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Response inhibition deficits in math-anxious individuals

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Abstract

We examined whether math anxiety is related to a response inhibition deficit and, if so, whether it is a domain-specific inhibition deficit in numerical tasks or a general inhibition deficit. Behavioral performance and electroencephalogram activity were recorded while 28 highly math–anxious (HMA) and 28 low math–anxious (LMA) individuals performed both a numerical and a non-numerical Go/Nogo task. In the numerical task, single-digit numbers were presented, and participants were asked to press a button if the number was even. In the non-numerical task, letters were presented, and the button had to be pressed if the letter was a vowel. Nogo trials were answered less accurately and elicited larger Nogo-N2 and Nogo-P3 than Go trials in both tasks and both groups. Importantly, behavioral and brain response differences between tasks were only found in the HMA group. First, they were more error-prone in numerical Nogo than in non-numerical Nogo trials; and second, their Nogo-N2 and N2d (Nogo–Go difference) were smaller in the numerical task than in the non-numerical task. No differences were found in the LMA group. These results suggest that HMA individuals' response inhibition is impaired specifically when dealing with numbers, which could contribute to their low achievement in math tasks.

KEYWORDS
attentional control, Go/Nogo task, math anxiety, Nogo-N2, Nogo-P3, response inhibition

INTRODUCTION

Math anxiety is highly prevalent and has detrimental consequences for learning and mastering mathematics.[1] It is defined as feelings of tension that some individuals suffer in situations where they have to deal with numbers and can impair not only their academic achievement in math but also their performance in daily activities (e.g., calculating money for purchases or evaluating the economic conditions when applying for a loan). It is noteworthy that highly math–anxious (HMA) individuals usually avoid the science, technology, engineering, and mathematics (STEM) disciplines, so this type of anxiety negatively affects career choices and, consequently, professional success and economic incomes.[2] Given these negative effects of math anxiety, it is important to get a better understanding of why math-anxious people underperform in math. This could help in the search for solutions that could be offered to them.

Several explanations have been put forward to account for why math anxiety is negatively related to math achievement,[3] with one of the most investigated claiming that HMA people might have a deficit in executive functions. Executive functions (also called executive control or cognitive control) are top-down mental processes essential for all types of cognitive performance, since they allow individuals to solve problems, shift strategies flexibly, ignore distractors, inhibit irrelevant impulses, and monitor their actions. According to Miyake et al.,[4] there are three core executive functions: inhibition, updating, and shifting. Inhibition is the ability to ignore dominant, automatic, or prepotent responses or information that are irrelevant to task processing. It includes behavioral inhibition (i.e., the ability to suppress an overbearing response or an inappropriate action in a given context) and cognitive inhibition[5,6] (i.e., interference control). Updating is the ability to take information into account or manipulate it and work with it, updating working memory representations. People have to encode new information and must decide what content should be removed from working memory.[4] Last, shifting is the ability to shift attention between multiple tasks or change perspective during problem-solving.[4] This ability requires the use of updating and inhibition functions,[5] since to change the perspective, we must deactivate or inhibit the previous perspective and activate the new one in working memory.

Attentional control theory[7,8] (ACT), developed from processing efficiency theory,[9] accounts for the adverse effects that general anxiety may have on executive functions. According to ACT, anxiety decreases the efficiency of attentional control, with inhibition and shifting being the most impaired executive functions in threatening conditions. Moreover, ACT claims that anxiety affects processing efficiency (i.e., the use of cognitive resources to perform the task; usually measured by response time or neural activity) more than performance effectiveness (i.e., the ability to perform the task at a standard level; usually measured by response accuracy). So, under some circumstances, anxious people might recruit additional cognitive processes (i.e., they make more effort) to avoid performance impairments in tasks that require attentional control.[10]

In the field of math anxiety, previous studies have shown that HMA individuals, compared with lowly math–anxious (LMA) people, show inefficient attentional control.[11–13] HMA individuals showed worse interference control than their less math-anxious peers in a numerical Stroop task[14] and in an emotional Stroop task when math-related words were presented[15] (although other studies[16,17] found no association between math anxiety and interference control in emotional Stroop tasks), so it has been suggested that they are more vulnerable to distraction in these tasks. More recently, a less efficient shifting function in HMA individuals who had difficulties when switching between arithmetical operations (i.e., additions and subtractions) was reported.[11] Therefore, to date, math anxiety has been related to impairments in the shifting and interference control functions of attentional control. However, it remains to be determined whether HMA individuals may also have impairments in behavioral inhibition, another executive function that is necessary to perform math tasks, which, according to ACT, might also be impaired by anxiety. The main objective of this study was to fill this gap by investigating whether HMA individuals may also suffer a deficit in the behavioral inhibition system. Response inhibition deficits have been found, for example, in children with attention-deficit/hyperactivity disorder (ADHD),[18] which, though not considered a learning disability, undoubtedly makes learning difficult. An inefficient withholding of incorrect responses in HMA individuals could be because they adopt rigid and inflexible strategies when performing mathematics tasks, which could lead them to produce incorrect answers or be inefficient in math assessment situations.

To study behavioral inhibition (i.e., the ability to suppress inappropriate actions), one of the most used paradigms is the Go/Nogo task. In this task, participants are presented with a series of stimuli of frequent Go trials, in which they have to respond, and infrequent Nogo trials, in which they have to withhold their response. Go trials are more frequent than Nogo trials, usually at a ratio of 3:1, to create a prepotent tendency to respond that allows the measurement of behavioral response inhibition. The incidence of false alarms in this task (i.e., commission errors in Nogo trials) is the standard measure for behavioral inhibition: a higher rate of false alarms indicates that there are difficulties in motor inhibition.

Behavioral inhibition can also be studied by recording event-related brain potentials (ERPs) in Go/Nogo tasks. There are two ERP components elicited by Nogo trials at the frontocentral electrodes, known as Nogo-N2 and Nogo-P3, which are suggested to reflect brain activity associated with inhibitory control.[19,20] Nogo-N2 is a frontocentral negative wave with a latency of around 200–300 ms post-stimulus, which is followed by Nogo-P3, a positive wave with a latency of around 300–500 ms after stimulus onset. Nogo-N2 and the subsequent Nogo-P3 have been linked to attention and cognitive control: Nogo-N2 is thought to reflect the first stage of the inhibition of a planned response before the actual motor process and is related to conflict monitoring,[20] whereas Nogo-P3 is thought to reflect the actual inhibition of the motor response in a later stage of the inhibition process[21] or, alternatively, the monitoring of the outcome of inhibition[22] (i.e., an evaluation process). Nogo-N2 amplitudes are larger in individuals with lower false alarm rates[20] and smaller in children with ADHD, in contrast with the nonclinical population,[18,23,24] so it has been suggested that Nogo-N2 is an index of successful response inhibition.[20,25] Source-localization studies have found that Nogo-N2 and Nogo-P3 are generated in prefrontal areas, including the orbitofrontal cortex and the anterior cingulate cortex.[26]

As for the impact of emotional context on response inhibition, some studies have found that emotional stimuli impaired behavioral response inhibition.[27–30] According to the dual competition framework,[31] emotion can either enhance or impair behavioral performance depending on the level of threat. Thus, when the emotional content is high in a threatening situation, performance is impaired because the processing of emotional content is prioritized and competes for attentional resources. Previous studies have found that emotional content impairs response inhibition not only behaviorally but also at the neural level, decreasing accuracy in Nogo trials[27,28] and attenuating Nogo-N2 amplitudes.[29,30]

Regarding math anxiety, it is important to understand not only whether it is associated with an impairment in the behavioral inhibition function but also, if so, to disentangle whether it is a domain-general or domain-specific deficit when dealing with numbers. Previous studies have found contradictory results concerning HMA deficits in cognitive inhibition: some found that they had worse interference control (i.e., worse cognitive inhibition) in tasks containing math-related stimuli,[14,15] while others found they had impaired interference control in Stroop and flanker tasks that did not contain numerical or mathematical stimuli.[32,33] Importantly, according to the dual competition framework,[31] impairments in executive functions are expected only when the emotional content is high in a threatening situation, that is, in the context of a numerical or mathematical task in the case of math-anxious individuals.

The aim of this study was to examine whether HMA individuals suffer from a deficit in the behavioral inhibition system and to determine whether this is a specific numerical inhibition deficit or a general inhibition deficit, compared to their LMA counterparts. To address these questions, inhibition skills were assessed in HMA and LMA individuals while they performed a numerical and a non-numerical Go/Nogo task. Behavioral and ERP measures were analyzed, focusing on differences between tasks in both groups. Based on the previously discussed research, our predictions are as follows. If math-anxious individuals have a general inhibition deficit, we expected they would show an increase in error rate in Nogo trials (i.e., more false alarms) both in the numerical and the non-numerical tasks as compared to their less math-anxious peers; similarly, the HMA group should show a smaller Nogo-N2 than their less math-anxious counterparts in both tasks. However, if task differences were found in the HMA group (i.e., more false alarms in Nogo trials and less negative Nogo-N2 in the numerical than in the non-numerical task), this would indicate that math-anxious individuals have a specific numerical inhibition deficit.

METHODS

Participants

Fifty-six healthy volunteers participated in the study, 28 of whom had low scores on the Shortened Mathematics Anxiety Rating Scale[34] (SMARS), and 28 had high scores. The sample size was determined using an *a priori* power analysis[35] (G*Power). To detect a medium effect size[36] (partial eta squared = 0.06) with 95% of expected power and an alpha at 0.05 in a mixed analysis of variance (ANOVA), the recommended total sample size was 54. Participants in the LMA group (16 females and 12 males) scored below the first quartile on the SMARS (Q_1 = 53), while those in the HMA group (21 females and 7 males) scored above the third quartile (Q_3 = 78). SMARS and State-Trait Anxiety Inventory (STAI)[37]-Trait quartiles were calculated in a sample of 1547 undergraduates (78% females and 22% males) with a mean age of 21.92 years (SD = 5.15) in the framework of a larger project. In addition, given the adverse effects that trait anxiety may have on executive functions, the groups were formed by controlling for trait anxiety, to prevent this variable from confounding our results. First, no participants rating above the third quartile (Q_3 = 33) in the trait subscale of the STAI were included as part of the sample, to rule out the results being due to high levels of trait anxiety. Second, participants in one group were matched with those in the other group according to their scores on trait anxiety (i.e., participants in both groups were paired according to their STAI scores to ensure that the two groups did not differ in terms of trait anxiety). As expected, groups differed in math anxiety ($t(54) = 18.70$, $p < 0.001$, $d = 5$) but not in trait anxiety ($t(54) = 0.70$, $p = 0.489$, $d = 0.19$). They neither differed in age ($t(54) = 0.04$, $p = 0.970$, $d = 0.01$) nor in gender ratio ($X^2(1) = 1.99$, $p = 0.158$). Table 1 shows the means and SEMs for both groups in these variables as well as the number of men and women.

All participants had normal or corrected-to-normal visual acuity, and none reported any history of neurological or psychiatric disorders. They were naïve as to the purposes of the study and gave their informed consent before beginning the experiment, which was conducted according to the principles of the Declaration of Helsinki. The experimental protocol was approved by the Ethics Committee of the University of Barcelona.

Materials

SMARS

The SMARS[34] is comprised of 25 five-point Likert-scaled items that respondents must rate from 1 (no anxiety) to 5 (high anxiety) depending on the level of anxiety they felt when imagining dealing with different math-related situations (e.g., studying for a math test). The final score ranges from 25 (low math anxiety) to 125 (high math anxiety) and represents general levels of math anxiety. The Spanish version of the SMARS was used in the present study to select the participants.[38] The original SMARS was adapted to the Spanish population and reported that its scores have good 7-week test-retest reliability ($r = 0.72$) and strong internal consistency ($\alpha = 0.94$).

STAI

The STAI-Trait subscale[37] was used in this study. It consists of 20 four-point Likert-scaled items that respondents must rate from 0 (almost never) to 3 (almost always) depending on the frequency with which they feel various emotions (e.g., I have disturbing thoughts). Total scores range from 0 (low trait anxiety) to 60 (high trait anxiety) and represent a relatively stable tendency to respond with anxiety. The 9th Edition of the STAI-Trait subscale's Spanish adaptation was used in the present study.[39] Good internal consistency of this subscale's scores ($\alpha = 0.94$) was reported.[40]

Procedure

Participants were tested individually. Before the experiment, they signed the informed consent and were asked to complete a demographic information questionnaire. They were then fitted with an electroencephalogram (EEG) sensor cap with the electrodes attached and seated 150 cm away from a computer screen in an electrically shielded, sound-attenuating recording room.

Participants were asked to perform two different Go/Nogo tasks. They were instructed to press the left button of the mouse for Go trials as quickly as possible but to refrain from pressing the button for Nogo trials. Each task comprised a list of 200 trials divided into two blocks, each one with 75 Go and 25 Nogo trials randomly presented. A 3:1 ratio was used because we wanted the Go response to be prepotent. For the numerical Go/Nogo task, odd numbers (3, 5, 7, 9) were used in the Go condition and even numbers (2, 4, 6, 8) in the Nogo condition. We used

TABLE 1 Means and standard errors of the means (SEM; in brackets) for math anxiety, trait anxiety, and age (in years) for the LMA and HMA groups.

	Math anxiety	Trait anxiety	Age	Gender
LMA	44.11 (1.45)	17.46 (1.41)	21.82 (.66)	16/12
HMA	90.46 (2.01)	18.86 (1.42)	21.86 (.68)	21/7

Note: Number of women and men (women/men) is also given.
Abbreviations: HMA, highly math-anxious; LMA, low math-anxious.

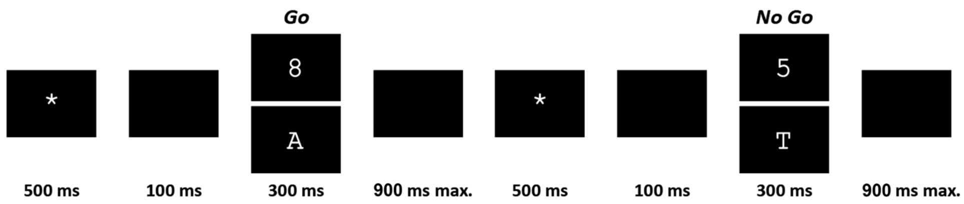

FIGURE 1 Example of Go (left) and Nogo (right) trials in the numerical (top) and non-numerical (bottom) tasks.

this parity task because we wanted the numerical processing to be relevant to the performance of the task. For the non-numerical Go/Nogo task, vowels (A, E, O, U) were used in the Go condition and consonants (P, S, T, H) were used in the Nogo condition. Neither the same stimulus nor two Nogo trials were consecutively presented. The order of the tasks was counterbalanced across subjects for each group.

At the beginning of each task, participants were given the corresponding instructions and received a short training session consisting of 16 trials, similar to the experimental trials. The stimuli were horizontally and vertically centered, in bold, 50-point size Courier New font, and colored in white on a 640 × 480 pixel resolution black screen. As shown in Figure 1, each trial started with a 500-ms fixation point (an asterisk). Then, a blank screen was presented for 100 ms, just before the 300-ms presentation of the target. Participants had a 500 ms rest after clicking the mouse or 1200 ms had passed with no response detected. They had a mandatory resting time of 30 s between blocks, to which they could add as much time as needed until they decided to continue with the following block. Experimental tasks were presented and the behavioral responses were recorded using the E-prime software 3.0 (Psychology Software Tools Inc.).

Electrophysiological recording

Continuous EEG data were recorded using the Scan 4.5 hardware and software (Compumedics Neuroscan, Inc.) from 32 tin electrodes that were mounted in a commercial WaveGuard EEG Cap (Eemagine Medical Imaging Solutions GmbH. ANT Advanced Neuro Technology). The extended 10/10 International System was used for positioning the electrodes: eight electrodes were located on the midline at the FPz (placed on every participant at 10% of the nasion-inion distance), Fz, FCz, Cz, CPz, Pz, POz, and Oz positions; 12 lateral pairs of electrodes were located on standard sites at the prefrontal (FP1/FP2), frontal (F3/F4, F7/F8), frontocentral (FC3/FC4), frontotemporal (FT7/FT8), central (C3/C4), temporal (T7/T8), centroparietal (CP3/CP4), temporoparietal (TP7/TP8), parietal (P3/P4, P7/P8), and occipital (O1/O2) positions. Two electrodes located on the right and left mastoids were used as the rereference. Both vertical and horizontal electrooculogram movements were recorded by two independent electrodes located below the left eye and at the outer canthus of the right eye, respectively. Another independent electrode located on the tip of the nose was used as the common reference. Finally, the ground was positioned between the Fz and the FPz. EEG channels were continuously digitized at a rate of 500 Hz by an amplifier, and electrode impedances were below 5 kΩ.

Data analysis

Behavioral data

Medians of response times for correctly solved trials in Go trials were analyzed with an ANOVA, using Task (numerical vs. non-numerical) as the within-subject factor and Group (LMA vs. HMA) as the between-subjects factor. The hit rate was also analyzed with an ANOVA with the same factors described for response time analysis but adding the Type of response (Go vs. Nogo) as a second within-subject factor. Finally, Go−Nogo differences in the hit rate were computed and submitted to an ANOVA, taking Task (numerical vs. non-numerical) as the within-subject factor and Group (LMA vs. HMA) as the between-subjects factor. The F value, the degrees of freedom, the probability level, and the η_p^2 effect size index[41] are reported.

EEG data

The EEG data were preprocessed with EEGLAB 2022.1, a toolbox of the MATLAB 9.13 (R2022b) software The MathWorks, Inc). They were filtered using a band-pass filter from 0.5 to 30 Hz and then rereferenced with the data from the mastoids. After removing non-stereotypical signal fragments, we ran an independent components analysis,[42] using the Binica algorithm provided by EEGLAB[43] to correct the noise generated by eye movement and some other muscle artifacts. Next, epochs for each participant and each experimental condition were averaged relative to a prestimulus baseline of 100 ms, using ERPLAB. Only accurate trials were used to determine the average ERP. The mean number of epochs included in each average ERP was 130.32 (SEM = 1.30; range: 111–146) for the Go condition and 37.29 (SEM = 0.42; range: 25–48) for the Nogo condition.[44]

To study the Nogo-N2 and Nogo-P3 components, two ANOVAs were performed, taking Response (Go vs. Nogo) and Task (numerical vs. non-numerical) as the within-subject factors and Group (LMA vs. HMA) as the between-subjects factor. We defined Nogo-N2 as the mean amplitude in the 250–350 ms window post-stimuli in a frontal region of interest by averaging data from three electrodes (F3, Fz, and F4). For Nogo-P3, the mean amplitude in the 500–600 ms window post-stimuli in the same region was calculated. These electrodes were selected because Nogo-N2 and Nogo-P3 have their maximum amplitude in the frontal area.[45] Windows for studying both ERP components were selected based on visual inspection. Statistical analyses were performed as described for the hit rate. Moreover, difference waveshapes (Nogo minus Go) were computed and the mean amplitudes for N2d (in the 250–350 ms window) and P3d (in the 500–600 ms windows) in the frontal region were submitted to an ANOVA, taking Task (numerical vs. non-numerical) as the within-subject factor and Group (LMA vs. HMA) as the between-subjects factor.

Data were analyzed using IBM SPSS Statistics v. 27.

RESULTS

Behavioral measures

Response time and hit rate

ANOVA for the response times showed a significant main effect of Task [F(1,54) = 20.62, $p < 0.001$, $\eta_p{}^2 = 0.276$], with responses being slower in the numerical task (mean = 387.31, SEM = 8.44) than in the non-numerical task (mean = 365.31, SEM = 8.22). Neither Group nor the interaction Group × Task reached significance.

Regarding hit rate, there was a significant main effect of Type of response [F(1,54) = 24.37, $p < 0.001$, $\eta_p{}^2 = 0.311$], showing that more errors were committed in Nogo than in Go trials, and of Task [F(1,54) = 4.06, $p = 0.049$, $\eta_p{}^2 = 0.070$], showing that more errors were committed in the numerical than in the non-numerical task. However, these effects were modulated by the interaction Type of response × Task [F(1,54) = 10.66, $p = 0.002$, $\eta_p{}^2 = 0.165$]. In order to study this interaction in more detail, separate ANOVAs were performed for Go and Nogo trials, taking Task as the within-subject factor and Group as the between-subjects factor. The results showed no significant effects for Go trials. However, in Nogo trials, there was a significant main effect of Task [F(1,54) = 8.402, $p = 0.005$, $\eta_p{}^2 = 0.135$], showing that more errors were committed in numerical than in non-numerical Nogo trials. Moreover, hit rate differences were computed (Nogo–Go) and submitted to an ANOVA. This analysis showed that Nogo–Go differences were larger in the numerical (mean = −0.13, SEM = 0.02) than in the non-numerical (mean = −0.07, SEM = 0.02) task [F(1,54) = 10.66, $p = 0.002$, $\eta_p{}^2 = 0.165$].

As for the interaction Group × Task × Type of response, it failed to reach statistical significance [F(1,54) = 1.551, $p = 0.218$, $\eta_p{}^2 = 0.028$]. However, because we anticipated differences between the numerical and non-numerical tasks for the HMA group but not for the LMA group, separate ANOVAs were executed for each group, taking hit rate as the dependent variable. For the LMA group, there was a main effect of Type of response [F(1,27) = 22.66, $p < 0.001$, $\eta_p{}^2 = 0.456$], showing the expected Go–Nogo effect (i.e., more errors in Nogo than in Go trials). Importantly, for the HMA group, there was not only a main effect of Type of response [F(1,27) = 8.30, $p = 0.008$, $\eta_p{}^2 = 0.235$], but also a significant Task main effect [F(1,27) = 4.36, $p = 0.046$, $\eta_p{}^2 = 0.139$]; individuals in the HMA group were more error-prone in the numerical than in the non-numerical task and Type of response × Task interaction [F(1,27) = 9.56, $p = 0.005$, $\eta_p{}^2 = 0.261$]. Further analysis performed to study this interaction in the HMA group showed that tasks did not differ in hit rate for Go trials [t(27) = 1.537, $p = 0.136$, $d = 0.291$], but they did for Nogo trials [t(27) = 2.892, $p = 0.007$, $d = 0.547$]: the HMA group was more error-prone in numerical than in non-numerical Nogo trials. As for the LMA group, no task differences in hit rate were found either for the Go [t(27) = 0.737, $p = 0.468$, $d = 0.139$] or the Nogo trials [t(27) = 1.244, $p = 0.224$, $d = 0.235$]. Moreover, the Go—Nogo difference in hit rate was larger in the numerical than in the non-numerical task only in the HMA group [t(27) = 3.09, $p = 0.005$, $d = 0.584$]. No differences between tasks were found in the LMA group [t(27) = 1.48, $p = 0.151$, $d = 0.279$]. Table 2 includes means and standard errors of the means for all behavioral measures for the LMA and HMA groups in both tasks.

ERP measures

Figure 2 shows the grand averages in Go and Nogo trials at electrode Fz in the numerical and non-numerical tasks for the LMA and HMA groups. Nogo-N2 and Nogo-P3 were observed in both tasks in both groups. Figure 3 shows Nogo–Go difference waveshapes for both tasks in the two groups. Notably, it can be seen that the amplitude of N2d in the Nogo–Go difference wave was larger for the non-numerical than for the numerical task only in the HMA group. There were no task differences in the LMA group.

Nogo-N2

Regarding Nogo-N2 amplitude, there was a main effect of Type of response [F(1,54) = 30.35, $p < 0.001$, $\eta_p{}^2 = 0.360$], showing more negative amplitudes in the Nogo than in the Go responses. The Task ×

TABLE 2 Means and standard errors of the means (SEM; in brackets) of response time (in milliseconds) in Go trials and hit rate (in percentage) in Go and Nogo trials, for the LMA and HMA groups in the numerical and the non-numerical task.

	LMA		HMA	
	Numerical	Non-numerical	Numerical	Non-numerical
Response time Go	378 (11.55)	360 (9.71)	398 (12.30)	377 (13.26)
Hit rate Go	0.927 (0.01)	0.922 (0.01)	0.916 (0.02)	0.904 (0.02)
Hit rate Nogo	0.817 (0.02)	0.839 (0.02)	0.789 (0.02)	0.839 (0.02)
Hit rate difference Go–Nogo	−0.110 (0.02)	−0.083 (0.02)	−0.127 (0.04)	−0.065 (0.03)

Abbreviations: HMA, highly math-anxious; LMA, low math-anxious.

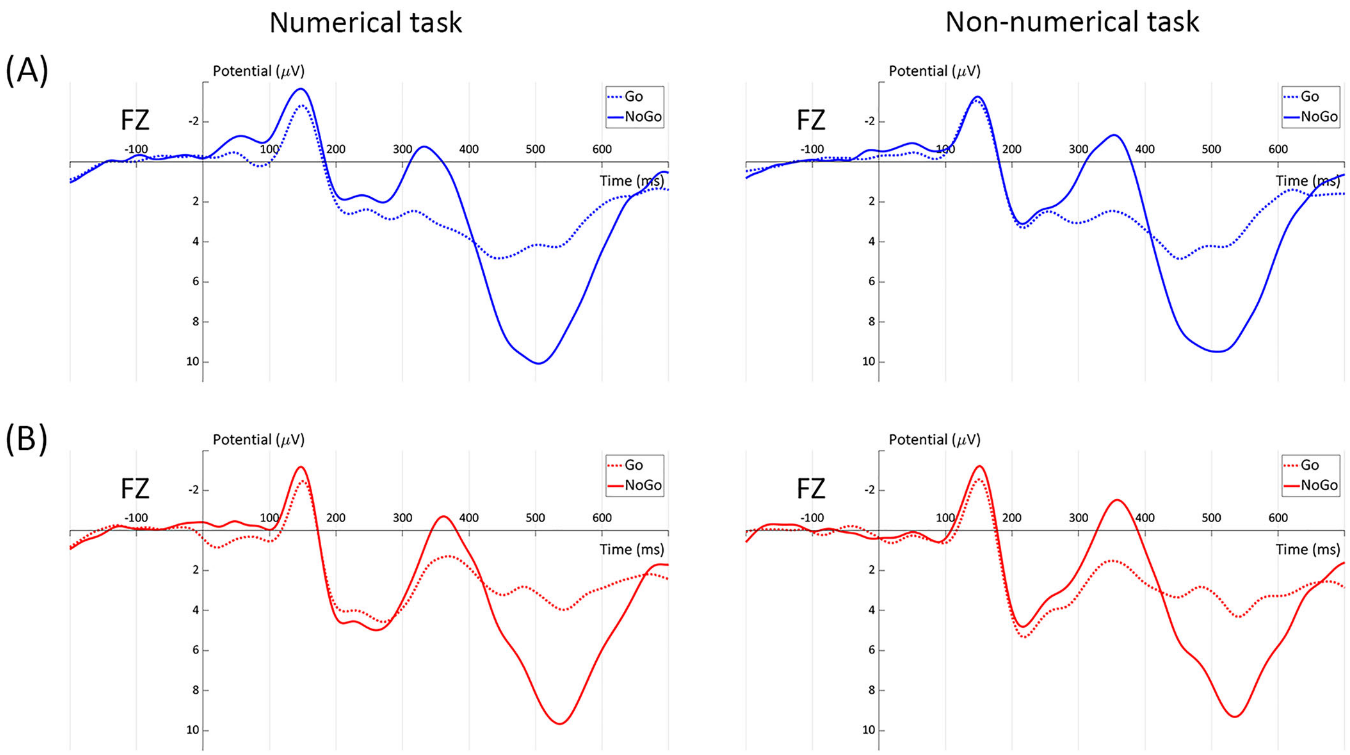

FIGURE 2 Raw grand average ERPs in Go and Nogo trials at Fz in the LMA (A) and the HMA (B) groups for the numerical (left) and non-numerical (right) tasks. Abbreviations: ERP, event-related brain potential; HMA, highly math-anxious; LMA, low math-anxious.

Group interaction was also significant [$F(1,54) = 5.04, p = 0.029, \eta_p{}^2 = 0.085$]. To study this interaction in more detail, separate ANOVAs were performed for each group. The main effect of Type of response was significant in both groups [$F(1,27) = 23.44, p < 0.001, \eta_p{}^2 = 0.465$ and $F(1,27) = 7.00, p = 0.013, \eta_p{}^2 = 0.206$, for the LMA and the HMA group, respectively], and it is noteworthy that, in the HMA group, this effect was modulated by the Task × Type of response interaction [$F(1,27) = 5.61, p = 0.025, \eta_p{}^2 = 0.172$]. In this group, the effect of Type of response was only significant in the non-numerical task [$F(1,27) = 13.373, p = 0.001, \eta_p{}^2 = 0.331$] and the Nogo–Go difference (i.e., N2d) was larger in the non-numerical than in the numerical task [$F(1,27) = 5.61, p = 0.025, \eta_p{}^2 = 0.172$]. No differences in N2d between the two tasks were found in the LMA group [$F(1,54) = 0.108, p = 0.745, \eta_p{}^2 = 0.004$]. Further analyses revealed group differences in the Nogo-N2 condition for the numerical task [amplitude was less negative for the HMA than for the LMA group: $F(1,54) = 5.97, p = 0.018, \eta_p{}^2 = 0.100$], but not for the non-numerical task [$F(1,54) = 0.74, p = 0.392, \eta_p{}^2 = 0.014$]. Table 3 shows the means and SEMs for the Nogo-N2 and N2d for both groups in both tasks.

Nogo-P3

ANOVA only showed a main effect of Type of response [$F(1,54) = 150.69, p < 0.001, \eta_p{}^2 = 0.736$], showing that amplitude was more positive in the Nogo than in the Go condition. The Nogo–Go differences (i.e., P3d) were analyzed and the results revealed that neither the main effect of Group nor its interaction with Task reached statistical significance. Finally, ANOVAs for Nogo-P3 and P3d peak latencies were performed taking Task as the within-subject factor and Group as

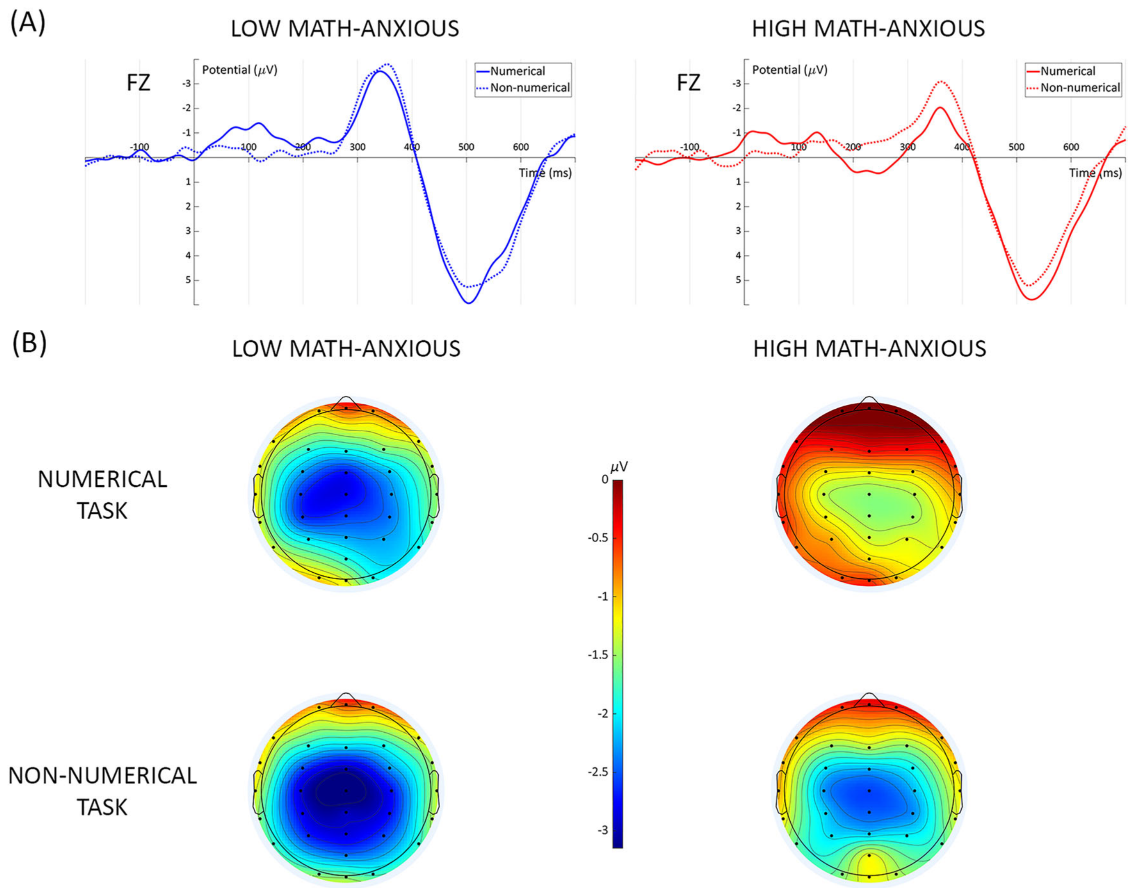

FIGURE 3 (A) Difference waves (Nogo minus Go trials) at Fz in the numerical and non-numerical tasks for the LMA and HMA groups. (B) Topographic maps of N2d (250–350 ms) for the LMA and HMA groups in both tasks. Abbreviations: HMA, highly math-anxious; LMA, low math-anxious.

TABLE 3 Amplitude (in microvolts) means and standard errors of the means (SEM; in brackets) for Nogo-N2, N2d, Nogo-P3, and P3d in the LMA and HMA groups in the numerical and the non-numerical tasks.

	LMA		HMA	
	Numerical	Non-numerical	Numerical	Non-numerical
Nogo-N2	1.07 (0.60)	1.01 (0.55)	3.15 (0.603)	1.68 (0.55)
N2d	−1.81 (0.45)	−1.96 (0.41)	−0.44 (0.45)	−1.46 (0.41)
Nogo-P3	7.57 (0.83)	7.60 (0.70)	8.17 (0.83)	7.46 (0.70)
P3d	3.99 (0.59)	4.28 (0.51)	4.69 (0.59)	3.78 (0.51)

Abbreviations: HMA, highly math-anxious; LMA, low math-anxious.

the between-subjects factor. This analysis did not show any significant effect.

DISCUSSION

The aim of this study was to examine whether HMA individuals have impaired behavioral inhibition control and, if so, whether it is a domain-general inhibition deficit or a domain-specific inhibition deficit when they deal with numbers. To this end, behavioral and brain responses were recorded while HMA and LMA individuals performed a numerical and a non-numerical Go/Nogo task, in which participants had to inhibit their response to infrequent Nogo trials. To the best of our knowledge, this is the first study to investigate whether the neural correlates of response inhibition are modulated by math anxiety in a numerical versus a non-numerical task. Differences between tasks in the Nogo-N2 and Nogo-P3 ERP components in HMA and LMA individuals were analyzed along with differences in behavioral measurements.

Our results confirmed the hypothesis that math anxiety is related to a domain-specific behavioral inhibition deficit. In the current study, differences were found between tasks in both ERPs and hit rate for Nogo trials in the HMA but not in the LMA group. Regarding ERPs, our results confirmed those of previous studies,[20] recording the frontal Nogo-N2 and Nogo-P3 for the LMA group in both tasks. This result suggests that this group inhibits a planned response in Nogo trials both in numerical and non-numerical tasks. Importantly, the present study revealed smaller Nogo-N2 (i.e., less negative amplitude) in the numerical than in the non-numerical task in the HMA group, but no task differences in the LMA group. In the same vein, the dN2 (Nogo–Go amplitude difference) was smaller in the HMA group than in the LMA group only in the numerical task. The amplitude of Nogo-N2 has been associated with successful response inhibition,[20] so, although both groups inhibited their planned response in Nogo trials in the non-numerical task, the HMA group might have exhibited worse inhibition of premature responses than their LMA peers in tasks involving numbers. It is noteworthy that, as outlined in our introduction, a reduced Nogo-N2 has also been found in ADHD as compared to nonclinical children,[18,23,24] and that response inhibition deficits are prominent in children with this type of disorder.[46] The current ERP finding is also consistent with those obtained in previous studies reporting a smaller Nogo-N2 amplitude in individuals with high trait anxiety,[29,30] which was interpreted as deficits in response inhibition in trait-anxious individuals. It is worth noting that in our study trait anxiety was controlled so that our group did not differ in their scores in this construct, meaning that we can rule out the possibility that our group differences in the numerical task could be explained by trait anxiety. Moreover, our groups did not differ in their Nogo-N2 amplitude in the non-numerical task.

With regard to behavioral measures, the results showed that math anxiety has a significant effect on behavioral response inhibition. The groups did not differ in response time in either the numerical or the non-numerical task, and responses to the numerical task were slower in both groups. Interestingly, task differences emerged in the hit rate in Nogo trials (as a measure of response inhibition) only in the HMA group. HMA and LMA individuals were more error-prone in Nogo trials, where they needed to suppress the prepotent Go response, than in Go trials in both tasks, reproducing previous studies in the general population. Importantly, the Go—Nogo difference in hit rate was larger in the numerical than in the non-numerical task only in the HMA group, due to the fact that they committed more errors in Nogo trials (more false alarms) in the numerical task than in the non-numerical task. The LMA group showed no differences between tasks in terms of Nogo trial accuracy. These results again suggest inefficient domain-specific behavioral inhibition in the HMA group when they have to inhibit a prepotent response in a numerical task.

The results described above add further evidence to the dual competition framework,[31] which hypothesizes that the prioritization of emotional content processing may impair executive functions (in our study, the behavioral inhibition). According to this framework, when the threat of emotional content is high, the processing of this content is prioritized and may compete for the attentional resources needed to perform the task. Thus, the depletion of these resources may impair behavioral performance. Evidence supporting this hypothesis comes from a study[30] where an emotional Go/Nogo task was used and it was found that emotional faces (i.e., happy and unhappy) impaired response inhibition as compared to neutral faces, decreasing the amplitude of the frontal Nogo-N2 and producing less accurate responses in Nogo trials. Similar behavioral results have previously been reported,[27,28] identifying weakened response inhibition when emotional processing is high. In our study, the numerical task might have produced a negative emotional context that might have imposed more demands on HMA's working memory (i.e., their worry and concerns about failures in this task might have been increased as compared to the non-numerical task), consuming the limited attentional control resources needed for the inhibition task. According to Lavie's load theory of selective attention,[47] if the working memory load is increased, the attentional control resources available to perform the inhibition task are reduced.

Our findings also support the predictions of ACT,[8] suggesting that math anxiety impairs executive cognitive control, specifically response inhibition in numerical tasks, a function that requires goal-driven attention allocation. Thus, we provide further evidence of an impairment of the efficiency of central executive functions in HMA individuals.[11,14,15] These findings highlight the importance of the role that attentional control may play in explaining the negative association between math anxiety and mathematics performance. Moreover, ACT assumes that anxiety impairs performance effectiveness (i.e., the quality of performance or accuracy) to a lesser extent than processing efficiency (i.e., the relationship between performance effectiveness and the use of processing resources) because highly anxious individuals may often use compensatory mechanisms (i.e., enhanced effort by increasing the use of attentional control resources) to achieve performance effectiveness.[48] However, in our numerical task, HMA individuals' compensatory strategies might not have successfully compensated for the demands on attentional control, due to the fact that this group showed more false alarms in the numerical than in the non-numerical task (i.e., math anxiety would have had a negative impact on their performance effectiveness), despite having spent longer on the numerical task than on the non-numerical one. Thus, for this group, even though they invested more cognitive effort in the numerical task, their performance effectiveness was impaired in Nogo trials.

With regard to Nogo-P3, we found that this component was elicited after the frontocentral Nogo-N2 in both groups, suggesting that the inhibition of motor response[21] and/or the evaluation of the inhibition outcome[22] were not modulated by math anxiety. This result is consistent with previous studies that found no relationship between frontocentral Nogo-P3 amplitude and trait anxiety.[49] Moreover, Nogo-P3 amplitude and peak latencies did not differ between tasks in our study either. Thus, since it has been posited that Nogo-N2 and Nogo-P3 are indexes of different inhibitory-related functions, the present results suggest that math anxiety might negatively impact the first stage of the inhibition of a planned response before the actual motor process (reduced Nogo-N2), but not at a later stage of the inhibition process in which the outcome of inhibition is evaluated (indexed by Nogo-P3).

As with other experimental studies, we have to recognize some limitations. First, in our study, most of the individuals were female and women usually report higher levels of math anxiety than men.[50] However, it is noteworthy that we formed our groups such that they did not differ in gender, so that we could rule out the possibility that any group difference was due to gender differences. Furthermore, although no studies have reported that there was an interaction effect between gender and trait anxiety effects on inhibitory control, future studies might want to investigate whether the same pattern of results can be reproduced for both genders separately. Second, although we had adequate statistical power, attempts should be made to replicate the present results in future studies using a larger sample size. Lastly, even if we presented our result as evidence of HMA individuals' inhibitory difficulties in the numerical domain as compared to the non-numerical one, task differences in this group could also be attributed to HMAs' difficulties in identifying whether a number is odd or even. Previous studies suggested that math-anxious individuals might suffer from a low-level numerical deficit.[51–53] However, in our study, HMAs only experienced difficulty when they had to withhold their response in Nogo numerical trials (i.e., HMAs had more false alarms and smaller Nogo-N2 in the numerical than in the non-numerical task), and no task differences were found in Go trials (either in response time or hit rate). Thus, our results give stronger support to the hypothesis of HMAs' inhibitory difficulties in the numerical domain.

As a final point, we should highlight the possible implications of our results in the applied context. HMAs' deficit in response inhibition would make it difficult for them to learn and perform mathematics properly; they may adopt rigid and inflexible strategies when performing math tasks, which might not allow them to inhibit a set of previous knowledge (e.g., misconceptions) and mean that they continue to use inappropriate or inefficient strategies in their attempts to solve math problems. Previous studies suggested that math-anxious individuals use inefficient strategies when they are presented with large-split solutions in an arithmetic verification task[54] and in ordinal judgments.[55] These studies suggested that HMA individuals might have difficulties inhibiting a strategy that was appropriate in previous trials but not in the current one. In the context of math assessment situations, a reduced behavioral inhibition might mean that HMA individuals are unable to inhibit a dominant incorrect response, thus increasing their mistakes. Although previous studies suggested an alteration in the response monitoring system in HMA individuals,[56,57] to date, this altered response monitoring has not been associated with a deficit in behavioral inhibition. Future studies might want to study this issue further.

CONCLUSION

In conclusion, our study makes a clear contribution by showing that math anxiety is related to a numerical domain-specific inhibition deficit. Specifically, we found that math-anxious individuals have difficulties in suppressing their responses in a numerical task as compared with a non-numerical task. This finding was found at the behavioral and neural levels. This result lends support to ACT's assumption that one of the executive functions impaired in anxious populations is behavioral inhibition, extending this assumption to the case of math anxiety in a numerical context. It also supports the dual competition framework, which posits that the prioritization of emotional content processing may impair executive functions. Additionally, this contribution allows us to consider new potential treatments that focus on math-anxious individuals' maladaptive response inhibition behavior and are oriented toward increasing their ability to inhibit prepotent behavioral responses when performing mathematics.

AUTHOR CONTRIBUTIONS

María Isabel Núñez-Peña: Conceptualization; formal analysis; funding acquisition; investigation; methodology; project administration; resources; supervision; validation; writing original draft; writing review and editing. **Carlos Campos-Rodríguez**: Formal analysis; writing review and editing.

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COMPETING INTERESTS

The authors declare no competing interests.

DATA AVAILABILITY STATEMENT

Data will be made available on request.

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PEER REVIEW

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