POST-ERROR RESPONSE INHIBITION IN HIGH MATH-ANXIOUS INDIVIDUALS: EVIDENCE FROM A MULTI-DIGIT ADDITION TASK

M. Isabel **Núñez-Peña**[1,2] , Elisabet **Tubau**[2,3] and Macarena **Suárez-Pellicioni**[4]

[1] Department of Social Psychology and Quantitative Psychology, Faculty of Psychology, University of Barcelona, Spain

[2] Institute of Neurosciences, University of Barcelona, Spain

[3] Department of Cognition, Development and Educational Psychology, Faculty of Psychology, University of Barcelona, Spain

[4] Department of Communication Sciences and Disorders, University of Texas at Austin

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Correspondence to:

Maria Isabel Núñez-Peña

Department of Social Psychology and Quantitative Psychology

Faculty of Psychology

University of Barcelona

Passeig Vall d’Hebron, 171

08035 Barcelona (SPAIN)

Tel. +34 93 312 58 53

Fax: +34 93 402 13 59

E-mail: inunez@ub.edu

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Abstract

The aim of the study was to investigate how high math-anxious (HMA) individuals react to errors in an arithmetic task. Twenty HMA and 19 low math-anxious (LMA) individuals were presented with a multi-digit addition verification task and were given response feedback. Post-error adjustment measures (response time and accuracy) were analyzed in order to study differences between groups when faced with errors in an arithmetical task. Results showed that both HMA and LMA individuals were slower to respond following an error than following a correct answer. However, post-error accuracy effects emerged only for the HMA group, showing that they were also less accurate after having committed an error than after giving the right answer. Importantly, these differences were observed only when individuals needed to repeat the same response given in the previous trial. These results suggest that, for HMA individuals, errors caused reactive inhibition of the erroneous response, facilitating performance if the next problem required the alternative response but hampering it if the response was the same. This stronger reaction to errors could be a factor contributing to the difficulties that HMA individuals experience in learning math and doing math tasks.

Key Words: Math anxiety; Post-error slowing; Post-error accuracy; Response inhibition

1. INTRODUCTION

Math anxiety is defined as an adverse emotional reaction to math or to the prospect of doing math (Hembree, 1990), and it is a topic of increasing interest because of its negative consequences for math achievement (for a recent review, see Suárez-Pellicioni, Núñez-Peña, & Colomé, 2016). High math-anxious individuals (hereinafter, HMA) perform more poorly on a range of numerical and mathematical tasks and obtain lower grades in math courses they take (Ashcraft & Krause, 2007), as compared with their low math-anxious peers (hereinafter, LMA). As a consequence, they avoid this subject in their academic curriculum (Hembree, 1990), limiting their opportunities at the professional level, which may result in a lower socioeconomic status. Moreover, math anxiety not only has an impact in formal settings (math classroom or math tests), but also in more everyday settings (e.g., checking a tip on a restaurant bill when other are watching; Ashcraft & Moore, 2009).

It should be noted that math anxiety has a high prevalence in the population. Evidence of this can be found in the latest PISA report (2012, Programme for International Student Assessment), in which 15-year-old students from member countries of the Organization for Economic Cooperation and Development (OECD) reported agreeing or strongly agreeing with the following statements: *I get very tense when I have to do mathematics homework* (33%), *I get very nervous doing mathematics problems* (31%), and *I feel helpless when doing a mathematics problem* (30%). Furthermore, in the United States, 25% of four-year college students and up to 80% of community college students suffer from math anxiety from a moderate to high degree (Beilock & Willingham, 2014). It is therefore important to study whether math anxious individuals do anything different when processing a mathematical problem, as compared with their low math anxious peers, as this can help to broaden our understanding of the factors contributing to the relationship between high math anxiety and low math achievement.

An important issue people face when solving a mathematical problem is how they react to errors. An error can affect the answer to subsequent problems in different ways. Intuitively, one might think that an error can help to improve performance because we learn from mistakes, hence the expression “mistakes are often the best teacher”. The idea here is that an error might help us realize why we committed it and to pay more attention to the following problem/task. Unfortunately, an error can also block us from effectively solving the following problem, undermining the positive contribution that the mistake can make to learning. This is usually the case when errors are particularly relevant.

Error adaptation has been widely studied (Danielmeier & Ullsperger, 2011; Dulilh, Vandekerckhove, Forstmann, Keuleers, Brysbaert, & Wagenmakers, 2012) and different accounts have been proposed to explain reactions to errors. The conflict monitoring account (Botvinick, Braver, Barch, Carter, & Cohen, 2001) claims that after an error or conflict the response threshold will increase. Thus, when an error is detected a compensatory control mechanism is activated in order to improve subsequent performance (i.e., we become more cautious after an error). Therefore, an increase in response time (known as *post-error slowing* – hereafter referred to as PES) and in hit rate (known as *post-error improvement in accuracy*) would be predicted following an error. This prediction has been confirmed in some studies (Danielmeier, Eichele, Forstmann, Tittgemeyer, & Ullsperger, 2011; Maier, Yeung, & Steinhauser, 2011; Marco-Pallarés, Camara, Münte, & Rodríguez-Fornells, 2008) and, as a result, PES has been considered a measure of cognitive control. According to this account, post-error adjustments would reflect an adaptive mechanism that would prevent the occurrence of further errors, supporting the learning function of errors.

An alternative view is offered by the orienting account (Notebaert et al., 2009), which claims that an error is an infrequent event that causes an orienting response, with post-error adjustment being considered as an attentional effect. Because of their infrequency, errors are unexpected, motivationally salient events which capture participants' attention and distract them during the processing of the subsequent stimulus. Thus, the orienting account predicts that previous errors will worsen performance, producing increased PES and a decrease in hit rate. Some studies have confirmed these predictions (Fiehler, Ullsperger, & Von Cramon, 2005; Rabbit & Rodgers, 1977). Hence, it has been suggested that post-error adjustments may result from a failure to disengage attention from the error (Carp & Compton, 2009) or from a failure to disengage from performance difficulties including increased response conflict (Compton, Arnstein, Freedman, Dainer-Best, & Liss, 2011). In this context, it is also worth noting a recent study by Van der Borght, Braem, and Notebaert (2016), who reported differences in post-error adaptations depending on trait anxiety and time. Using a Simon task they reproduced previous results showing that PES increased and post-error accuracy decreased with short inter-trial intervals (ITI), and that these effects were reduced or even reversed (for post-error accuracy) with increasing ITIs (Danielmeier & Ullsperger, 2011; Jentzsch & Dudschig, 2009). As suggested by Van der Borght et al. (2016) these results are consistent with the idea that people have difficulties disengaging attention from the error shortly after error commission. Interestingly, the ITI effect on post-error adaptations depended on trait anxiety level. Only low-anxious individuals improved their performance when the ITI was long, suggesting that high-anxious individuals have difficulties disengaging from an error, even when time allows for it.

Finally, the inhibitory account (Ridderinkhof, 2002) suggests that the commission of an error activates an inhibitory mechanism that increases the strength of motor suppression or inhibition of responses on a subsequent trial. In this view, PES is linked to motor stopping or suppression of an action (i.e., behavioral response) that is considered inappropriate in a given context. The predictions made by this account for post-error behavioral effects are the same as those of the orienting account, namely that errors will worsen performance in the following trial, producing increased PES and a post-error decrease in accuracy. Marco-Pallarés et al. (2008) reported psychophysiological evidence supporting the inhibitory account. In their event-related fMRI experiment they found a coincidence between brain regions related to inhibition in a stop-signal task (consisting in presenting a red square in 25% of the trials, signaling to participants that they should inhibit their response) and the activation observed on correct trials occurring after error commission in a flanker task. They also found that PES correlated with an increase in beta band power, which has been associated with inhibitory processes and, specifically, with motor inhibition. These results suggest that PES is probably due to an increase in the amount of response inhibition after an error.

Although error adaptation has been widely studied, nothing is known about how HMA individuals behaviorally adapt after errors committed in a mathematical problem. This is an important question and exploring it could help in understanding the extent to which math anxiety reduces or interferes with learning from errors. In this context, Suárez-Pellicioni, Núñez-Peña, and Colomé (2013), using event-related brain potentials (ERP), found that math anxiety is related to an abnormal error monitoring processing. These authors formed two groups according to participants' level of math anxiety and asked them to perform a numerical Stroop task (participants were presented with a pair of numbers of different size and had to report the number of larger numerical magnitude while ignoring its physical size) and a classical word-color Stroop task. An increase in error-related brain activity (i.e., the error-related negativity potential - ERN) was found in the HMA group, as compared with their LMA counterparts, when they solved the numerical Stroop task, but not when they solved the classical one. Given that a source localization analysis of this component identified the right insula as being at the basis of this ERN enhancement for the HMA group in the numerical (vs. the non-numerical) task, the authors interpreted the result according to the motivational significance theory of the ERN (Hajcak & Foti, 2008; Hajcak, Moser, Yeung, & Simons, 2005) and suggested that HMA individuals might be characterized by a greater sensitivity to — and concern over — errors in numerical tasks. Suárez-Pellicioni et al. (2013) found differences between HMA and LMA participants after errors only in the ERN signature, and not at the level of post-error adjustments in performance (RT and accuracy). However, they used a numerical Stroop task and nothing is yet known about how HMA individuals react to errors in a more genuine mathematical task, like solving an arithmetic problem.

In the present study we examined post-error adjustments in high and low math-anxious individuals when they performed a multi-digit addition verification task. Two groups were formed according to their scores on the Shortened Mathematics Anxiety Rating Scale (Alexander & Martray, 1989) and on the trait subscale of the State-Trait Anxiety Inventory (Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983), such that groups were extreme on the former but did not differ on the latter; thus, we could rule out the possibility that group differences could be explained by trait anxiety. In comparison with previous studies on error monitoring from our lab (Suárez-Pellicioni et al., 2013) the present study introduces two important new aspects: First, as mentioned above, we administered an arithmetic task which we believe is more informative regarding the difficulties HMA individuals face when they have to deal with math class requirements (as compared with a numerical Stroop task, which is an attentional task). Second, participants were given external error feedback, because we expected that becoming aware of their mistakes would be more emotionally arousing for the HMA group. In fact, error feedback can act in HMA individuals as a reinforcement of their own perceived low math self-efficacy, that is, of their belief in their low potential to do math successfully (Meece, Wigfield, & Eccles, 1990).

Given that previous studies have consistently shown that HMA individuals are characterized by an attentional control deficit when they have to process math information (e.g., Suárez-Pellicioni, Núñez-Peña, & Colomé, 2015), which would make them more vulnerable to distraction, and considering previous evidence from our lab showing that HMA individuals present an abnormal error response to numerical errors (Suárez-Pellicioni et al., 2013), we expected that an error in an arithmetic verification task, being an adverse stimulus for the HMA group, would draw their attention away from the task and would undermine their performance in the following trial. Hence, we predicted that task performance after errors would be more impaired for HMA individuals, resulting in increased PES and a post-error decrease in accuracy.

Returning to the post-error adjustment accounts described above, both the orienting and inhibitory accounts predict performance impairment (response time and hit rate) in a trial following an error. On the one hand, the orienting account of post-error adjustment (Notebaert et al., 2009) states that errors are events that capture individuals' attention, slowing response time and decreasing accuracy in the following trial. According to this account, the impairment in performance after an error will be general (i.e., an error would worsen any kind of response in the following trial). On the other hand, the inhibitory account of post-error adjustment (Ridderinkhof, 2002) states that performance after an error worsens because the error causes behavioral inhibition or motor suppression. According to this account, two possible patterns of results could be expected. In one, the behavioral inhibition of motor response may be general, affecting any kind of response following an error; in other words, both possible responses in our verification task would be inhibited. In this case, predictions would be the same as those based on the orienting account, that is, general post-error impairment. In the other possible pattern of results, behavioral inhibition may be more reactive and specific to the motor response given previously; in other words, PES and a decrease in post-error accuracy would be expected only for responses to problems requiring an identical response to the previous one, the one which resulted in an error (e.g., having to say in the current trial that the proposed solution for the addition is correct, when in the previous trial the participant committed an error by reporting a given proposed solution as correct). In the present study we wanted to shed light on this issue by examining whether a previous error in an arithmetic task would impair the performance of HMA individuals in the following trial in general (i.e., error followed by any kind of response) or if such an error would impair performance only when the same response as that previously given needs to be repeated in the current trial (i.e., having to give the same answer in the current trial as the one which has just produced a mistake).

2. METHODS

2.1 Participants

Thirty-nine healthy volunteers were tested in this study, all of them selected from a sample of 629 students from the University of Barcelona who were assessed for math anxiety and trait anxiety (see Materials)[1]. Means and standard errors of the mean (SEM) on the Shortened Mathematics Anxiety Rating Scale (sMARS) (Alexander & Martray, 1989) for the larger sample were 64.97 and 0.67 respectively. The first quartile on the sMARS scores was 53 and the third quartile was 77.

The LMA group comprised 19 participants who scored below the first quartile on the sMARS, whereas the HMA group included 20 participants scoring above the third quartile on that test. In order to control for trait anxiety, participants in both groups were matched according to their scores on the *State-Trait Anxiety Inventory (STAI)* (Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983), i.e. participants in both groups were paired according to their STAI scores, so that groups differed in math anxiety but not in trait anxiety. Math anxiety and trait anxiety are correlated (Hembree, 1990), so by controlling the latter we could rule out the possibility that group differences could be explained by trait anxiety. One LMA participant who was initially selected was excluded from the final sample due to technical problems during data acquisition. For more detailed information about the two groups, see Table 1.

Groups differed in math anxiety ($t(37) = 19.52$, $p < .001$) but not in trait anxiety ($t(37) = 1.15$, $p = .25$), age ($t(37) = .30$, $p = .76$), years of formal education ($t(37) = .94$, $p = .35$), or handedness ($\chi^2 = .30$, $p = 1$).

All had normal or corrected-to-normal visual acuity and did not report any history of neurological or psychiatric disorders. Participants were naive as to the purposes of the study.

Insert Table 1 approximately here

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[1] The present work and Núñez-Peña & Suárez-Pellicioni (2015) are subsets of the same larger dataset. In Núñez-Peña & Suárez-Pellicioni the time course of neural processing was investigated without taking into account previous response effects. The current results correspond to a completely novel analysis of those data.

2.2. Material

Shortened Mathematics Anxiety Rating Scale (sMARS) (Alexander & Martray, 1989). The sMARS is a 25-item version of the Math Anxiety Rating Scale (MARS) (Richardson & Suinn, 1972). This instrument measures anxiety by presenting 25 situations which may cause math anxiety (e.g., *Thinking about the math exam I will have next week*). The respondent indicates the level of anxiety associated with the item using a five-point Likert scale ranging from 1 (no anxiety) to 5 (high anxiety). The sum of the item scores provides the total score for the instrument, which ranges from 25 to 125. In the present study we used the Spanish version of the sMARS (Núñez-Peña, Suárez-Pellicioni, Guilera, & Mercadé-Carranza, 2013). The scores for the Spanish version of the sMARS have shown strong internal consistency (Cronbach's alpha = .94) and high 7-week test-retest reliability (intra-class correlation coefficient = .72).

State-Trait Anxiety Inventory (STAI) (Spielberger et al., 1983). The STAI is a 40-item scale used to measure state (STAI-S) and trait (STAI-T) anxiety, 20 items each. Only the STAI-T subscale, which measures a more general and relatively stable tendency to respond with anxiety, was used in this study. This subscale comprises 20 statements describing different emotions, and for each item respondents use a four-point Likert scale (ranging from 0: almost never, to 3: almost always) to indicate how they feel "in general". Good to excellent internal consistency (Cronbach´s alpha = .95), adequate 30-day test-retest reliability with high-school students (r = .75), and 20-day test-retest reliability with college students (r = .86) has been reported for the Spanish version of this subscale (Spielberger, Gorsuch, & Lushene, 2008).

A two-digit addition task was presented to each participant. Addends ranged between 12 and 29 and were presented horizontally on the screen (e.g., 14 + 17). Each pair of addends was followed by the proposed solution, which could be correct (e.g., 31) or incorrect (+10 from the correct solution; e.g., 41). From all possible combinations of addends in the abovementioned range, those which could generate confusion with other processes (e.g., rule application) were excluded; thus, numbers 10, 11, 20, and 21, tie problems (e.g., 12+12), and consecutive addends (e.g., 12+13) were not included. From all the remaining possible combinations, two hundred additions were randomly selected. All participants were administered with the same set of problems. Numbers were presented in font size 50 (Courier New) in white against a black background and subtended at visual angles of 6.30° (addition) and 2.29° (proposed solution) horizontally and 1.48° vertically.

2.3 Procedure

Participants were tested individually. Upon entering the experimental room, participants completed standard procedures concerning informed consent, along with a demographics questionnaire asking their age and number of years of formal education. They were then seated 100 cm away from the computer screen and detailed task instructions were given. The session began with a training period of 25 trials, for which participants received feedback on their performance. The training trials were only used to familiarize participants with the task, and they were excluded from the statistical analysis. After completing the training trials, participants began the experimental session, which consisted of four blocks of 50 stimuli (200 total trials) separated by a 1-minute rest. Trials were randomly presented to each participant.

The task for participants consisted in indicating whether the proposed solution for the presented addition was true or false by pressing the left or right button of the mouse. Response buttons were counterbalanced within each group. Participants were encouraged to answer as fast and as accurately as possible. Each trial began with a fixation sign (an asterisk) shown for 500 ms, which was followed by the addition, presented for 1500 ms with a pre- and post- 100 ms inter-stimulus interval (ISI). The proposed solution then appeared and remained on screen until the participant gave a response (or for a maximum of 2000 ms), after which a 500 ms pause was presented. Then, feedback lasting 1000 ms was given, indicating correct response, incorrect response or no response. Finally, the trial ended with a variable inter-trial interval ranging from 600 to 900 ms, with 100 ms increments (all pauses consisted of a black screen).

The E-prime 2.0 program (Psychology Software Tools Inc., Sharpsburg, PA, USA) was used to control the presentation and timing of the stimuli and the measurement of response accuracy and response times.

3. DATA ANALYSIS AND RESULTS

Data from one participant in the HMA group were discarded due to the high percentage of errors (close to chance level; 50%), suggesting that this participant might have been answering randomly to the task. The reported effects did not change after excluding the data from this participant. Response time (RT) outliers of the remaining 38 participants (19 in each group) were also removed. Outliers were identified on a normal model distribution-basis, taking into account the within-subject variables *Previous accuracy* (error and correct answer) and the between-subjects variable *Math anxiety group* (LMA and HMA). Of all trials, 1% had an estimated residual below/above the 5% confidence limit and they were removed from the RT analyses. This analysis was carried out using the *extremevalues* package in R (van der Loo, 2010).

In order to study post-error effects in relation to the type of response transition from previous to current trial (repetition or alternation), responses were coded as *repetitions* when the response given by the participant in the current trial coincided with the one previously given and as *alternations* when they differed (note that this coding was always in relation to the response given by the participant, regardless of its accuracy and, accordingly, it was generated before the removal of errors and outliers; see above). The first trial of each block was also excluded from these analyses (because there was no previous response for these trials). Means of RTs for the remaining correctly solved trials and the percentage of hits were submitted to separate ANOVAs with the within-subject factors *Previous accuracy* (correct, error) and *Type of response transition* (repetition, alternation), and the between-subjects factor *MA group* (HMA, LMA).

RT analysis showed significant effects of *Previous accuracy* ($F(1,36) = 4.26$, $p = .046$; responses were slower after erroneous responses than after correct answers; means were 779 ms and 749 ms for post-error and post-correct, respectively) and *MA group* ($F(1,36) = 6.59$, $p = .014$; HMA participants showed slower responses than their LMA peers; means were 844 ms and 684 ms, respectively). The main effect of *Type of response transition* was not significant ($F(1,36) = 1.88$, $p = .18$). Nevertheless, the *Previous accuracy x Type of response transition* interaction was significant ($F(1,36) = 7.87$, $p = .008$). Separated analyses for each type of response transition showed that responses after errors were significantly slower than after correct answers (significant PES) for response repetitions (effect of *Previous accuracy for repetitions:* $F(1,36) = 10.25$, $p = .003$) but not for response alternations (effect of *Previous accuracy for alternations:* $F<1$). In addition, after errors, response repetitions were slower than response alternations (effect of *Type of response transition after errors: F*(1,36) = 5.57, *p* = .025), whereas this difference was not significant after correct answers (effect of *Type of response transition after correct answers*: *F*(1,36) = 2.40, *p* = .13). None of the remaining interactions (*Previous accuracy x MA group*; *Type of response transition x MA group; Previous accuracy x Type of response transition x MA group)* was significant (*Fs*<1). Means of RTs and standard errors of the mean (SEM) according to *Previous accuracy* and *Types of response transition* for the HMA and LMA groups are given in Table 2.

Insert Table 2 approximately here

The ANOVA for percentage of hits showed significant main effects of *Previous accuracy* (*F*(1,36) = 6.43; *p* = .016; responses were less accurate after errors than after correct responses; 84% and 87%, respectively) and *MA group* (*F*(1,36) = 6.52, *p* = .015; HMA participants were less accurate than their LMA peers; 83% and 89%, respectively). The main effect of *Type of response transition* was not significant (*F*<1), neither any of the two-way interactions (*Type of response transition x Previous accuracy*: *F*(1,36) = 1.18, *p* = .28; *Type of response transition x MA group: F*(1,36) = 2.20, *p* = .15; *Previous accuracy x MA group: F<1*). Importantly, the three-way interaction *Previous accuracy x Type of response transition x MA group* was significant (*F*(1,36) = 5.09, *p* = .03). In order to study this interaction in more detail, separate ANOVAs were performed for each group. For the HMA group, the ANOVA showed a significant *Previous accuracy x Type of response transition* interaction (*F*(1,18) = 5.68, *p* = .03). More specifically, for these individuals the post-error reduction in accuracy was significant when a response repetition was required (effect of *Previous accuracy for response repetitions:* $F(1,18) = 8.08$, $p = .01$) but not in the case of response alternation (effect of *Previous accuracy for response alternations*: $F<1$). For the LMA group, neither the effect of *Previous accuracy* ($F(1,18) = 2.75$, $p = .12$), nor the *Previous accuracy x Type of response transition* interaction were significant ($F<1$). Means and SEMs of percentage of hits according to *Previous accuracy* and *Types of response transition* for the HMA and the LMA group are given in Table 3.

Insert Table 3 approximately here

4. DISCUSSION

The aim of the present study was to investigate how HMA individuals react to errors in an arithmetic task. To this end, we selected two groups of participants with extreme scores on math anxiety (low and high math anxious groups) but no differences in trait anxiety. Individuals were presented with a multi-digit addition verification task and their responses to trials following correctly and incorrectly answered problems were compared. In this way, we sought to broaden our understanding of the impact mistakes might have on HMA individuals' subsequent performance on an arithmetic task. This is an important question because errors are often considered a critical part of the learning process. Although errors can be the "best teacher" and may play a positive role in the learning process, they are also associated with negative feelings, which might interfere with math learning and math performance in general.

The present study confirms previous findings showing that accuracy decreases and response time is slower after having committed an error (Fiehler, Ullsperger, & Von

Cramon, 2005; Rabbit & Rodgers, 1977), and that HMA individuals are slower and more error-prone than their LMA counterparts in solving arithmetic problems (Hembree, 1990). Importantly, the present study adds further evidence to our understanding of post-error behavioral adjustments (response time and hit rate), since our results suggest that these adjustments depend on the type of response transition and math anxiety. Specifically, as for response time, we found that both HMA and LMA individuals were slower in verifying problems after having committed an error than after having given a correct answer but only when they needed to give the same response as the one given in the previous trial (i.e., PES were significant only for response repetitions). Regarding accuracy, post-error adjustment depended not only on the type of response transition but also on math anxiety: post-error reduction in accuracy was only found for the HMA group when they needed to repeat the previously given response. By contrast, no difference in hit rate was found in the LMA group when their responses after errors were compared with their responses after correct answers.

Our findings may have important implications for existing accounts of behavioral post-error adjustment. Since PES was found only when the current trial required the same response as that previously given, it seems that error commission is followed by direct response suppression (i.e., inhibition response). This result lends support to the inhibitory account of post-error adjustment (Ridderinkhof, 2002). It should be noted that according to the orienting account (Notebaert et al., 2009) we would not have expected differences in post-error behavior depending on the response transition (repetition versus alternation between responses from the previous to the current trial), because the orienting response would have affected any response following an error. In this way, our results add further evidence to previous brain imaging studies suggesting that PES reflects a mechanism of response inhibition (Marco-Pallarés et al., 2008) and to behavioral studies suggesting that PES reflects activity of the Behavioral Inhibition System (BIS) (Kleiter & Schwarzenbacher, 1987) and is positively related to BIS scores (Boksem, Tops, Kostermans, & De Cremer, 2008). The BIS is a motivational system proposed by Gray (1989) that is sensitive to signals of punishment and inhibits behaviors that may have aversive consequences.

Importantly, the present results showed that post-error behavior in an arithmetic task differed according to math anxiety. LMA individuals showed PES when they had to repeat their previous response, but no post-error decrease in accuracy: there was no difference between their accuracy after errors and after correct answers. So, LMA individuals' responses after an error were slower but accurate. However, when their HMA peers committed an error, they were not only slower but also less accurate, specifically when the same response (true/false) was required by the following arithmetic verification problem. This post-error behavior shown by HMA individuals is compatible with the inhibitory account of post-error adjustment (Ridderinkhof, 2002) (i.e., they become slower and more error prone after error commission because they over-inhibit the response associated with that error). The response over-inhibition in the HMA group that our results suggest is consistent with previous studies reporting that higher levels of trait anxiety are related with enhanced response inhibition. In an ERP experiment, Sehlmeyer et al. (2010) used a Go/No-go task in which participants had to respond to the Go condition and withhold responses to the No-go condition. They found that the No-go N2 ERP component, assumed to reflect inhibition or revision of a motor plan prior to motor execution (Falkenstein, Hoormann, & Hohnsbein, 1999), was enhanced in high anxious individuals. They concluded that high trait-anxious people can be characterized by enhanced evaluation of their behavioral outcomes, which may be reflected in increased inhibition-related No-go N2.

The present results are also compatible with a stronger engagement of HMA individuals in counterfactual thoughts or in the simulation of the alternative response “ought to have done” after errors, as observed in other memory and reasoning tasks (Markman & Weary, 1996). If this were the case, the mental simulation of the alternative response might increase its activation and, as a consequence, the chances of committing an error if the same instead of the alternative response were required (Tops & Boksem, 2011). Errors in math tasks might be particularly adverse for the HMA group, and in order to avoid erring again they would prepare the alternative response (e.g. the one which would have been correct in the previous erroneous trial). In contrast, after correct answers, counterfactual thoughts would not be generated, which would be consistent with the absence of significant response transition effect.

Previous studies have already reported abnormal error monitoring in HMA individuals (Suárez-Pellicioni et al., 2013). In their study, Suárez-Pellicioni et al. (2013) concluded that HMA individuals may suffer from a greater sensitivity to — and concern over — errors committed in a numerical task, as compared with errors in a non-numerical task, and that this hypersensitivity to self-generated errors might play a role in the maintenance of math anxiety. The results of the current study add evidence of abnormal error adaptation in HMA individuals by showing how their errors in a more ecological math setting (i.e., a multi-digit addition task) have a clear impact on their subsequent behavior, slowing their response time and decreasing their accuracy.

As for LMA individuals’ post-error behavior, the fact that in our study they showed a PES (in terms of RT) but no post-error accuracy effect is consistent with the finding that these effects are reduced or even disappear with increasing ITIs (Danielmeier & Ullsperger, 2011; Jentzsch & Dudschig, 2009). Thus, our LMA participants would have had enough time to adapt to their errors, avoiding their negative impact on performance in the following trial. However, their HMA counterparts seemed to have had trouble adapting to an error even if enough time was given. This conclusion is further supported by the results of a recent study by Van der Borght, Braem, and Notebaert (2016), who found that only low trait-anxious individuals (but not their high-anxious peers) could counteract the detrimental effect of errors when time allowed for it.

The evidence provided in the present study may have practical implications for understanding how HMA individuals learn mathematics and why they show low math achievement as compared with their LMA peers. Whereas committing errors in a math task did not decrease accuracy in the following trial in the LMA group, errors increased the probability of committing more errors in the HMA group when the same, previously erroneous response was required. The difficulties HMA individuals face when they have to solve additions after having committed an error suggests that their processing resources might be reduced due to the effort of inhibiting the response associated with that error (it seems that HMA individuals try to avoid making a subsequent error in the arithmetic task by means of an over-activation of the BIS to prevent them from repeating the response that made them commit an error) and/or due to the simulation of the alternative response.

Although the results are quite specific, since the effect is shown only when the same, previously erroneous response is required, our findings suggest that HMA individuals show an abnormal adaptation to errors committed in a math task, an adaptation which, instead of translating into better performance, seems to affect it negatively. Thus, despite being specific, any effect that can explain HMA individuals' negative math performance should be considered of relevance and studied in more detail.

5. CONCLUSION

In conclusion, the current study demonstrated a different behavioral reaction in HMA and LMA individuals when dealing with errors in mathematics. Whereas response to an addition following an error was slower in both groups, the HMA group also showed a post-error decrease in accuracy (i.e., after an error they were not only slower but also less accurate). Importantly, this impairment was shown only when the required response to the current addition was the same as the one previously associated with an error. Hence, this study supports behavioral over-inhibition of HMA individuals as a reaction to errors in an arithmetic task, which might occur together with a stronger tendency to simulate the alternative response. The abnormal response of HMA individuals to self-committed errors could be a factor contributing to their difficulties in the learning of math and in their low math achievement.

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Table 1. Means and standard error of the mean (SEM; in brackets) for age, math anxiety, trait anxiety, handedness, and years of formal education for the low math-anxious (LMA) and high math-anxious (HMA) groups.

	LMA	HMA
Age	22.00 (3.35)	21.70 (2.83)
Math anxiety	44.79 (7.39)	86.40 (5.86)
Trait anxiety	16.79 (7.01)	20.15 (10.69)
Handedness	18	18
Years of formal education	9.64 (1.64)	9.90 (1.51)

Note. Math anxiety measured with the sMARS (Alexander & Martray, 1986); Trait anxiety measured with the trait subscale of the STAI (Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983); Handedness: number of right-handed. Years of formal education: counting from 12 years old onwards.

Table 2. Mean RTs (in milliseconds; SEM in brackets) for correctly solved trials according to accuracy in the previous trial and to the type of response transition from previous to current trial in the HMA and LMA groups. Distribution of trials (in %) for the three-way design is also given.

	High Math Anxious group		Low Math Anxious group	
	Repetition	Alternation	Repetition	Alternation
Previous error	886.96 (32.23)	845.37 (36.95)	709.51 (31.73)	674.18 (34.06)
(% trials)	6.7	8.3	4.7	4.5
Previous correct	817.02 (34.56)	827.29 (35.79)	667.57 (26.82)	683.04 (28.73)
(% trials)	42.6	42.4	44	46.8

Note. *Repetition:* when the response given by the participant in the current trial (always correct in the RT analyses) coincided with the one previously given (which could be correct or incorrect); *Alternation:* when the response given by the participant in the current trial differed from the one previously given.

Table 3: Percentages of hits (SEM in brackets) according to accuracy in the previous trial and to the type of response transition from previous to current trial in the HMA and LMA groups. Distribution of trials on average (in %) for the three-way design is also given.

	High Math Anxious group		Low Math Anxious group	
	Repetition	Alternation	Repetition	Alternation
Previous error	78.12 (2.11)	84.39 (1.73)	88.97 (1.99)	85.68 (1.81)
(% trials)	7.8	8.3	5.0	4.9
Previous correct	85.78 (1.04)	83.31 (1.66)	90.52 (0.93)	90.30 (1.03)
(% trials)	41.5	42.4	43.5	46.6

Note. *Repetition:* when the response required by the current problem was the same as the one previously given by the participant; *Alternation:* when the response required by the current problem was not the one previously given by the participant.