insult (e.g., ugly, clumsy, silly) categories, which are rated as unpleasant-low arousing. Unpleasant-low arousing cues have less catastrophic negative consequences and do not require fight or attack responses; instead, they produce the attentional response of orientation, which favors the processing of stimuli and contextual information.

The dispersion of math-related words along the defensive arm in the high MA group (Figure 1, left panel) prompted us to perform additional analyses (k-means; see Results section) to identify the characteristics of the most aversive math-related cues. The most aversive math words differed from the others in the number of syllables, but not in any other word characteristics (i.e., number of letters, frequency, familiarity, imageability, and concreteness). Therefore, aspects other than physical word characteristics (except word length) might be responsible for the differences in emotional assessment between clusters. There are two plausible explanations. First, words from cluster 2 (rated as less aversive) refer to concepts or operations that are learned during the first few years of compulsory education and are frequently used in everyday life (not only in academic situations); as such, they may be more familiar to people. Second, they refer to simpler concepts or operations (e.g., numbers or addition), while those in the first group may be more complex (e.g., equations or statistics). This latter explanation is in line with findings indicating that the performance of individuals with MA is most affected when complex operations are involved (Ashcraft & Faust, 1994). Further research is needed to elucidate the reasons for the differences in ratings given to math-related words. In any case, a clear recommendation arises from these results: studies using math-related words for investigating cognitive responses in MA should control for stimuli valence and arousal, given that, according to the automatic vigilance hypothesis (which stresses that attentional resources are automatically directed away from an attended task to undesirable stimuli; Pratto & John, 1991), the negative valence of threatening stimulus depletes cognitive resources.

The results for the dominance scale in this study were also remarkable. Participants with high MA reported less control when viewing math-related than neutral words (vs. control participants, who rated both word categories similarly in terms of dominance). The groups only differed in math-related words (low-MA > high-MA). This submissiveness reported by the high-MA group is characteristic of anxiety disorders (Russell & Mehrabian, 1974); for example, it is seen in individuals with specific phobias when exposed to cues related to their fear (Bradley & Lang, 2007). The diminished perception of control over anxiety-inducing events/stimuli (i.e., math-related words) can lead anxious people (i.e., MA people) to believe that they are unlikely to be able to manage their reaction to this type of stimuli (Chorpita, 2001), which further increases the anxiety levels. Increasing perceived control over math-related content could help reduce symptoms, as observed across the anxiety disorders spectrum (Chorpita, 2001; Gallagher et al., 2014; Nunn, 1988; St-Yves et al., 1989). Likewise, improving perceived control might positively impact on performance (e.g., high-MA individuals who successfully reappraised their negative emotional responses to the prospect of doing math problems and applied emotional control processes to these responses at an early stage showed better performance in math tasks; Lyons & Beilock, 2012b). It is also possible that the lower ratings in the dominance dimension of the high-MA participants reflect subjective appraisal of their competence in mathematics. A recent meta-analysis of 65 studies by Li et al. (2021) revealed a moderate correlation (r = -.48) between math-competence beliefs (i.e., self-concept and self-efficacy) and MA. Therefore, scores for math-related words in the dominance dimension could reflect individuals' perceptions of their control over math-related situations and academic outcomes.

Our data also revealed significant main effects in all three emotional dimensions, indicating that participants as a whole experienced lower valence and dominance, and higher arousal, when exposed to math-related words compared to neutral words. These findings align with the study of Daches-Cohen et al. (2021), in which participants rated unpleasant, neutral, and math-related words on a threat scale. Results showed that math-related words were rated as more threatening than neutral words. Further, when considering only the math words, the ones perceived as more math-related were also rated as more threatening. Daches-Cohen et al. (2021) concluded that math-related words are related to negative emotional valence. Our results provide further insights by indicating that the negative evaluation of math-related words is specific to MA individuals, i.e., it is not seen in individuals without MA symptoms. In fact, math-related words are processed as neutral stimuli by individuals who do not experience MA.

Overall, the present study contributes to our understanding of emotional processing of math-related words and its role in MA, highlighting that, along with numeric cues, words associated with math negatively affect individuals with high MA (but not people with low MA). These findings are consistent with studies indicating that individuals with high MA show an attentional bias to math-related words (Rubinsten et al., 2015; Suárez-Pellicioni et al., 2015), suggesting that these words have become threatening cues. Thus, individuals with MA might experience negative emotions even before performing a math task, i.e., by simply reading or visualizing math-related words. This interpretation is supported by previous studies indicating that participants with high MA show increased activity in regions associated with the detection of bodily threats and the experience of visceral pain when presented with a cue previously associated with a math task (e.g., a yellow circle; Lyons &

Beilock, 2012b). Thus, instructions relating to the imminent performance of math tasks (e.g., “You will then carry out some math *operations*”) may immediately generate an altered state of emotional reactivity in people with MA, which may help explain the previous findings of brain cortical network changes in anticipation of doing mathematics (Klados et al., 2015).

Limitations and future research

When interpreting the findings of the current study, several limitations should be considered. First, despite the groups being matched for gender, the majority of the participants were females. This gender imbalance was due to the low number of men who scored in the upper quartile of MA. As gender was included as a matching variable; the automatic matching selection procedure led to a small number of men in the lower quartile group. Although this inequality of gender in the high MA group is in line with the higher prevalence rates among females than males reported by most studies (e.g., Baloğlu & Koçak, 2006; Else-Quest et al., 2010; Ma & Cartwright, 2003), the inclusion of more males should be considered in future studies[2]. Another drawback is that we only assessed undergraduates. Increasing the diversity of the sample (i.e., to include children, adolescents, and undergraduates in different fields) would enhance the generalizability of the results to other populations. Finally, we only included subjective emotional evaluations in this study. Future studies might benefit from including psychophysiological correlates of emotional processing (e.g., blink startle reflex, electromyography corrugator and zygomatic responses, and skin conductance responses), which may enhance our understanding of the altered math-related affective processing seen in people with MA.

Despite its limitations, our study is significant in that we have used a robust theoretical framework and strict methodology (widely used in studies of human fear and

[2] A set of parallel analyses after excluding 5 male participants (7% of the sample) indicated that the results are largely consistent with those obtained for the entire sample.

anxiety disorders) to shed light on the subjective emotional processing of math-related words in MA. Another strength is that we tightly controlled word selection, i.e., controlled for word characteristics that are known to affect word processing. Specifically, word categories were matched in terms of number of letters, number of syllables, frequency, familiarity, imageability, and concreteness. We also matched the groups in terms of general anxiety, given its well-known relationship with MA (e.g., Hembree, 1990; Wang et al., 2014, Hill et al., 2016). Therefore, the results of the present study could not be attributed to group differences in general anxiety. Finally, our results may have clinical and educational implications; for example, they could inform intervention programs, such as habituation-related programs aiming to decrease excessive emotional reactivity to math cues. In this regard, expressive writing interventions, which have been found to be effective for reducing levels of MA (e.g., Park et al., 2014; Ramirez & Beilock, 2011), may promote habituation to feared math-related stimuli (Sloan et al., 2005).

Conclusion

The present study showed that individuals with high MA experienced math-related words as moderately unpleasant, activating, and dominant, contrary to the low-MA participants, who assessed them as neutral. These findings contribute to the existing literature by demonstrating that MA is also characterized by altered emotional processing of math-related words, and by demonstrating that, as well as numeric cues, verbal cues associated with math play a role in MA. This knowledge might facilitate the development of more specific interventions emphasizing the control of negative emotional responses to mathematical stimuli, such as math-related words, which are commonly encountered in the academic environment and everyday life. By contributing to our theoretical understanding of the processes underlying in MA, the findings of this study represent a step forward in terms of clarifying the emotional impact of math-related cues on individuals that suffer from MA.

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Data availability

The data that support the findings of this study are available from the corresponding author upon request.

Disclosure of interest

The authors report no conflicts of interest.

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