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RESEARCH REPORT

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Math anxiety and the shifting function: An event-related potential study of arithmetic task switching

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Abstract

Why is math anxiety usually related to less efficient math processing? According to attentional control theory, anxiety leads to reduced attentional control, which often entails a greater investment of resources (e.g., more time or effort) to carry out a cognitive task. The executive functions mainly affected by anxiety are inhibition and shifting. Previous studies suggest that math anxiety may impair the inhibitory function. In the present study, the relationship between math anxiety and shifting efficiency when switching between two-digit additions and subtractions was examined. Twenty highly math-anxious and 20 low math-anxious individuals participated in an event-related potential (ERP) transition-cueing experiment. Math anxiety was expected to delay the shifting process, leading to a larger switch cost in response time and no centroparietal cue-locked switch-specific positivity registered in the electroencephalogram during the cue-target interval. Highly math-anxious individuals showed a larger switch cost than their low math-anxious peers. Asymmetrical switch effects between operations in response time were found in both groups, which might be due to larger sequential difficulty effects after subtractions than after additions. The cue-locked switch-specific positivity was present only in the low math-anxious group. The present results suggest that highly math-anxious individuals take longer to shift task sets. Additionally, the highly math-anxious group showed a more positive frontal P2 after the cue that announced a switch to subtraction, probably indicating stronger attentional capture by this cue, because the most threatening condition is anticipated. Taken together, these data suggest that math anxiety also impairs attentional control when switching between arithmetic tasks.

KEYWORDS

arithmetic operations, attentional control theory, frontal P2, math anxiety, switch positivity, task switching

List of Abbreviations: ACT, attentional control theory; ERP, event-related brain potential; sMARS, Shortened Mathematics Anxiety Rating Scale; STAI, State–Trait Anxiety Inventory.

[Correction added on 25 April 2023, after first online publication: Supporting information has been updated in this version.]

1 | INTRODUCTION

The school bell rings. John stops chatting and shifts his attention to the new task instructions on the blackboard. He gets nervous: It is math time. 'Today we will practice two-digit operations. Please solve these additions and subtractions', says the teacher. 'I won't be able to do it', John thinks. This emotional state of tension and dread that emerges in math-related academic or daily contexts is referred to as math anxiety, and it is highly prevalent in society (Eden et al., 2013; Suárez-Pellicioni et al., 2016).

Math anxiety has been repeatedly found to correlate negatively with arithmetic processing and performance (e.g., Ashcraft & Faust, 1994; Núñez-Peña & Suárez-Pellicioni, 2015). This can have important repercussions. For example highly math-anxious individuals will likely have a more limited range of employment opportunities (Foley et al., 2017). It is therefore essential to elucidate further the cognitive processes that underpin the negative effects of math anxiety on mathematical achievement. A considerable amount of empirical evidence (e.g., De Agostini, 2020; Núñez-Peña et al., 2019; Pletzer et al., 2015) points to an impairment of attentional control and executive functions in the highly math-anxious population. Executive functions are the central control processes of the cognitive system (Miyake et al., 2000): they are fundamental to the correct execution of cognitive tasks in general (Miyake et al., 2000), and math tasks in particular (e.g., Blair et al., 2008; Vosniadou et al., 2018). Furthermore, as executive functions related with attentional control can also be recruited during emotional processing and emotional regulation (e.g., Sperduti et al., 2017), and the capacity to regulate negative emotions may in turn influence math performance (e.g., Lyons & Beilock, 2012a), inefficient executive processing might be doubly detrimental for good math achievement during bouts of anxiety.

The idea that impaired executive control underlies the difficulties that highly math-anxious individuals experience when faced with math tasks is consistent with attentional control theory (ACT, Eysenck et al., 2007). A key premise of ACT is that anxiety affects cognitive processing by impairing the efficiency of the central executive component of the working memory system (Baddeley, 1986), weakening, primarily, the executive functions related with attentional control. This hypothesis rests on the assumption that when individuals feel endangered it is more adaptive to spread attentional resources (i.e., prioritizing so as to allocate them to internal or external threatening information) than it is to focus on a particular task, thus decreasing the role of the goal-directed (top-down) attentional system in favour of the stimulus-driven (bottom-up) one (Corbetta & Shulman, 2002). This diminished attentional control usually results in a greater investment of time or effort (reduced processing efficiency) to achieve cognitive performance. When the increment of time or processing resources remain insufficient to compensate for the lack of attentional control, effectiveness (i.e., quality of task results) can also be reduced.

According to ACT, the executive functions most affected by anxiety would be shifting and inhibition (Eysenck et al., 2007).[1] The first executive function is conceived by ACT and the present study based on Miyake et al.'s (2000) definition: 'shifting back and forth between multiple tasks, operations, or mental sets (Monsell, 1996)' (p. 55). Thus, the shifting function involves using attentional control to switch the allocation of attention in order to concentrate on task-relevant processes. Inhibition refers to the ability to use attentional control to avoid distracting stimuli or dominant responses that are irrelevant to one's goals. These two executive functions therefore ensure that the attentional focus can be both led to and held where it is needed to achieve a goal. In accordance with ACT, an impairment of the inhibitory function would affect the ability to ignore task-irrelevant external information as well as the distracting worrisome thoughts and emotions that a state of anxiety usually involves (such as the 'I won't be able to do it' thought by John at the beginning of this article). As for an impairment of the shifting function, this could make it harder to direct attentional focus back to the task-relevant mental set, and also to switch between different task processes. In support of the ACT framework, several studies have shown reduced inhibition in highly math-anxious individuals (e.g., Hopko et al., 2002; Núñez-Peña et al., 2021). The aim of the present study is to investigate whether math anxiety is related to inefficient shifting when performing maths.

The shifting function is needed for switching between different elements in a mathematical problem (Blair & Razza, 2007) and even in everyday arithmetic tasks (Curtis, 2012). Indeed, shifting ability is positively associated with math performance during both childhood (e.g., Clark et al., 2010) and adulthood (e.g., Molzhon, 2010; Schwaighofer et al., 2016). Hence, testing shifting efficiency seems an important step towards a better understanding of math difficulties among highly math-anxious individuals.

Derakshan and Eysenck (2009) suggested that the optimal methodology for testing the ACT's prediction that anxiety impairs shifting efficiency 'is one based on task-switching paradigms' (p. 173). These paradigms consist of two (or more) tasks to be performed in two different conditions: the switching condition, implying changing from one task to another, and the non-switching condition, where the same task is performed successively (Monsell, 2003). When a task switch is required, participants' performance usually decays. This is known as the 'switch cost' and it frequently affects time efficiency (slower response time).

There are many types of task-switching paradigms (for a summary, see Monsell, 2003, box 2). In the traditional task-switching paradigm (Jersild, 1927), mean response time in single-task blocks is compared with mean response time in switching blocks in which participants are asked to alternate tasks. The different value was originally thought to reflect the switch cost. However, it was later found that if a task is repeated in a two-task block, the response is usually slower than in a single-task block. Therefore, costs measured by the traditional task-switching paradigms consisted of mixing costs and not just of a switch cost. This led researchers to design new task-switching paradigms, such as the task-cueing paradigms, in which switching and repeating trials are randomly presented (a cue informs the participant about the task to be performed) and the switch cost is computed as the difference between switching and repeating trials. The occurrence and the magnitude of the switch cost depend on several factors. For example, proffering task-explicit cues reduces it (Rubinstein et al., 2001), and providing long cue-target intervals can even avoid the switch cost (e.g., Wylie et al., 2009).

The present study shares the assumption that task switching relies, at least partially, on executive control and, specifically, on the shifting function. Indeed, this function is 'also referred to as "attention switching" or "task switching"' (Miyake et al., 2000, p. 55). This idea led ACT to state that high anxious people experience a larger switch cost in response time than do low anxious individuals when demands on attentional control are high, as a consequence of the less efficient shifting generated by anxiety (Eysenck et al., 2007). Proactive and reactive control can be executed in task switching paradigms (Karayanidis & Jamadar, 2014). Proactive control is the goal-directed control involved in mental preparation for an upcoming switch, and it is expected to be the one impaired by anxiety (Braver, 2012), and also by math anxiety (Colomé et al., 2022). In the present study it is assumed that, at least when there is a long enough interval between tasks to minimize interference of the previous task set (Monsell, 2003), shifting is the main function required during goal-directed task-set reconfiguration (for more information and definitions of the concepts of task set and reconfiguration, see, for example, Rogers & Monsell, 1995, Schneider & Logan, 2007 or Grange & Houghton, 2014; see also Koch et al., 2010 and Wylie et al., 2003a for other relevant accounts of the executive processes that may explain preparation for a switch).

Derakshan et al. (2009) tested the ACT's prediction of anxiety impairing shifting by using a traditional task-switching paradigm. In the study by Derakshan et al., participants were asked to perform arithmetic operations. In switching blocks two arithmetic tasks alternated and goal-directed task-set reconfiguration was required. State anxiety of participants was measured after they were instructed about the experiment and, the sample was then divided into a low anxious and a high anxious group. State anxiety was also assessed in the middle and at the end of the test. Derakshan and colleagues found no switch effect in the low anxious group. As expected, the high anxious group did show a switch cost in response time. The switch cost was related to state anxiety but not to trait anxiety. Although these authors did not study math anxiety, the fact that the high anxious group comprised participants who reported greater state anxiety after knowing the mathematical nature of the tasks (and also during the experiment), together with the use of arithmetic task switching, makes this study a relevant antecedent for the current one. However, their data must be taken cautiously because this traditional task-switching paradigm confounds switch costs and mixing costs (e.g., Monsell, 2003).

As for previous studies evaluating shifting in the field of math anxiety, in a functional neuroimaging study, Pizzie et al. (2020) examined if neural activity associated with mathematical calculations was enhanced or decreased by math anxiety when demands on executive functions increase. With regard to shifting, they used a task-switching paradigm in which variable-length sequences of an arithmetic task and a non-mathematical task were alternated inside each block. Given the unpredictable nature of the sequence and the absence of cues, the task to perform was only recognizable by the task-specific type of stimuli presented in each trial. Therefore, shifting could not be proactively anticipated and the task set was activated in a reactive manner. Decreased neural activity when switching to math was found in the highly math-anxious group, which the authors attributed to 'a reduced ability to recruit neural networks that would effectively subserve mathematical computations' (Pizzie et al., 2020, p. 323). By contrast, the low math-anxious group was able to quickly and properly recruit the networks underlying arithmetic processing in math switching trials. Pizzie and colleagues also found speeded responses when the highly math-anxious group switched to the math task, which they described as a mathematics avoidance behaviour. Results were interpreted as a disruption of working memory caused by distracting internal stimuli (e.g., intrusive rumination) in highly math-anxious individuals.

From the perspective of ACT, this disruption of working memory consists in reduced attentional control. The highly math-anxious participants in Pizzie et al.'s experiment might have exerted more executive effort in math-switching trials in order to compensate for the reduced attentional control. Because mental effort is associated with an aversive emotional response that may motivate task disengagement (Kurzban et al., 2013), avoidance behaviour in the more control-demanding and emotionally negative trials (i.e., switching + math trials) would be likely to occur among highly math-anxious individuals when the task contains both mathematical and non-mathematical trials, explaining their speeded responses in math-switching trials. However, the presence of avoidance speeding-up behaviour introduces a confounding factor which prevents the use of switch cost as a tool to examine group differences in the shifting process. This fact and the use of a paradigm in which the task set is mainly bottom-up activated by task-specific stimuli, makes it difficult to use these results to test the specific prediction of ACT regarding proactive shifting efficiency.

In the present study, to determine whether math anxiety is associated with a less efficient shifting function when performing math operations, two groups of participants who rated low and high on trait-math anxiety were asked to switch between two arithmetic tasks, so that there was no possibility of avoiding math through a speeding-up strategy. Considering that the impairment of the shifting function requires the actual experience of anxiety (Derakshan et al., 2009), the level of state anxiety generated by the task was measured to ensure that groups also differed in state-math anxiety, as expected. Because proactive task-set reconfiguration can be temporally distinguished by measuring electrophysiological modulations during preparation for a switch (Karayanidis & Jamadar, 2014), event-related brain potentials (ERP) were recorded. An interval wherein shifting could be anticipated was provided by using a task-cueing paradigm with transition cues. In this task-switching paradigm, which is novel in the framework of both ACT and math anxiety, a cue is presented before the target in every trial informing participants whether to repeat or switch the task, without explicitly indicating the operation. Both tasks are performed in all blocks, and hence, the upcoming task is unpredictable and depends on the information provided by the cue. In addition to allowing proactive control to be separated from the task itself and examined as an ERP modulation (Karayanidis & Jamadar, 2014), the switch cost measured by task-cueing paradigms (i.e., the cost in switching trials when compared with repeating trials) should better capture the cost of shifting, because other costs (i.e., longer-lasting mixing costs of multiple-task blocks compared with single-task blocks, as well as restart costs generated by cue interruption) are nullified (e.g., Foxe et al., 2014). Moreover, transition cues pose higher attentional control demands than do task cues and provide 'the opportunity to investigate the internal generation of task sets' (Forstmann et al., 2005, p. 944). Because these cues do not directly activate a specific task set in mind, the goal-directed control process of shifting can be better examined (Grange & Houghton, 2014).

Considering the findings of Derakshan et al. (2009), as well as previous evidence showing decreased processing efficiency (longer response time) among highly math-anxious individuals (e.g., Núñez-Peña et al., 2019), it was hypothesized that math anxiety would reduce shifting efficiency when switching between mathematical tasks, delaying the shifting process and, therefore, deferring the onset of mathematical calculation and increasing time switch costs. According to some previous task-cueing studies, when the cue-target interval is set long enough and task-set reconfiguration can be completed before the target appears, no behavioural switch cost is detected (e.g., Barceló & Cooper, 2018; Foxe et al., 2014; Wylie et al., 2006, 2009). Moreover, low anxious individuals in Derakshan et al.'s study did not show any switch cost. Based on this evidence, allowing a preparation interval long enough for non-impaired attentional control to anticipate shifting (but short enough to pose a challenge in the event of impaired attentional control) may result in a switch cost only in participants with a less efficient shifting function, that is, highly math-anxious individuals.

At the same time, neural responses were measured during the interval in which the proactive attentional shift from one task set to another could be executed before beginning any mathematical calculation. Since math anxiety was hypothesized to be associated with a delayed shifting process, it was expected that only the low math-anxious group would present the neural correlate of shifting during that cue-target interval. ERP studies usually show an increase in late positivities when switching is anticipated after a transition cue (e.g., Barceló et al., 2008; Hsieh & Wu, 2011; Rushworth et al., 2002). Switch positivities are thought to reflect proactive control (Karayanidis & Jamadar, 2014) and their time window varies from 300 to 1000 ms, approximately. Several studies have found significant negative associations between the amplitude of late switch positivities and behavioural switch costs. For example, negative correlations between switch costs in response time and cue-locked switch positivities from 600 to 900 ms led Kieffaber and Hetrick (2005) to propose that efficient switch-specific control processes that anticipate reconfiguration of attentional set explain those electrophysiological positivities in task-switching tests.

Interestingly, Barceló and Cooper (2018) examined the several late frontoparietal positivities elicited in task-switching, go/no-go, and oddball tasks. They found that, from among the positivities that were larger after a transition switching cue that after a transition repeating cue, only those measured in centroparietal electrodes during a later cue-locked late positive component (LPC) window (750–850 ms after cue onset) were solely elicited by switching cues (they were not elicited by repeating or no-go cues). Thus, later switch positivities with a more centroparietal topography more purely reflected the switch-specific process executed by higher-level control (hereinafter, 'switch-specific positivity'). Hence, this specific ERP modulation was the one analysed in the present study to further ensure that proactive shifting, as conceived by ACT, was the process measured. Therefore, it was expected that only a non-impaired shifting function would relocate attentional focus to the new task set around that latency after the switching cue onset, generating a switch-specific positivity over the centroparietal scalp region in this late LPC window. As far as we know, this is the first study to examine a neurophysiological correlate of the shifting function in the field of math anxiety.

In addition to studying the switch-specific component, the relationship between math anxiety and the cue-locked frontal P2, another ERP modulation that is sometimes observed in the switching condition (e.g., Tieges et al., 2007; West et al., 2011), was also explored. In general, P2 is an attention-related component that emerges around 150 to 250 ms after the stimulus over the frontal scalp (e.g., Hillyard & Münte, 1984; Smid et al., 1999). Some studies have correlated P2 amplitude with the negative valence or the threatening content of attended stimuli (e.g., Carretié et al., 2001; Massar, 2012), or with the investment of attentional resources when facing emotionally salient stimuli (e.g., Yuan et al., 2009). Because cognitive effort is perceived as emotionally negative (Kurzban et al., 2013), the more positive P2 that is sometimes seen after certain switching cues, compared with repetition cues, might be explained by the increased relevance of cues that announce a greater cognitive effort. Indeed, there are studies in which P2 is only increased when switching cues indicate higher complexity (e.g., Han et al., 2018; Kieffaber & Hetrick, 2005). In this line, Vermeylen et al. (2019) showed that switching cues can be evaluated as negative when there is an associated effort: the larger the time switch cost is, the larger the affective cost. According to these authors, a less efficient executive control would be related to a more negative valence of the cue. Therefore, given that the reduced attentional control in individuals experiencing anxiety usually generates a greater cognitive effort (Ansari & Derakshan, 2011; Eysenck et al., 2007), it was expected that highly math-anxious participants would perceive switching cues as more negative than repetition cues, and hence that the former cues would more strongly engage their attention, thereby generating a more positive frontal P2. Also of relevance here is the study by Bar-Haim et al. (2005) in which angry faces were found to elicit a more positive P2 in high trait-anxious participants, indicating a 'greater mobilization of attentional resources' (p. 19). This attentional bias towards emotionally negative stimuli, usually associated with anxiety (Yiend, 2010), was also proposed as an explanation for the larger P2 found in highly math-anxious individuals when solving a multi-digit addition task (Núñez-Peña & Suárez-Pellicioni, 2015). Given that math anxiety has been related to a greater cognitive effort during demanding tasks (Núñez-Peña et al., 2019) and to neural correlates of threat and pain when anticipating difficult trials (Lyons & Beilock, 2012b), the decision of analysing frontal P2 was taken to explore whether cues announcing relative harder upcoming cognitive effort would act as threat alerts able to recruit greater selective-attention resources in highly math-anxious people.

Considering all the above, predictions in this study were as follows. First, since highly math-anxious individuals are prone to experiencing higher state anxiety when performing maths (e.g., Conlon et al., 2021; Di Lonardo Burr & LeFevre, 2021), groups were predicted to differ in state-math anxiety. Second, because executive functions are required during arithmetic processing, math anxiety was expected to be associated with a general deficit in time efficiency (i.e., longer response time), and given the use of highly demanding tasks (two-digit numbers and both carrying and non-carrying operations), with worse math performance effectiveness as well (i.e., less accuracy). Third, an interaction between group and cue type (i.e., repeating or switching) in the response time results was predicted. Considering the long cue-target interval, as well as Derakshan et al.'s results, it was hypothesized that low math-anxious individuals would be able to preempt and execute shifting before the occurrence of operands in most trials. Therefore, they were not expected to present any switch cost—or, if anything, a smaller residual switch cost—while highly math-anxious individuals were expected to show larger switch cost in response time. Fourth, and importantly, it was anticipated that the switch-specific positivity would only be detected in low math-anxious individuals, as a correlate of this efficient proactive control. Finally, frontal P2 amplitude in each condition was explored. It was predicted that highly math-anxious individuals would present a more positive frontal P2 when a harder cognitive effort was announced.

2 | MATERIALS AND METHODS

2.1 | Participants

Forty students (22 female and 18 male) from the University of Barcelona participated in this study. They were selected from a sample of 827 students who had been previously assessed for trait anxiety and math anxiety in the framework of a larger project. Based on this assessment, two groups differing strongly in their level of math anxiety were formed. The low math-anxious group comprised 20 students from among those who had scored below the first quartile ($Q_1 = 53$) on the *Shortened Mathematics Anxiety Rating Scale* (Alexander & Martray, 1989), while the highly math-anxious group was formed by 20 of their peers who had scored above the third quartile ($Q_3 = 77$). Thus, groups differed in math anxiety ($t[38] = 15.40$, $p < .001$). In selecting participants, it was also ensured that the two groups were equivalent in terms of trait anxiety ($t[38] = .33$, $p = .75$); trait and math anxiety are highly correlated (Hembree, 1990), and matching the groups on the former was therefore important to rule out the possibility that any group differences were due to this variable. In addition, and given that, according to ACT (Eysenck et al., 2007), extreme values of trait anxiety might affect attentional control, participants who scored within the central 80% region of the sampling distribution on the *State–Trait Anxiety Inventory* (i.e., from 9 to 36, percentile 10 and 90 of the aforementioned larger sample; Spielberger et al., 1983) were selected. For the present study, working memory span was also measured by running a computerized Corsi test (see Section 2.2) on a different day, because it has been suggested that working memory capacity might mediate the relationship between anxiety and shifting efficiency (Edwards et al., 2015). The results of this test showed no differences between groups in working memory span ($t[38] < 1$, $p = .89$), with scores ranging from 5 to 9 in both the low math-anxious and highly math-anxious groups. Finally, groups did not differ in gender (9 males in each group), handedness ($\chi^2[1] = 1.03$, $p = .31$) or age ($t[38] = 1.49$, $p = .14$). The age range of participants was 20–31 years old. More detailed information about the two groups is provided in Table 1.

None of the participants were taking any medication that might affect their performance or electrophysiological response. All of them reported normal hearing and properly corrected vision. They each signed an informed consent statement and were asked about their handedness before starting the experiment. They were paid for their participation. This study was conducted within a broader research project that was approved by the Ethics Committee of the University of Barcelona.

2.2 | Materials

2.2.1 | Shortened Mathematics Anxiety Rating Scale (sMARS)

The Shortened Mathematics Anxiety Rating Scale (sMARS; Alexander & Martray, 1989) is a 25-item version of the Math Anxiety Rating Scale (MARS; Richardson & Suinn, 1972). Respondents rate their level of anxiety in response to each of 25 situations that might cause math anxiety (e.g., 'being given a set of subtraction problems to solve'), using a 5-point Likert-type scale ranging from 1 (no anxiety) to 5 (high anxiety). Item scores are summed to obtain the respondent's total score, which therefore ranges from 25 to 125 points. Here the Spanish version of the sMARS (Núñez-Peña et al., 2013) was used, which has good psychometric properties (Cronbach's alpha was .94 and the intra-class correlation coefficient for 7-week test–retest reliability was .72).

2.2.2 | State–Trait Anxiety Inventory (STAI)

The State–Trait Anxiety Inventory (STAI; Spielberger et al., 1983) comprises 40 items, half of which are used to measure state anxiety (STAI-S), while the other half assess trait anxiety (STAI-T). In the present study the Spanish version of the STAI (Spielberger et al., 2008), which has shown good psychometric properties (Cronbach's alpha = .95 and 20-day test–retest reliability with college students = .86), was used. The STAI-T subscale, which measures a more stable tendency to respond with anxiety, was used during the process of selecting

TABLE 1 Means and SEM (in brackets) for math anxiety, trait anxiety, working memory span and age for both groups. Number of women and right-handed participants is also shown.

	Math anxiety	Trait anxiety	Working memory span	Age	Gender	Handedness
Low math-anxious group	43.50 (1.43)	21.05 (1.39)	6.55 (.24)	22.40 (.55)	11	19
Highly math-anxious group	86.60 (2.41)	21.75 (1.63)	6.60 (.28)	23.65 (.64)	11	20

participants. The 20 statements in the STAI-T subscale describe different feelings that respondents must rate using a 4-point Likert-type scale, ranging from 0 (*almost never*) to 3 (*almost always*), indicating how they feel 'in general'. The total score on this subscale therefore ranges from 0 to 60. The STAI-S subscale measures a transitory emotional state of anxiety by asking about different feelings at a particular moment, and it was used here during the experimental session. Items on the STAI-S are also rated using a 4-point Likert-type scale, ranging from 0 (*not at all*) to 3 (*very much*). Several studies (e.g., Davey et al., 2007; Van Knippenberg et al., 1990) have shown that valid short versions of the STAI-S subscale can be created by selecting certain items. In order to quickly measure the level of state anxiety generated by the arithmetic tasks (hereinafter, state-math anxiety), four items (3, 5, 12 and 17) were selected from the six included in the short version of the subscale used by Fioravanti-Bastos et al. (2011), which has also shown a good fit in the Spanish population (Buela-Casal & Guillén-Riquelme, 2017). At the end of each item, the statement 'due to the arithmetic task I am doing' (e.g., 'I feel tense due to the arithmetic task I am doing') was added. The total score for each participant on this short version of the STAI-S subscale ranged from 0 to 12. A similar short questionnaire, also developed from the STAI-S to measure state-math anxiety, has recently been shown to have good psychometric properties in children (Orbach et al., 2020).

2.2.3 | Corsi test (Corsi, 1972)

As mentioned above (see Section 2.1), working memory span was measured to control that group differences in behavioural and ERPs results were not due to differences in working memory capacity. For this purpose, the Corsi test, which is a classical task designed to calculate a person's working memory span, was used. Information regarding normative data of the Corsi test in its classical non-electronic version can be found in Kessels et al. (2000). Electronic versions provide several advantages over traditional standardized versions while obtaining analogous average span rates (Brunetti et al., 2014). Here the PsyToolkit computerized version was used (https://www.psytoolkit.org/experiment-library/corsi.html; implementation from Professor Gijsbert Stoet; Stoet, 2017). Nine pink blocks were presented on the screen, a specific spatial sequence of blocks was signaled (by being lit up in yellow on the screen), and participants were then asked to click the previously lit blocks in the same order. Sequences started with two lit blocks and increased in difficulty after each accurate trial by adding one more block to remember. The test finished after two consecutive error trials. The participant's working memory span was the number of blocks of the longest accurate sequence. Further details can be found at the abovementioned link.

2.2.4 | Arithmetic operations

All participants were presented with the same 25 additions and 25 subtractions (see Appendix S1). They were required to verify the correct solution among two options. Both operands and solutions were two-digit numbers. Operands were selected from within the same number range for additions and subtractions: in all cases, the first operand ranged from 42 to 69, and the second operand from 12 to 29. Operands ending in 0 or 1 were not included. Operations with both operands ending with the same unit (e.g., $53 + 23 = 76$), those comprising a first operand that was a multiple of the second one (e.g., $48–24 = 24$), and those resulting in a number ending in 0 (e.g., $57 + 23 = 80$) were also excluded because they might be much faster to calculate (Ashcraft, 1982; LeFevre et al., 2004).

All possible additions and subtractions that met these criteria were generated using MATLAB® 9.1.0.441655 (R2016b) software (Copyright [C] 1994–2020 The MathWorks, Inc.), and 50 of them were randomly selected (see Appendix). Each possible first operand appeared in at least one of the 50 operations. In order to make the tasks demanding enough to allow anxiety-linked impairment of the shifting function to be detected (Derakshan et al., 2009), 25 of the two-digit operations (12 additions and 13 subtractions) required carrying (e.g., $62–24 = 38$), because carrying operations have been shown to increase executive demands (Imbo et al., 2007). In addition, to avoid the use of strategies such as verifying only units, incorrect solutions (see Section 2.3) were generated by adding ±10 (large-split) or ±2 (small-split) to the correct solution. Each of the 50 operations was presented four times during the task (see Section 2.3) so as to control for the correct-response hand (correct solution presented on the right or left side of the screen) and the type of incorrect solution presented (large-split vs. small-split). The same operation was never displayed in successive trials.

2.3 | Procedure

Participants were tested individually. They were seated 150 cm away from the computer screen in an electrically shielded, sound-attenuating recording chamber. EEG sensor electrodes were then attached. Participants were asked to stay still and quiet while performing the test.

The task-switching test consisted in repeating or switching between the verification of two types of arithmetic operations traditionally used in task-switching studies (e.g., Baddeley et al., 2001; Jersild, 1927): additions and subtractions. Each trial began with a transition cue, instructing the participant either to repeat the same operation done immediately before or to switch it (see Figure 1). The words 'repite' (repeat) or 'cambia' (switch) were shown for 600 ms, horizontally centred and slightly above the centre of the screen (at the same vertical position in which the operands were next presented) in a 32-point font size (all stimuli were displayed in a white bold Courier New font). Participants were asked to pay attention to this word (repeat or switch) so as to know whether to add or subtract. The cue-to-stimulus interval was variable between 350 and 500 ms. Therefore, the cue-target interval lasted between 950 and 1100 ms, a period expected to be enough for participants with non-impaired attentional control to proactively execute task-set shifting beforehand (according to several previous studies; e.g., Barceló & Cooper, 2018; Wylie et al., 2009) in order to be ready to start calculation as soon as the operands appeared (that is, to execute an efficient shift and reduce or even avoid a switch cost). Next, the operands (in a 50-point font size) appeared on the screen. The first operand was located at the 41% position and the second operand at the 59% position along the horizontal axis of the screen. Both numbers were presented at the 40% position along the vertical axis. There was no mathematical symbol between the operands (i.e., no explicit task cue). The operands were presented alone on the screen for 1500 ms to allow the onset of calculation before the solutions appeared, dissuading participants from waiting to process the magnitude of the solutions to reactively shift the task set. Next, two possible solutions (the correct solution and the incorrect one) were shown underneath (slightly below the centre, at the 60% position along the vertical axis of the screen, and a bit closer together than the operands, specifically at the 43% and 57% positions along the horizontal axis) in a 42-point font size. Participants were instructed to choose the correct solution, responding as accurately and quickly

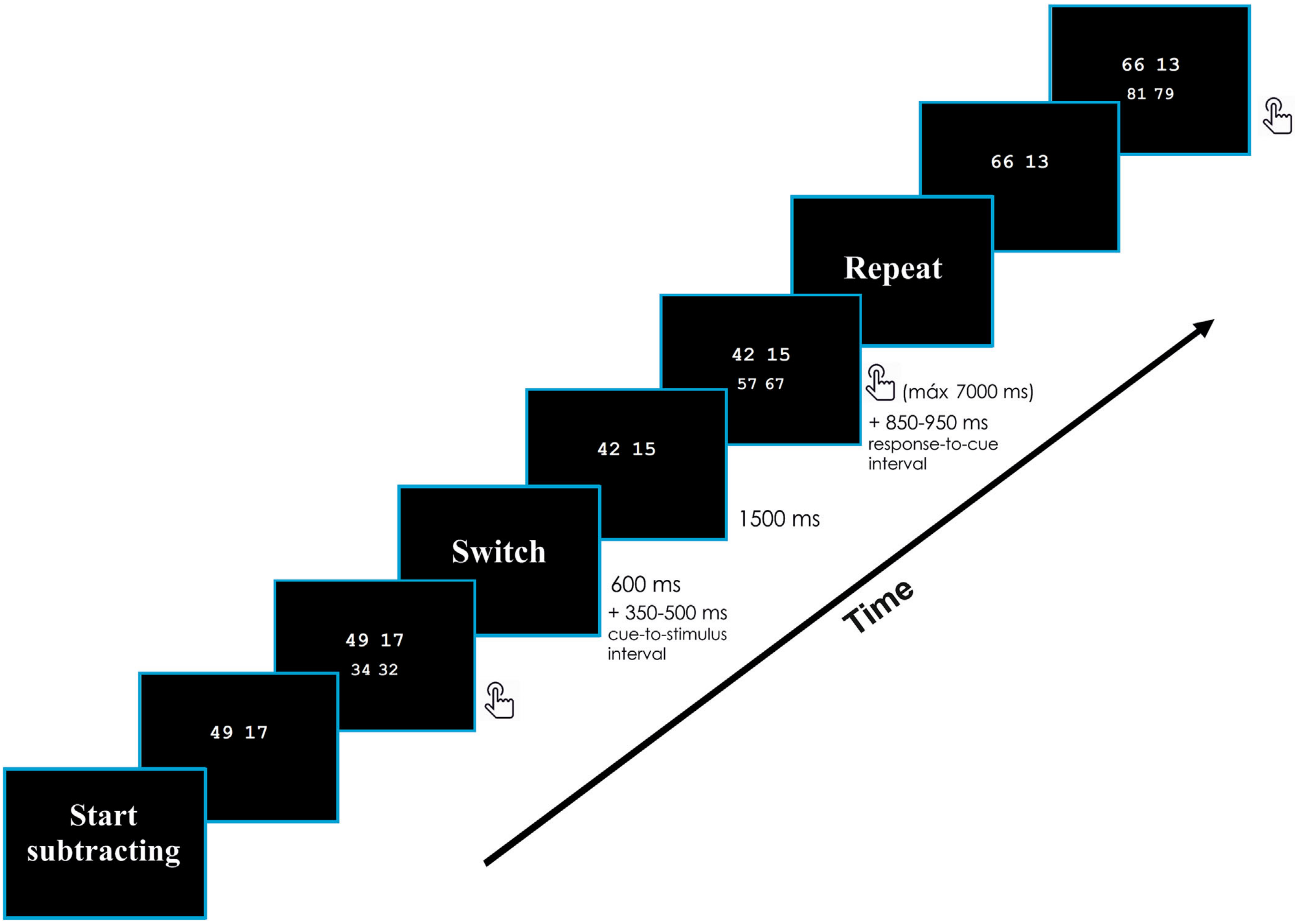

FIGURE 1 Example of the start of a block, with a beginning trial indicating the initial operation, followed by a switching trial and a repeating trial.

as possible, by pressing the mouse buttons with their left or right thumb. Both operands and solutions were presented on the screen until the participant answered, or for a maximum of 7 s. The response-cue interval was randomly variable between 850 and 950 ms. This long interval served both to ensure clean cue-locked ERP epochs (e.g., free from error-related negativity) and to reduce the activation of the previous task-set (Gade & Koch, 2005) so that performance would not be influenced by group differences in inhibition efficiency.

The recording session consisted of 10 blocks with 20 arithmetic operations, yielding a total of 200 trials. Before each block, there was an extra trial (hereinafter, beginning trial) in which the cue indicated whether to start adding or subtracting. The structure of these trials and the criteria for selected operations was the same as in the experimental trials, but operations were extracted from an independent pool of additions and subtractions, and they were not entered in the analyses. There were pauses between blocks to let participants rest and blink freely. Participants decided when to continue with the experiment. In the middle of the test (during the fifth pause), they completed the state math-anxiety questionnaire.

Additions and subtractions were equally distributed in both repetitions and switches. There was a maximum of four consecutive repetitions (hereinafter, repetition series) and a maximum of three consecutive switches. In total, there were 20 repetition series of additions and 20 repetition series of subtractions, 10% of which consisted of just one repetition; 20% involved two consecutive repetitions, 30% three consecutive repetitions, and 40% four consecutive repetitions. Given that in repetition trials following a switch there might not be a complete recovery from a task-switch cost when unpredictable sequences are used (Monsell, 2003), the first trial in each repetition series were excluded from the analysis. Therefore, 160 trials were included in the analysis, 40 trials for each experimental condition: switching to additions, repeating additions, switching to subtractions, and repeating subtractions. To control for the split effect (Núñez-Peña & Escera, 2007), large-split and small-split solutions (see Section 2.2.4) were equally distributed in the four experimental conditions.

Using MATLAB® software (version 9.1.0.441655 R2016b), a single sequence of 200 trials that could be segmented into 10 blocks of 20 trials fulfilling the above-mentioned criteria was generated. Each participant was presented with these 10 blocks in random order. The specific operands used for each trial were also selected randomly for each participant from the pool of experimental operations (see Section 2.2.4).

The recording session was preceded by a training block, identical to an experimental block (i.e., $1 + 20$ trials). After this block, participants received feedback about their performance. If their accuracy was lower than 80%, they received a second training block before starting the experiment.

The task was designed and presented using the E-Prime 2.0 software (Psychology Software Tools Inc., Sharpsburg, PA). Stimuli were displayed on a black background and presented on a square NEC MultiSync FE770-bk monitor (image size: 16″). During the experiment, the pixel resolution was 1024×768, and there was a vertical refresh rate of 59.8 Hz.

2.4 | Electrophysiological recording

The EEG signal was recorded using the Scan 4.5 hardware and software (Compumedics Neuroscan, Inc., Herndon, VA), with a sampling rate of 500 Hz. To measure brain signal 32 tin electrodes whose position in the elastic electro-cap followed the 10/10 International System were used: eight electrodes placed over the midline sagittal plane sites at Fpz, Fz, FCz, Cz, CPz, Pz, POz and Oz locations, together with 12 lateral pairs of electrodes over standard sites in 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, and with the ground electrode located between FPz and Fz. The electro-cap was also placed according to the 10/10 International System, with FPz at 10% of the nasion-inion distance.

Five independent electrodes were also employed. One of them was placed on the outer canthus of the right eye and another below the left eye to record the horizontal and vertical electro-oculogram movement, respectively. A further two electrodes were then placed at the mastoids and used later for re-referencing. Finally, the common reference electrode was placed on the tip of the nose. Electrode impedance was always maintained below 5 kΩ.

2.5 | Data analysis

2.5.1 | Behavioural data

First, a t-test was run to analyse whether highly math-anxious and low math-anxious individuals also differed in state-math anxiety when performing complex arithmetic operations.

Second, medians of response time (measured from the moment at which solutions appeared on the screen) were computed for each condition and participant, as medians provide measure of central tendency that is less skewed by outliers (Maxwell & Delaney, 2004). Only accurate trials were included. These were first examined using ANOVA, taking Cue Type (Repeat vs. Switch) and Operation (Addition vs. Subtraction) as the within-subject factors, and Group (low math-anxious vs. highly math-anxious) as the between-subjects factor. The F value, the degrees of freedom, the probability level and the η_p^2 effect size index are reported.

Third, to compute the switch effect per group and operation, the difference value obtained when subtracting the median response time in repeating trials from the median response time in switching trials was calculated for each participant and for both operations. Switch effects were submitted to t-tests in order to evaluate whether they differ from zero.

Fourth, Spearman's correlation was used to examine the association between the participants' scores on the sMARS and their mean switch effect.

Finally, to examine differences in accuracy between groups and to determine whether there was any switch cost in accuracy, hit rate (i.e., the proportion of trials responded accurately for each condition in each participant) was also analysed. The same statistical analyses run in response time were performed for hit rate: an ANOVA was carried out, taking Cue Type and Operation as the within-subject factors, and Group as the between-subjects factor, and the switch effect (difference value between Cue Type conditions) was submitted to a t-test for each operation and group.

All statistical analysis were conducted using IBM SPSS Statistics (Version 24) software. Significance level was set at $p \leq .05$ (Fisher, 1932) and only significant results are reported in the text. Complete ANOVA tables for response time, hit rate and EEG results are provided in the supporting information (Appendix S2).

2.5.2 | EEG data

The EEG data were pre-processed using the 2019.0 version of EEGLAB, a toolbox of MATLAB® 9.7.0.1319299 (R2019b) software (Copyright (C) 1994-2020 The MathWorks, Inc). Because most task-switching studies that analyse ERPs have used mastoids as a reference (e.g., Barceló et al., 2008; Barceló & Cooper, 2018; Han et al., 2018), the present data were also re-referenced to the average of the mastoid signal. A band-pass finite impulse response filter was initially applied from .5 to 70 Hz (half-amplitude cutoff with transition bands of .5 and 5 Hz, respectively), before running an independent components analysis. Also, before running the independent components analysis, a few non-stereotypical artifacts (e.g., a brief fragment of signal with an unusually large amplitude because of an exceptional impedance problem or abrupt movement) were rejected. On average, 11% of trials were rejected (range across subjects = 0%–1%). The independent components analysis was run using the Infomax algorithm provided by EEGLAB (Delorme & Makeig, 2004) in order to correct the signal for eye movement-related activity and other stereotypical artifacts, such as those from forehead and temporalis muscle activity (Mozaffar & Petr, 2002). After artefact correction, data were low-pass filtered at 30 Hz (transition band of 5 Hz). Finally, ERPLAB (Lopez-Calderon & Luck, 2014) was used to extract and average cue-locked epochs (−100 ms to 900 ms) for each experimental condition of every participant, relative to a pre-stimulus baseline of 100 ms. Only trials wherein the correct solution was selected were included in the ERP average. The mean number of epochs included in the ERP averages for each condition of each participant was 33.65 (SEM = .65).

Since Barceló and Cooper (2018) found a cue-locked switch-specific positivity in central and parietal electrodes from 750 to 850 ms after transition cues, mean amplitudes in that time window in central (C3, Cz and C4), centroparietal (CP3, CPz, and CP4), and parietal (P3, Pz and P4) electrodes were examined. The same factors used in the response time analysis were introduced in an ANOVA, adding Frontality (Central, Centroparietal and Parietal) and Laterality (Left, Midline and Right) as within-subject factors. Greenhouse–Geisser correction was applied when needed. The F value, the degrees of freedom, the probability level, the ε value (only when sphericity could not be assumed), and the η_p^2 effect size index are reported.

For the frontal cue-locked P2, the time window (200–240 ms after the cue onset) was chosen based on previous studies that used transition cues (e.g., Adrover-Roig & Barceló, 2010). Moreover, previous experiments that found a threat-related modulation in frontal P2 also used a similar time window (e.g., Massar, 2012). P2 is a component usually elicited over the anterior scalp, and modulations in task-cueing paradigms linked to the complexity of the process announced by a switching cue have previously been found also in frontal electrodes (e.g., Han et al., 2018). The frontal midline electrode was chosen as a representative electrode, since it is a commonly selected site for measuring frontal P2, also in task-cueing studies that used transition cues (e.g., Adrover-Roig & Barceló, 2010), and where P2 is usually large.[2] The same factorial ANOVA as used in the behavioural analysis was performed. Moreover, in order to explore which cue elicited a more positive P2 in each group, so to further study relative differences in threat perception after each announcement of task condition, mean amplitudes for P2 in each condition (after the cue that announce a repetition of additions, after that announcing a repetition of subtractions, after the switching-to-additions cue and after the switching-to-subtractions cue) were compared between them by using t-tests. The Hochberg procedure was used to control for the increase in Type I error for multiple comparisons (Hochberg, 1988). Only significant comparisons following this procedure are reported.

3 | RESULTS

3.1 | Behavioural results

3.1.1 | State-math anxiety

Groups differed in state anxiety generated by the arithmetic test ($t[38] = 4.486$, $p < .001$), with highly math-anxious participants reporting higher state-math anxiety (mean = 5.7, SEM = .7) than their low math-anxious peers (mean = 2.3, SEM = .4).

3.1.2 | Response time

Two main effects were significant: Operation, $F(1,38) = 62.70$, $p < .001$, $\eta_p^2 = .62$, and Group, $F(1,38) = 10.30$, $p = .003$, $\eta_p^2 = .21$. Subtractions took longer (mean = 2567.1 ms, SEM = 132.0) than additions (mean = 2045.7 ms, SEM = 111.9) to be verified, and highly math-anxious individuals were generally slower (mean = 2684.7 ms, SEM = 166.7) than their low math-anxious peers (mean = 1928.2 ms, SEM = 166.7). Interestingly, Cue Type × Operation ($F(1,38) = 13.86$, $p = .001$, $\eta_p^2 = .27$) and Cue Type × Group ($F(1,38) = 4.91$, $p = .03$, $\eta_p^2 = .11$) interactions were also significant. Regarding the Cue Type × Operation interaction, the Cue Type effect (i.e., switch minus repeat) was larger for additions (mean = 96.8 ms, SEM = 61.9) than for subtractions (mean = −246.4 ms, SEM = 90.6; $t[39] = 3.77$, $p = .001$), where a cost for repetition was observed (i.e., repeating trials were slower than switching trials). As for the Cue Type × Group interaction, highly math-anxious individuals were slower than low math-anxious individuals in both switching trials ($F(1,38) = 12.40$, $p = .001$, $\eta_p^2 = .25$) and repeating trials ($F(1,38) = 7.04$, $p = .01$, $\eta_p^2 = .16$), although the group difference was greater in switching than in repeating trials (894.9 vs 618.2 ms, respectively). The Cue Type effect was larger for highly math-anxious individuals (mean = 63.6 ms, SEM = 103.06) than for their low math-anxious peers (mean = −213.1 ms; SEM = 70.46; $t[38] = 2.22$, $p = .03$).[3]

Regarding the analysis of switch effects, the low math-anxious group showed no significant Cue Type effect for additions (mean = −52.5, SEM = 88.0; $F[1,19] < 1$, $p = .56$, $\eta_p^2 = .02$). By contrast, the highly math-anxious group did show a significant Cue Type effect ($F[1,19] = 7.96$, $p = .01$, $\eta_p^2 = .30$), with a switch cost of 246.2 ms (SEM = 87.2). As for subtractions, the low math-anxious group showed a significant Cue Type effect ($F[1,19] = 12.13$, $p = .002$, $\eta_p^2 = .39$) in the form of a repetition cost (mean = − 373.7 ms, SEM = 107.3). There was no significant Cue Type effect in the highly math-anxious group (mean = − 119.0 ms, SEM = 146.0; $F[1,19] < 1$, $p = .42$, $\eta_p^2 = .03$). The asymmetry in switch effects depending on the task (i.e., the difference between the switch effect in additions minus the switch effect in subtractions) was positive and significant for both the low math-anxious group (mean = 321.2 ms, SEM = 136.6; $t[19] = 2.35$, $p = .03$) and the highly math-anxious group (mean = 365.2 ms, SEM = 123.9; $t[19] = 2.95$, $p = .008$), and it did not differ between groups ($t[38] = .24$, $p = .81$).

Finally, the level of math anxiety (i.e., sMARS scores) was positively correlated with the switch cost mean ($r = .34$; $p = .03$).

Boxplots of response time for both operations and groups are shown in Figure 2.

3.1.3 | Hit rate

The main effect of Operation was significant ($F(1,38) = 37.42$, $p < .001$, $\eta_p^2 = .50$), with subtractions being less accurate (mean = .80, SEM = .02) than additions (mean = .87, SEM = .01). The low math-anxious group (mean = .87, SEM = .02) was more accurate ($F(1,38) = 5.21$, $p = .03$, $\eta_p^2 = .12$) than the highly math-anxious group (mean = .80, SEM = .02). Cue Type was not significant ($F(1,38) = 1.15$, $p = .29$, $\eta_p^2 = .03$), and no switch effect in hit rate was significant for any group or operation.

Boxplots of hit rate for both operations and groups are shown in Figure 2.

3.2 | ERP results

3.2.1 | Switch-specific positivity

The main effect of Cue Type ($F(1,38) = 8.21$, $p = .007$, $\eta_p^2 = .18$) was significant (amplitude was more positive for Switch than for Repeat), as well as the main effects of

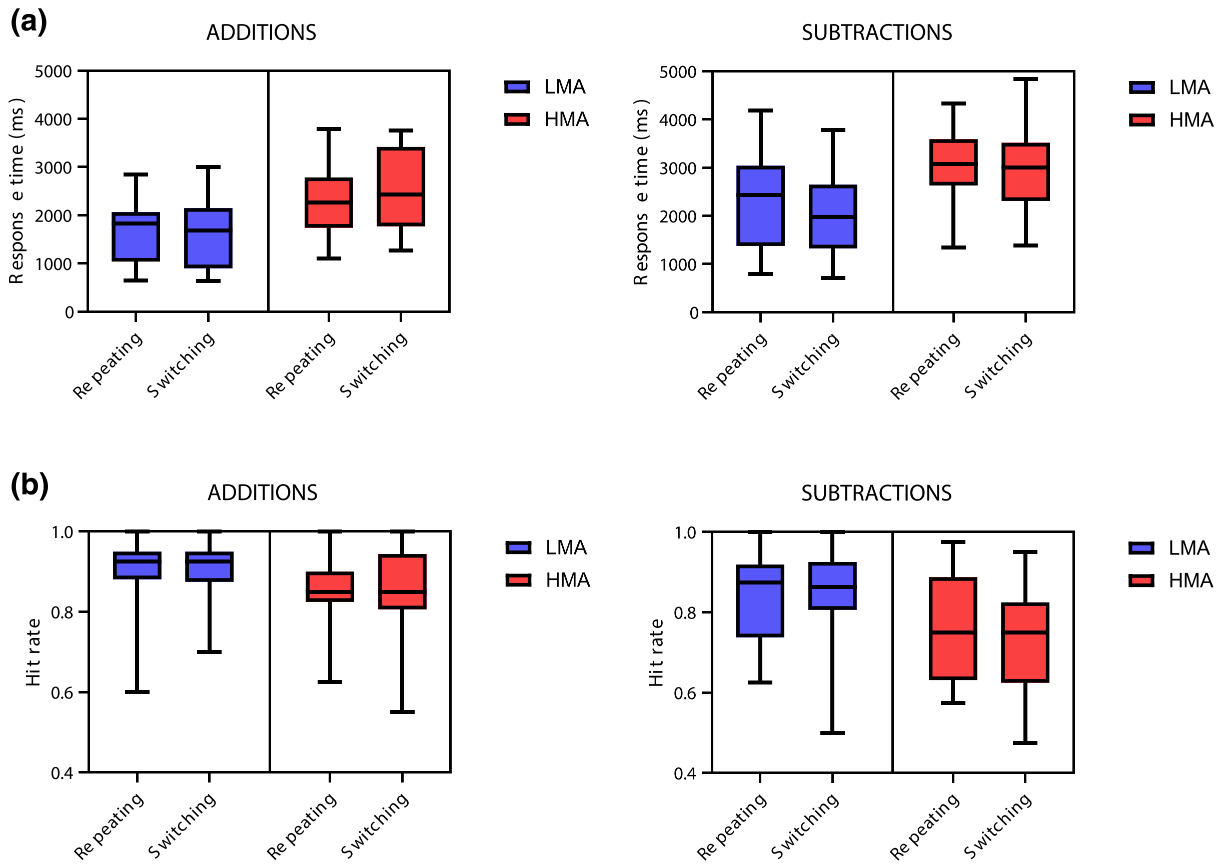

FIGURE 2 Boxplots of response time (a) and hit rate (b) for each operation, group and cue type.

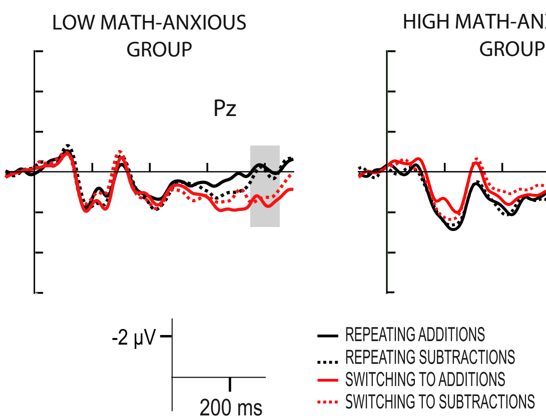

FIGURE 3 Grand-average cue-locked ERPs at Pz for each condition in the low math-anxious and highly math-anxious groups. The time interval for the switch-specific positivity, which was only elicited in the low math-anxious group, is shaded. Negative voltage is up.

Frontality (F[2,76] = 16.00, $p < .001$, $\eta_p^2 = .30$), with amplitude increasing from parietal to central scalp, and Laterality (F[2,76] = 9.77, $p = .001$, $\eta_p^2 = .21$), with larger amplitude in midline electrodes. No interactions with either Frontality or Laterality were significant. Interestingly, there was a Cue Type × Group interaction ($F(1,38) = 6.24$, $p = .02$, $\eta_p^2 = .14$). To study this interaction, separate ANOVAs by Group were conducted. The results showed a Cue Type effect in the low math-anxious group (F[1,19] = 16.72, $p = .001$, $\eta_p^2 = .47$) but not in the highly math-anxious group (F[1,19] < 1, $p = .81$, $\eta_p^2 < .01$).

ERP waveforms in the midline parietal electrode are displayed in Figure 3. Topographical distribution over the scalp is shown in Figure 4.

3.2.2 | Frontal P2

ANOVA showed a significant main effect of Operation ($F(1,38) = 7.75$, $p = .008$, $\eta_p^2 = .17$), with more positive amplitude for subtractions than additions. This main effect was modulated by the significant Operation × Cue Type × Group interaction ($F(1,38) = 8.17$, $p = .007$, $\eta_p^2 = .18$). To study this interaction, separate ANOVAs for each group were performed.

In the low math-anxious group, there were no significant effects (all p-values > .10).

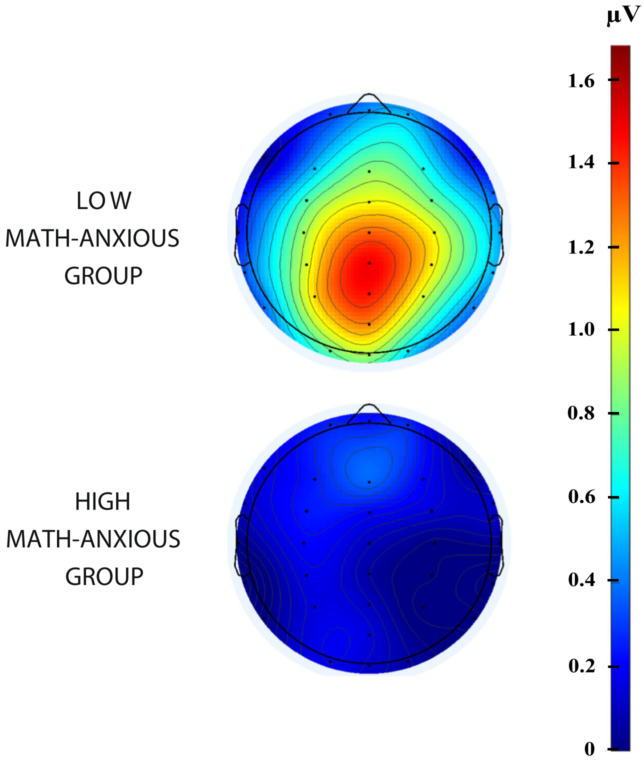

FIGURE 4 Scalp topography for the switch-specific positivity, measured as the mean difference (switch minus repetition) for each group in the 750- to 850-ms window after the cue. While the low math-anxious group showed the expected late centroparietal switch positivity, the highly math-anxious group did not show it.

Regarding the highly math-anxious group, a main effect of Operation was found ($F[1,19] = 9.05$, $p = .007$, $\eta_p{}^2 = .32$), modulated by the Operation × Cue Type interaction ($F[1,19] = 5.54$, $p = .03$, $\eta_p{}^2 = .23$). Separate ANOVAs for each operation were then carried out. For additions, Cue Type was not significant ($F[1,19] = 2.48$, $p = .13$, $\eta_p{}^2 = .11$). A main effect of Cue Type ($F[1,19] = 4.58$, $p = .05$, $\eta_p{}^2 = .19$) was obtained in subtractions, with the switching cue eliciting more positive amplitude than the repeating cue.

Regarding comparisons between conditions, there were no significant differences between conditions in the low math-anxious group. In the highly math-anxious group, the P2 amplitude after the cue that anticipated a switch to subtractions was significantly more positive than were the amplitudes after both cue types in addition trials (switching cue to subtractions vs. switching cue to additions, $t(19) = 3.41$, $p = .003$; switching cue to subtractions vs. repeating cue to additions, $t(19) = 2.52$, $p = .02$). No other comparison yielded significance following the Hochberg method.

Figure 5 shows frontal P2 in Fz for both operations by group.

4 | DISCUSSION

In the present study, proactive shifting between arithmetic operations mental sets was examined in highly math-anxious and low math-anxious individuals by measuring the switch cost in response time (Monsell, 2003) and the switch-specific positivity in ERPs (Barceló & Cooper, 2018). In accordance with ACT (Eysenck et al., 2007), the proactive shifting function was expected to be less efficient in the highly math-anxious population.

Regarding behavioural measures, as expected, highly math-anxious individuals reported more state-math anxiety than their low math-anxious peers. Based on ACT, state math-anxiety was predicted to reduce the efficiency of executive control, which (besides specifically hampering performance in switching trials) would generally impair arithmetic processing. As predicted, highly math-anxious participants performed arithmetic more slowly and less accurately than the low math-anxious group. Moreover, participants were in general slower and more error-prone when solving subtractions than additions. As for cue-type (i.e., switch vs. repeat) effects on response time, the expected interaction with math anxiety was found. Math anxiety was positively associated with the switch cost. In addition, an unexpected interaction of cue type with operation was also found, with subtractions yielding a repetition cost. The variation in the cue-type effect between operations (i.e., the asymmetrical cue-type effect) was similar for both groups. In other words, subtractions were associated with a lower cue-type effect than were additions, regardless of the group. The effect of math anxiety was superimposed on this asymmetry, drawing the cue-type effect towards a switch cost. Although it was observed in both groups and thus is not related to the subject of the present study, the dissimilar effect of cue type depending on the task, may be understood in terms of asymmetrical switch costs (Allport et al., 1994) and deserves to be discussed.

Throughout task-switching research, it has been repeatedly observed that the alternation between two task sets that differ in difficulty, dominance or familiarity leads to a smaller switch cost when switching from the easier to the harder task, as opposed to the other way round. This asymmetry was first reported by Allport et al. (1994) and has been replicated various times with several pairs of task sets (e.g., Leleu et al., 2012; Spitzer et al., 2019; Yeung & Monsell, 2003), including arithmetic task sets (e.g., Campbell & Arbuthnott, 2010) and, specifically, additions and subtractions (e.g., Barutchu et al., 2013; Ellefson et al., 2006). Taking the definition of task difficulty proposed by Schneider and Anderson (2010), whereby an easy task involves shorter response times and less errors than a difficult task, in the present

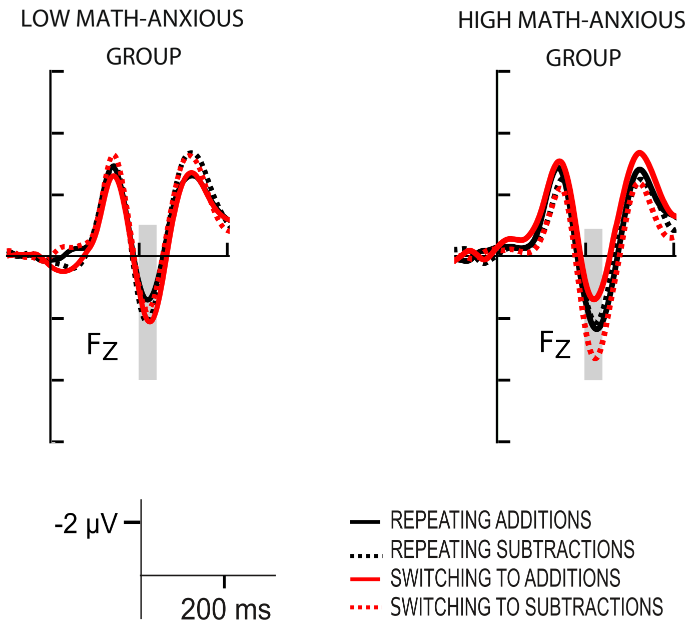

FIGURE 5 Grand-average cue-locked ERPs at Fz for each condition in the low math-anxious and highly math-anxious groups. The time window for frontal P2 is shaded. Negative voltage is up. The highly math-anxious group showed a more positive P2 after the cue indicating a switch to subtractions.

study subtractions were more difficult than additions. This unequal difficulty of additions and subtractions had already been observed and explained in earlier studies (e.g., Campbell & Xue, 2001; Rubinstein et al., 2001), which led Schneider and Anderson (2010) to choose the verification of two-digit additions and subtractions to illustrate their account for asymmetrical switch costs. Although several explanations have been put forward to account for asymmetrical switch costs that might complement the interpretation (e.g., Yeung & Monsell, 2003), the fact that Schneider and Anderson (2010) used an arithmetical task-switching paradigm with similar operations to those used here makes their model (supported by several subsequent studies; e.g., Mosbacher et al., 2020) highly relevant for interpreting the present asymmetrical cue-type effect.

Schneider and Anderson (2010) proposed that an asymmetrical reshaping of costs when switching between tasks differing in difficulty could be explained by confounding sequential difficulty effects that are not related to task switching. In their account, they assumed that cognitive resources are limited and that the quantity needed for processing a task depends on its difficulty. After performing a difficult task there is a transitory depletion of cognitive resources and the following trial is likely to be affected by it. This phenomenon was referred to as a sequential difficulty effect. According to Schneider and Anderson (2010), when two unequal-difficulty tasks are used in a task-switching test, this effect would be greater in trials following performance of the harder task (i.e., repetitions of the harder task and switches to the easier task). As time passes after processing a difficult task, the availability of cognitive resources gradually recovers. Thus, the longer the inter-trial interval, the smaller the sequential difficulty effects will be in the next trial (Schneider & Anderson, 2010). Given, therefore, that the more difficult task requires a larger quantity of resources, the remaining reduction is more likely to limit the resources necessary for harder-task repetition trials, even after a relatively long inter-trial interval. Consequently, performance in this latter condition may be impaired to a greater extent than is performance in switches to the easier task. When at the onset of the easier-task switching trials the amount of available resources is already larger than what is needed for this easier task, no impairment of performance should be detected in these switches. According to Schneider and Anderson (2010), what determines whether the asymmetry consists of a smaller, null or reversed switch cost for the harder task is the balance between the switch cost and these sequential difficulty effects.

Therefore, the asymmetrical cue-type effect between operations found in the present study is likely to rely on the asymmetry between sequential difficulty effects after performing additions and subtractions. Both the sequential difficulty effects and the switch cost should be considered in order to understand the switch effects obtained. On the one hand, the cognitive resources required must have been greater when subtracting, which accounts for the slower response time (and the increase in errors) in both groups when performing this task. After subtraction trials, the availability of resources was probably lessened to a greater extent than after additions trials (i.e., greater sequential difficulty effects associated with subtractions). Subsequently, the available resources slowly increased during the response-cue interval (which was set long enough to allow for clean ERP cue-locked epochs). This partial recovery may have been sufficient to exceed the level of resources required to verify additions (i.e., sequential difficulty effects did not hamper performance in switches to addition to a very greater extent than they did in repetitions of additions). By contrast, demands during subtractions might still have exceeded the maximum available in repetition trials, increasing response times even more in these trials. This asymmetry in sequential difficulty effects between operations was similar in the two groups. On the other hand, the switch cost did differ between groups. Low math-anxious individuals efficiently shifted the task set before the operands appeared and, therefore, they did not exhibit any switch cost. Thus, in this group the balance between these effects resulted in similar response times in addition trials with both cue-types and led to a repetition cost in subtractions. In the highly math-anxious group, by contrast, calculation was delayed in switching trials because of the impaired shifting function, increasing the response time in switches (i.e., entailing a switch cost). Hence, the aforementioned balance resulted in a (detected) switch cost in additions and no cue-type effect (i.e., no significant repetition cost) in subtractions.

The results regarding the interaction between math anxiety and cue type support the predictions of ACT (Eysenck et al., 2007) and are consistent with previous evidence about the effects of state anxiety on shifting between arithmetic operations. Derakshan et al. (2009) reported that highly state-anxious individuals exhibit larger costs in switching vs. single-task blocks than their low state-anxious peers; in fact, although the difference did not reach significance, their low state-anxious participants were faster in the switching condition than in the single-task condition, especially with the more difficult arithmetic operations. Although the local switch cost (i.e., the specific cost of switching from one task to another) cannot be distinguished in that study (the measure used by Derakshan et al. reflects mixing costs, Monsell, 2003), our results suggest that less efficient shifting explained, at least partially, Derakshan et al.' results, as the authors claimed. As for the interaction between operation and cue type found here, unfortunately, because in this classical paradigm the response time in the switching condition is calculated as the mean response time in the alternating block, response times when switching to additions or subtractions were not analysed separately. Similarly, single-task blocks of these operations were collapsed in their ANOVA and thus not compared either. Consequently, the operation (addition vs. subtraction) effect and its interactions could not be analysed, and neither switch cost nor repetition cost could be estimated specifically for each operation. Thus, it is not possible to know whether asymmetrical sequential difficulty effects might also have influenced Derakshan et al.'s results.

In the present study, the low math-anxious group did not present any switch cost, as in Derakshan et al.'s (2009) study. It has been suggested that no matter how long the preparation interval is, a residual switch cost is always present because task-set reconfiguration cannot be completed by proactive control until attributes of task stimuli help to finish the process in a stimulus-driven fashion (Rogers & Monsell, 1995). However, the current results are consistent with studies suggesting that a long cue-target interval can allow a complete task-set shifting (e.g., Barceló & Cooper, 2018; Foxe et al., 2014; Jost et al., 2008). For example, in a functional neuroimaging study, Wylie et al. (2006) observed that when task-related brain activity was triggered by the cue, there was no residual switch cost. This brain preactivation of task-relevant areas was believed to indicate that control processes had successfully activated the new task set, a process that here is considered to be executed by the shifting function based on ACT (Eysenck et al., 2007). According to Wylie et al. (2006), 'if subjects are able to activate the neural circuitry associated with performing a given task prior to the presentation of the task stimuli, then they might be able to switch to that task without a cost to performance' (p. 400). Therefore, the present results align with previous evidence suggesting that residual switch costs can be avoided if task-set shifting is efficiently anticipated. The discrepancy between this evidence and that from studies that find a residual switch cost even when providing a long preparation interval may either be due to differences in task-set complexity and task-context particularities (i.e., some tasks can be prepared in advance under certain circumstances, e.g., Wylie et al., 2006), support other accounts for residual switch cost (e.g., the probabilistic account of De Jong, 2000) and/or suggest that the existence of residual switch cost depends on participants' proactive control efficiency (e.g., Foxe et al., 2014). The fact that in the present results the absence of switch cost was confined to the low math-anxious group suggests that proactive control efficiency is, at least, one of the factors that can underlie the former difference, because it shows that only participants with efficient proactive control are able to achieve enough level of cognitive readiness during moderately long switch preparation intervals so as to avoid a cost in response time. However, the exact proactive executive processes during this preparation interval cannot be determined by this particular result. As in the study of Wylie et al. (2006), the absence of switch cost found in low math-anxious individuals in the present study is both consistent with an interpretation of goal-directed task-set reconfiguration being completely executed and with goal-biased competition between the activated pathways (i.e., the now-irrelevant task set and the now-relevant task set) being sufficiently solved (Wylie et al., 2003a). In both cases, the present results suggest that the proactive activation of the task-relevant goal was impaired in the highly math-anxious group and are therefore consistent with ACT and Braver's (2012) proposals that task goals cannot be proactively sustained when experiencing anxiety.

Importantly, regarding the neural correlate of shifting, the cue-locked centroparietal switch-specific positivity, which according to Barceló and Cooper (2018) better reflects the high-order control process of task switching, was only detected in the low math-anxious group, as predicted. This result also supports the main hypothesis of this study about math anxiety affecting the shifting function. Therefore, both the behavioural and neural results point to an impairment of proactive shifting when highly math-anxious individuals are asked to switch between arithmetic operations. Considering that previous research has pointed to the late switch positivity and the switch cost as negatively associated measures of proactive shifting efficiency (e.g., Elchlepp et al., 2012), both results are likely to be related and to reflect less efficient preparation for a switch in this population. A reduced shifting efficiency is likely to impair math processing. For example, the ability of shifting has been shown to predict performance in complex arithmetic tasks (Molzhon, 2010) and to improve the flexible use of strategies when processing two-digit operations (Hodzik & Lemaire, 2011). Moreover, shifting efficiency has been linked to the ability to use mathematical concepts (Vosniadou et al., 2018). Thus, the difficulties that highly math-anxious individuals usually show in arithmetic (e.g., Ashcraft & Faust, 1994) and in the use of problem-solving strategies (which is, in turn, associated with their low math performance; Ramirez et al., 2016) may be at least partly explained by a less efficient shifting function when experiencing state-math anxiety.

To our knowledge, this is the first time that a specific neural component of shifting has been measured in the field of math anxiety. Beyond this field, the present results suggest that this neural ERP component, together with a transition-cueing paradigm, would provide a useful basis for future studies addressing the relationship between anxiety and proactive shifting. In addition, the fulfillment of the prediction regarding the difference in this switch-specific positivity between groups differing in proactive shifting efficiency supports previous evidence (e.g., Barceló & Cooper, 2018; Han et al., 2018; Kieffaber & Hetrick, 2005) pointing to this later centroparietal switch positivity as the one reflecting the top-down control process of task switching. This topography is also consistent with the proposal made by Wylie et al. (2003b), who suggested that a late parietal positivity during preparation for a switch may reflect 'changes in processing within attentional control areas of the parietal cortices' (p. 2338). Following their biased competition proposal, if the new task set becomes more activated than the older (i.e., efficient goal-biased attention), there would be no cost of competition. Considering together the neural and behavioural results obtained here and their model, the presence of the switch-specific positivity would reflect the winning of the relevant task-set in the attentional competition. Moreover, the robustness of this later centroparietal switch positivity is also shown here by replicating a few previous studies in which a switch positivity with similar topographical distribution and latency had also been found to be elicited with linguistic transition cues (e.g., Hsieh & Wu, 2011). However, the number of epochs that could be included in the ERPs was inevitably low due to limitations inherent to the goal of this study: although error trials (which were not included in the ERPs) were expected to be high, it was necessary to use a highly demanding task to evaluate the ACT prediction. At the same time, we chose not to increase the number of trials per condition to a great extent so to prevent fatigue. Therefore, future replications are needed.

The fact that, as expected, math anxiety was related with larger switch cost in response time but not in accuracy supports the ACT's proposal that anxiety affects the processing efficiency of executive control to a higher extent than its performance effectiveness (Eysenck et al., 2007). Unfortunately, the present study cannot distinguish whether the impairment can be completely solved with a longer preparation interval, or whether math anxiety permanently hampers the ability to fully anticipate the task-set reconfiguration in a proactive way (i.e., it always entails a residual switch cost and no distinct neural footprint).

It has been proposed that inhibition, whose efficiency is also likely to be affected by math anxiety, may modulate task-switching performance as well (Koch et al., 2010). However, with the present design, groups differences in the inhibition component were unlikely to influence results. For example, a long response-cue interval (RCI) was used and thus the previous task set was probably already less activated when the cue appeared (Gade & Koch, 2005). Indeed, Grange and Houghton (2009) observed that, with the RCI duration used in the present study, there was no influence of backward inhibition on behavioural performance. Moreover, the idea that inhibition might influence switch cost was posited as an explanation for asymmetrical switch costs (Allport et al., 1994): if the less efficient inhibition function in the highly math-anxious group had contributed to their larger switch cost, a difference in the task-related asymmetry of the cue-type effect should also be expected between both populations, and this did not happen. In addition, according to previous studies (e.g., Barceló & Cooper, 2018), ERP modulations reflecting inhibition should occur in an earlier latency and with a more frontal topographical distribution. Therefore, it is unlikely that group differences in inhibition influenced the present results.

As for cue-locked frontal P2 modulations, participants showed a more positive amplitude in subtractions trials, which is consistent with previous interpretations relating P2 amplitude to the recruitment of attentional resources that are determined by the difficulty of the announced task (Kieffaber & Hetrick, 2005) and the negative valence of the stimulus (Carretié et al., 2001). Interestingly, and regarding the secondary hypothesis about math anxiety enhancing P2 amplitude after switching cues, the highly math-anxious group showed a more positive P2 just after being presented with the cue that announced the hardest trial: switching to subtractions. This cue heralded the start of a major cognitive effort (that is, solving the more difficult mathematical task after exerting shifting effort). Both executive control and arithmetic performance generate subjective effort, which is perceived as negative (Kurzban et al., 2013). It has been reported that a cue that anticipates an arithmetic task activates neural regions related with threat and pain (Lyons & Beilock, 2012b) and recruits more attentional resources (Liu et al., 2019) in the highly math-anxious population. All things considered, it is likely that the most effortful trial would have perturbed highly math-anxious individuals to a greater extent, triggering a negative emotional reaction, biasing selective attention, and generating a more positive P2 when presented with the corresponding cue. Indeed, in an emotional spatial cueing task, Massar (2012) similarly found more positive cue-locked P2 amplitude after threat cues than after neutral cues, which he interpreted as indicating that threatening stimuli are strongly or more automatically selected by attention. For their part, Baas et al. (2002) described a larger frontal selection positivity (which has been proposed to be equivalent to the P2 component; Potts, 2004) after fear-inducing cues sometimes followed by a painful shock. This attentional bias to threat, usually higher when experiencing anxiety (Yiend, 2010), has lately been also related to the reduced attentional control and the imbalance between top-down and bottom-up attentional systems (e.g., Eysenck et al., 2007; Mogg & Bradley, 2016). Thus, the more positive frontal P2 might reflect a stronger attentional engagement with this cue because it announced the most relevant, effortful, and threatening condition for highly math-anxious individuals, representing the affective consequence of anticipating an increment in cognitive effort while suffering anxiety.

Summarising, the present study suggests that the shifting function may be impaired in highly math-anxious individuals when switching between arithmetic tasks and that the anticipation of the most demanding condition might recruit more attentional resources in highly math-anxious individuals, probably because the announcement of an even larger upcoming effort is perceived by them as threat. Based on ACT, as well as on previous literature about math anxiety (see reviews of Chang & Beilock, 2016, and Suárez-Pellicioni et al., 2016), the less efficient shifting function found in the present study is interpreted as a consequence of math anxiety that contributes to generating worse math performance. This interpretation is also consistent with experiments pointing to less efficient attentional control in highly math-anxious individuals beyond arithmetic tasks (e.g., Núñez-Peña et al., 2019) and, especially, with evidence of highly math-anxious individuals showing reduced attentional control even when math ability is controlled (Suárez-Pellicioni et al., 2013). However, the possibility that the less efficient shifting shown by highly math-anxious participants is related with lower arithmetic skills of this population cannot be conclusively ruled out. Neither can it be discerned from this study whether the less efficient shifting shown by highly math-anxious individuals is confined to mathematical tasks, due to the lack of a control non-mathematical task-switching test. In addition, although many confounding variables were controlled (e.g., trait anxiety, WM span, etc.), general intelligence was not. However, it is unlikely that this factor explains differences between groups, since previous studies suggest that the association between math anxiety and general intelligence is weak or even negligible (e.g., Hembree, 1990; Young et al., 2012). Moreover, previous research has pointed to attentional control deficits in highly math-anxious individuals after controlling for general intelligence (e.g., Liu et al., 2019; Pletzer et al., 2015). In any case, showing differences between highly math-anxious and low math-anxious individuals when proactive shifting between mathematical operations is required, regardless of whether this is due to anxiety, as suggested by ACT, or whether it is a math-capacity-linked deficit independent of state anxiety, broadens the understanding of the difficulties this population faces at least when performing math and may help to design appropriate interventions.

To conclude, the neurophysiological and behavioural evidence provided by this study adds to previous research pointing to a less efficient attentional control in highly math-anxious individuals when performing math. While the inhibitory function has been the main focus of research in this field to date, the present study is the first to show evidence of an impairment of shifting. The extent to which this might account for the effect of math anxiety on math processing at different ages and in different math tasks should therefore be addressed in future research. Future studies should continue investigating the effects of math anxiety on attention and executive functions so as to design integrative interventions than can best help individuals like our hypothetical John to deal with math-related contexts.

AUTHOR CONTRIBUTIONS

BELÉN GONZÁLEZ-GÓMEZ: Conceptualization; data curation; formal analysis; funding acquisition; investigation; methodology; project administration; resources; software; visualization; writing–original draft; writing–review and editing. **MARIA ISABEL NÚÑEZ-PEÑA:** Conceptualization; formal analysis; funding acquisition; methodology; project administration; resources; supervision; visualization; writing–review and editing. **ÀNGELS COLOMÉ:** Conceptualization; funding acquisition; methodology; project administration; supervision; writing–review and editing.

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CONFLICT OF INTEREST STATEMENT

None.

DATA AVAILABILITY STATEMENT

The data that support the findings of the present study are openly available at https://osf.io/5zy7c/?view_only=b1698e6abdc54dc4936193c1c4f0bd5f.

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PEER REVIEW

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ENDNOTES

[1] Additional evidence supporting the theory's predictions has been compiled subsequently (Berggren & Derakshan, 2013; Derakshan & Eysenck, 2009; Eysenck & Derakshan, 2011). The recent meta-analysis from Shi et al. (2019) provides further evidence about anxiety impairing shifting and inhibition.

[2] Beforehand, P2 amplitude in frontal electrodes was compared in the present data by submitting mean amplitude to an ANOVA taking Laterality (F3, Fz and F4) as a within-subject factor, and it was confirmed that amplitude was significantly more positive in the midline electrode. The effect of Laterality was significant, $F(2,76) = 4.92$, $p = .01$, $\eta_p^2 = .11$. Fz was more positive than both F3 ($p = .004$) and F4 ($p = .04$). There were no differences between F3 and F4 ($p = 1$).

[3] To ensure that there was no cue-repetition benefit in task repetitions, response time in all task-repetition trials (including first trials of repetition series, which were previously excluded) was submitted to an ANOVA taking Cue Switching (Cue Switch, Cue Repetition), Operation and Group. There were no significant effects regarding Cue Switching and its interactions.

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