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Mathematical anxiety effects on simple arithmetic processing efficiency: An event-related potential study

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ABSTRACT

This study uses event-related brain potentials to investigate the difficulties that high math anxious individuals face when processing dramatically incorrect solutions to simple arithmetical problems. To this end, thirteen high math-anxious (HMA) and thirteen low math-anxious (LMA) individuals were presented with simple addition problems in a verification task. The proposed solution could be correct, incorrect but very close to the correct one (small-split), or dramatically incorrect (large-split). The two groups did not differ in mathematical ability or trait anxiety. We reproduced previous results for flawed scores suggesting HMA difficulties in processing large-split solutions. Moreover, large-split solutions elicited a late positive component (P600/P3b) which was more enhanced and delayed in the HMA group. Our study proposes that the pattern of flawed scores found by previous studies (and that we replicate) has to do with HMA individuals'difficulties in inhibiting an extended processing of irrelevant information (large-split solutions).

1. Introduction

Mathematics anxiety is defined as "the panic, helplessness, paralysis and mental disorganization that arises among some people when they are required to solve a mathematical problem" (Tobías & Weissbrod, 1980, p. 65). High math-anxious individuals tend to espouse negative attitudes toward math and hold negative self-perceptions about their math abilities (Ashcraft, 2002). A meta-analysis conducted by Hembree (1990) concluded that in the college population math anxiety shows strong negative correlations with enjoyment of math (−.47), self-confidence in math (−.65) and motivation in math (−.64). Moreover, it is widely asserted that math anxiety is a major contributor to what Ashcraft and Faust (1994) called global avoidance, namely the documented tendency of math-anxious individuals to avoid situations that are math-intensive, leading them to avoid educational pathways and career avenues that depend on the discipline (Ashcraft & Ridley, 2005). An obvious but unfortunate consequence of all this is that high math-anxious individuals are at a disadvantage when competence or mastery is assessed with standardized tests, which is the reason for the negative correlation between math anxiety and math achievement (−.31) in the college population (Hembree, 1990). Given the importance of mathematics for academic and professional development (Bynner & Parsons, 1997) and the poorer perspectives for those students suffering from math anxiety, the topic is attracting increasing interest and is now considered a social problem that merits serious attention, in terms of both assessment and intervention.

Many studies have focused on the cognitive consequences of mathematical anxiety. While several authors have shown that high math-anxious (HMA) individuals perform worse than their low math-anxious (LMA) peers on a wide range of arithmetical tasks (Ashcraft & Kirk, 2001; Ashcraft & Moore, 2009), others have suggested that HMA and LMA individuals do not differ equally on all tasks of this kind. Ashcraft and Faust (1994) coined the term *anxiety–complexity effect* to reflect the fact that HMA individuals performed the same as their LMA counterparts on simple arithmetic problems, but that their performance deteriorated when the stimulus conditions become more difficult or complex. In a subsequent study, Faust, Ashcraft, and Fleck (1996) tested this anxiety–complexity effect by manipulating the *split*, i.e., the numerical distance between the proposed and the correct solution in a problem verification task (Ashcraft & Battaglia, 1978; Ashcraft & Stazyk, 1981). More specifically, the split effect consists of a slower and less accurate response when the proposed solution is a number

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close to the correct solution (e.g., 4 + 7 = 12; hereinafter, small-split solution) than when a dramatically incorrect alternative is proposed (e.g., 4 + 7 = 25; hereinafter, large-split solution) (Núñez-Peña & Escera, 2007).

The split effect has been associated with the use of different strategies. When a small-split solution is given, individuals are expected to use an exhaustive verification strategy to achieve the exact solution of the operation and give a response. However, when a large-split solution is given, individuals may respond by using a plausibility strategy, which is easier and quicker than doing the whole calculation for such an obviously incorrect solution (Duverne & Lemaire, 2005; El Yagoubi, Lemaire, & Besson, 2003, 2005; Núñez-Peña & Escera, 2007). To study the effects of math anxiety on the split effect, Faust et al. (1996) formed four groups according to their subjects' level of math anxiety. Individuals had to perform an addition verification task involving simple and complex (multi-digit) additions in the form $a + b = c$. Simple addition problems consisted of one-digit additions with addends between 0 and 9, and four different split solutions were presented: ±1, ±5, ±9 and ±23 (with the proposed solution always being positive). To analyze what they coined "subjects' difficulties in processing", flawed scores[1] were computed by adding the proportion of error trials to the proportion of trials with extreme response times (outliers). According to the evidence on strategy selection, individuals would be expected to solve the large-split solution by using a plausibility strategy and, consequently, have a low level of flawed scores, whereas small-split solutions should be solved by an exhaustive verification strategy and, consequently, be associated with a higher level of flawed scores. However, Faust et al. (1996) found an unexpected pattern of flawed scores across the split levels in HMA individuals: in the large-split condition (±23), where the incorrect solution was dramatically wrong, HMA individuals generated as high flawed scores as they did in the split-1 condition. Thus, a difference was created between groups in a split level in which, given the simplicity of the task, no differences were expected. This curious finding, which nobody has tried to replicate since, constitutes the core of the present study.

Previous research studying the electrophysiological correlate of the split effect has reported a late positive component (LPC) every time an arithmetic rule is broken (i.e., an incorrect solution is proposed for a given problem) (Niedeggen & Rösler, 1999; Núñez-Peña & Escera, 2007). The LPC is a central-posterior distributed positive-going event-related brain potential (ERP) component that starts around 500 ms and generally extends up to at least 800 ms. In fact, a component of equal polarity, topography and latency (labeled P600) has been described in other types of violation: orthographic (mis-spelled words) (Münte, Heinze, Matzke, Wieringa, & Johannes, 1998), syntactic (Osterhout, Holcomb, & Swinney, 1994), musical (Patel, Gibson, Ratner, Besson, & Holcomb, 1998) and violations in non-linguistic abstract sequences (Besson & Macar, 1987; Lelekov-Boissard & Dominey, 2002).

Cognitive neuroscientists familiar with the attention and decision-making literature will see similarities between the LPC/P600 and one of the earliest known ERP components, the P300. Previous authors have suggested that the late positivity time-locked to syntactic irregularity is actually a member of the P300 family (Coulson, King, & Kutas, 2010). The most commonly studied component in this family may be the P3b, considered to be sensitive to cognitive aspects of processing and whose amplitude is taken as a measure of the amount of attentional resources allocated to the stimulus. Although P3b amplitude becomes smaller as task difficulty or complexity exceeds attention resources, moderate increases in task demands well within the subject's capabilities should increase it, as the subject devotes more resources to the task (Salisbury, Rutherford, Shenton, & McCarley, 2001). On the other hand, P3b latency is linked to the stimulus evaluation time, or more generally, to the speed of cognitive processing of the stimulus. It has been suggested that by measuring P3b latency researchers can break down the overtly observable response time into two portions, one stimulus-related and one response-related, with variations in P3b latency reflecting stimulus processing independently of response-level processing (Verleger, 1997).

Previous studies have reported P600/P3b differences in amplitude and latency in different samples of anxious subjects. P600/P3b amplitude enhancements were found in post-traumatic stress disorder (Kimble, Kaloupek, Kaufman, & Deldin, 2000), in post-traumatic syndrome (Alberti, Sarchielli, Mazzotta, & Gallai, 2001), and in panic disorder (Pauli et al., 1997) while amplitude reductions have also been reported for subjects suffering from generalized anxiety disorder (Boudarene, 1998; Boudarene & Timsit-Berthier, 1997). On the other hand, P600/P3b latency differences have also been found in several anxious samples (Miltner et al., 2005; Schucard, McCabe, & Szymanski, 2008). For example, shorter latencies have been reported for high trait-anxious participants (Rossignol, Philippot, Douilliez, Crommelinck, & Campanella, 2005) and post-traumatic stress disorder patients (Matthew et al., 2001), while delayed latencies have been found in panic disorder (Turan et al., 2002) and obsessive-compulsive disorder (Papageorgious & Rabavilas, 2003) patients.

Several studies exploring anxiety-related effects have given support to the attentional control theory (Eysenck, Derakshan, Santos, & Calvo, 2007; hereinafter, ACT). This theory, an extension of the processing efficiency theory (Eysenck & Calvo, 1992), distinguishes between *performance effectiveness* and *processing efficiency*. While the former refers to the quality of performance, the latter refers to the relationship between the effectiveness of performance and the amount of resources or effort that has to be used to attain a given performance level. The main point of this theory is that anxiety affects processing efficiency to a greater extent than performance effectiveness, which implies that high anxious individuals, despite showing the same performance level as their low anxious counterparts, make inefficient use of the cognitive resources (using auxiliary processing resources/making a greater effort) in order to succeed in the task. In this line, according to the ACT, anxiety impairs processing efficiency because it reduces attentional control, a key function of the central executive. More specifically, the ACT assumes that there are two attentional systems: a *goal-directed attentional system*, influenced by expectations, knowledge and current goals (top-down control of attention) and a *stimulus-driven attentional system* responding maximally to salient or conspicuous stimuli (bottom-up control of attention) (Corbetta & Shulman, 2002). According to the ACT, anxiety decreases the influence of the goal-directed attentional system, and increases the influence of the stimulus-driven attentional system. This imbalance has direct negative consequences in the inhibition and shifting functions. The shifting function involves the ability to shift back and forth between multiple tasks, operations, or mental sets (Miyake et al., 2000). Several studies have suggested impaired task-switching performance and impaired performance on secondary tasks in dual-task situations in high anxious individuals (Ansari et al., 2008; Derakshan, Smyth, & Eysenck, 2009). On the other hand, the inhibition function involves using attentional control to resist disruption or interference from task-irrelevant stimuli or responses. High anxious individuals generally attend to salient or conspicuous stimuli because these stimuli command attention

[1] Flawed scores are a measure created by Faust et al. (1996) to analyze subjects' difficulties in processing. Combining the proportion of errors and the proportion of extreme reaction time scores, this measure was expected to be sensitive to the subject's difficulties in processing, since it reflects both those difficulties that yielded an error and those that generated an inordinately slow reaction time.