Current Psychology (2024) 43:6533–6548
https://doi.org/10.1007/s12144-023-04828-2

Math anxiety and attention: Biased orienting to math symbols or less efficient attentional control?

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Accepted: 31 May 2023 / Published online: 15 June 2023

Abstract

Previous research about the existence of an attentional bias for math in highly math-anxious (HMA) individuals shows inconsistent results, and methodologies used so far cannot distinguish the various components of attentional bias. Here we adapted Grafton and MacLeod (2014)'s methodology to assess biases linked to math anxiety in engagement and disengagement when task-irrelevant math and neutral symbols are briefly presented. Twenty-one HMA and 21 low math-anxious individuals were asked to perform the attentional task just after solving an arithmetic task expected to generate group differences in state anxiety. Considering attentional control theory, state anxiety will likely increase allocation of attention to task-irrelevant stimuli. Therefore, individual differences in efficiency responding to this task, which despite being simple and non-mathematical is interrupted by task-irrelevant stimuli, were also analyzed to study whether HMA individuals show reduced attentional control. Our results provide evidence against the presence of an attentional bias towards/against mathematical symbols in visuospatial orienting of the HMA population, neither in the form of an engagement bias nor as a disengagement bias. Rather, HMA individuals were slower and could not take advantage of a longer interval to overcome distraction, which suggest less efficient attentional control, at least when they experience higher state anxiety. Therefore, it is unlikely that an attentional bias for math may originate or aggravate math anxiety. However, reduced attentional control may underlie the less efficient processing on math tasks usually shown by HMA individuals, so research on attention in math anxiety should keep focusing on HMA's difficulties in executive control.

Keywords Math anxiety · Attentional bias · Engagement · Disengagement · Attentional control theory · Executive control

Introduction

Some people find a page full of math problems threatening. The feeling of tension and dread when dealing with math-related contexts is called math anxiety and it can be considered a genuine phobia (Ashcraft & Ridley, 2005). As a type of anxiety, math anxiety might be associated with relevant modulations in two related aspects of attention: attentional selectivity and attentional control. Attentional selectivity refers to the allocation of attentional resources to certain stimuli so that only this selection of the incoming information is then adequately processed. Attentional control alludes to the executive processes that shift or maintain the allocation of attentional resources where they are needed to achieve one's goals (e.g., on task-relevant stimuli and mental sets), which prevents attention from being randomly allocated. Biased attentional selectivity towards math stimuli has been proposed as a mechanism that might contribute

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to originating, maintaining or aggravating math anxiety (e.g., Rubinsten et al., 2015; Suárez-Pellicioni et al., 2016). Reduced attentional control may explain, at least partially, the lower efficiency that highly math-anxious (hereinafter, HMA) individuals usually show during math performance (e.g., De Agostini, 2020).

The suggestion of biased attentional selectivity in HMA individuals is based on previous research pointing out that anxious people have a greater tendency to allocate attention to threatening or emotionally negative stimuli than to focus on neutral stimuli, even when the negative stimuli do not pose a danger at the present time. While low anxious individuals may, under certain circumstances, prioritize attending to task-relevant threatening vs. neutral stimuli, high anxious individuals show attentional bias (hereinafter, AB) for threat even when the threatening stimuli are task-irrelevant (Okon-Singer, 2018). This has also been observed with several specific anxieties and phobias (e.g., social anxiety or spider phobia) in relation to their specific objects of fear. It is assumed that this favored selection of threatening stimuli increases the frequency of experiencing distress, which contributes to the etiology and maintenance of anxiety and related disorders (e.g., Mathews & Macleod, 2002). Therefore, it is important to investigate whether math anxiety is also characterized by a biased selection of math information. If this was the case, a therapeutic intervention that reduces this bias, like attentional bias modification (e.g., Mogg & Bradley, 2018), would be useful to help the HMA population.

The suggestion of reduced attentional control in the HMA population comes from attentional control theory (hereinafter, ACT; Eysenck et al., 2007). According to ACT, anxiety decreases the efficiency of attentional control, which usually entails a larger investment of resources (time or effort) to maintain an adequate level of performance effectiveness (i.e., to avoid errors). Postulates of this theory are based, between others, on anxiety-linked AB towards threat. ACT claims that when anxiety is experienced, it is adaptive to allocate attention to the threatening stimuli, and that threat detection is favored by increasing the bottom-up attentional system at the expense of a decrease of the top-down attentional system. The imbalance between these systems favors the allocation of attention to task-irrelevant stimuli (whether they are threatening or not) and reduces the efficiency of the goal-directed executive functions that control attention. This impairs performance in tasks that are demanding of working memory. In math processing and learning, executive functions play a crucial role, insofar as math activities place great demands on attentional control (Clements & Sarama, 2019). Therefore, in the present study we aim to evaluate whether math anxiety is related to an AB for math stimuli and to shed more light on the association between math anxiety and attentional control. While the last association can be assessed in many ways, AB has been shown to be a phenomenon that is very difficult to measure (McNally, 2019). The difficulties in assessing AB, which are explained below, were considered in the present study to choose an appropriate experimental paradigm.

Anxiety-linked AB to threat was first studied in the past century with paradigms like the emotional Stroop (already used by Ray, 1979) and the dot probe (MacLeod et al., 1986). Both paradigms have been used in a large number of studies (see, for example, the review by Yiend, 2010). In the former, participants are asked to name the color in which differentially valenced (i.e., threatening or neutral) words are presented. However, slower response times (hereinafter, RT) observed in anxious individuals when naming the color of a threat word could be interpreted as an AB towards a fear-related meaning or as a "freezing" motor response when threat is visualized and anxiety experienced. This led researchers to focus mainly on paradigms that assess visual spatial orienting, such as the dot probe (double cueing) task. In this task, a threatening and a neutral stimulus appear simultaneously on the screen, followed by a dot that participants must detect, which can be displayed in the location where the threatening stimulus was or in the locus of the neutral one. Dot-probe experiments frequently observed faster responses of anxious individuals when the dot appeared in the location in which the threatening stimuli was presented. This was initially interpreted as a bias in engagement of attention. In 2001, Fox et al. suggested that anxiety-linked AB may also be due to a bias in disengagement. An engagement bias would indicate a bias in orienting attention toward threat (i.e., facilitated attentional capture by threat), while a delayed-disengagement bias would imply a tendency to hold attention on the threatening stimulus and greater difficulty in switching attentional focus away from threat. According to Fox et al., it was important to know which component of the orienting system led to the anxiety-linked AB. An engagement bias would indicate that the priority of the anxious population's attentional system is to locate threat, while delayed disengagement would suggest that anxious people need to further process and evaluate threat. The former bias might increase the frequency and level of anxiety experienced (since the person is informed about more potential dangers) and thus proneness to suffer anxiety. However, it may also be due to an adaptive function (it is relevant for people to locate danger when they are already feeling anxious). By contrast, delayed disengagement from threat may aggravate anxiety by leading to rumination and worry, which are key aspects of anxiety disorders. Fox et al. evaluated disengagement bias by using a single cueing paradigm, in which participants shift attention from central fixation to a peripherical differentially valenced cue, which is followed by a target that can appear in the cued or the uncued location. Delayed disengagement from threat was inferred from slower responses to uncued targets after a threatening vs. a neutral cue.

The results obtained with methodologies that were devised to measure specifically engagement (e.g., Pérez-Dueñas et al., 2009) or disengagement (e.g., Fox et al., 2002) seemed contradictory, with some favoring the attentional capture hypothesis and others supporting the delayed disengagement proposal. Moreover, a third component of AB has been described in some studies, usually following an engagement bias. It consists of attentional avoidance, that is, rapid disengagement from threat (e.g., Koster et al., 2006). According to Cisler and Koster (2010), anxiety-linked AB can be observed in all three forms but each reflects a different underlying mechanism: (1) facilitated engagement with threat would be related to increased vigilance even when there is no real threat in the present, (2) delayed disengagement would be a consequence of reduced attentional control, and (3) attentional avoidance would be mediated by an emotion regulation strategy that is activated to reduce the level of anxiety experienced, which requires attentional control. Each component may also have a different temporal signature, although this is not always replicated. For example, some studies found that attentional avoidance is observed with longer presentations of threatening stimuli, but this was not always replicated (Cisler & Koster, 2010). However, the use of long presentations may be problematic. For example, in the dot-probe task a long exposure duration of the pairs of stimuli makes it impossible to know the type of bias, as it allows multiples shifts of spatial attention between both stimuli (Yiend, 2010). This implies that RT results may only reflect where attention is deployed in this late probed time. Furthermore, the fact that it is not controlled whether attention is initially engaged with the neutral or with the threatening stimulus entails a potential confounding factor, the inhibition of return (hereinafter, IOR; Klein, 2000): when attention is oriented to a location, individuals are slower to respond to a target that appears several hundreds of ms later in this same location. Thus, initially engaging attention more frequently with the threatening stimulus of each pair, even in the absence of any bias in disengagement, may generate IOR more frequently in the location of the threatening stimuli, and thus, slower responses when the target appears there. This slowing, which is usually interpreted as attentional avoidance, would only be due to an engagement bias.

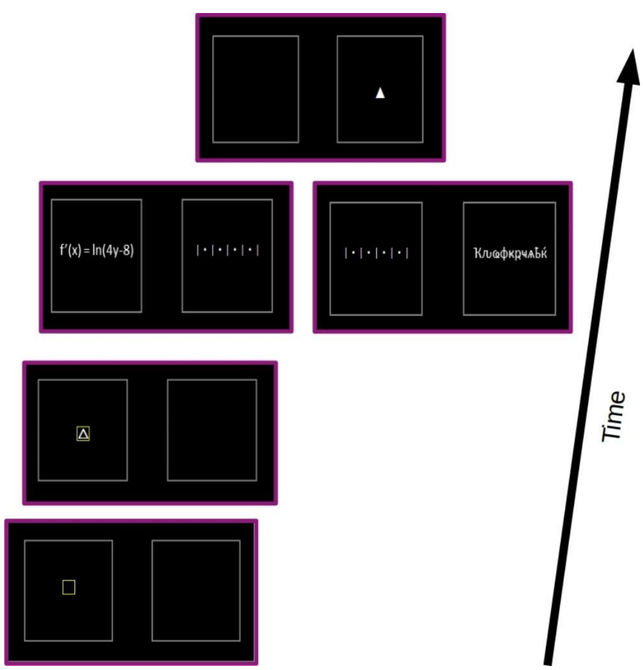


Fig. 1 Adapted ARDPEI task. An example of a math and proximal type of trial (left) is provided, and an example of a neutral and distal trial (right). In these examples, the target appears in the non-anchored region

In addition to the problems of the initial methods, in recent years the reliability of anxiety-linked AB to threat has been questioned (e.g., McNally, 2019). It has been pointed out that the methodologies that are usually used, including the single-cueing paradigm (e.g., Mogg et al., 2008), have too many confounds that question whether what they are measuring is AB and, if so, whether it is due to modulations in engagement or in disengagement. In this context, Grafton and MacLeod (2014) designed a new paradigm, based on the dot-probe task, such that the problems of the previous methodologies (e.g., the fact that the initial attentional spatial location was not ensured) were solved and differences in engagement and disengagement could be properly measured. This was called the Attentional Response to Distal vs. Proximal Emotional Information (ARDPEI) task. In this task (see our adaptation of it in Fig. 1), a stimulus whose identity participants should memorize (hereinafter, anchor) is presented either on the right or on the left side of the screen. The location of the initial spatial focus is therefore anchored. Then, a task-irrelevant stimulus that can be either threatening or neutral is briefly displayed either proximally (i.e., very close to the anchor, on the same screen side) or distally (opposite screen side). Trials in which this differentially valenced irrelevant stimulus is presented proximally are used to study the influence of the stimulus valence in disengagement from the already attended region, while trials in which the differentially valenced stimulus is presented distally are used to examine how the valence of the stimulus modulates engagement. In the unoccupied location another stimulus is presented at the same time as the differentially valenced stimulus to allow competition for attention. Finally, the target appears in one of the two loci and participants must answer whether it is the same or different from the anchor. The distribution of selective attention is first assessed separately for each type of valence by computing the difference value that reflects the relative speed of accurate responses in each target disposition (i.e., same vs. different loci than the differentially valenced stimulus). Then, this paradigm provides an Engagement Bias Index and a Disengagement Bias Index for each participant by assessing the difference in selective attention between threatening and neutral trials for distal and for proximal dispositions respectively. As the temporal signature of each component may differ, two exposure durations of the threatening/neutral stimulus are used. Grafton and MacLeod (2014) found that trait anxiety was related to facilitated engagement with threatening stimuli and to impaired disengagement from them. The same methodological approach was used later with specific anxieties; for example, Grafton and MacLeod (2016) found that social anxiety was related only to facilitated engagement with socially negative information.

In the field of math anxiety, to our knowledge, only classical methodologies have been used to examine attentional selectivity towards math stimuli in the HMA population. McLaughlin (1996), Hopko et al. (2002) and Suárez-Pellicioni et al. (2015) used the emotional Stroop paradigm. While the two first studies did not find any bias, the latter found that HMA individuals were slower when faced with math words. As stated before, this may be due to facilitated engagement, impaired disengagement or a freezing motor response. In Rubinsten et al. (2015), a single-cueing task was adapted so that participants were required to attend a differentially valenced cue (math or neutral), whose content was relevant for a dual task. Their results suggested that math anxiety was associated with delayed disengagement from math. Apart from the interpretation problems associated with the single-cueing methodology (e.g., Grafton & MacLeod, 2014), the fact that math and neutral cues were relevant for the subsequent task, and thus needed to be attended to, prevented this study from assessing differences in engagement. A single-cueing paradigm with task-irrelevant cues has been used recently by Shi et al. (2022). They found no AB for irrelevant math information in a child HMA population. However, in an adult HMA population, attentional orienting in the face of task-irrelevant math stimuli was examined in a fMRI study by Pizzie and Kraemer (2017). They used a classical dot probe and presented irrelevant pairs of math and neutral symbols or negative and neutral pictures for 1000 ms. Interestingly, math anxiety was associated with increased amygdala reactivity when participants were faced with symbols, which suggests that the HMA population evaluate irrelevant math stimuli as a threat. They also observed marginally different attentional selectivity when HMA were faced with symbols than with pictures. In picture trials, faster responses were observed when the target appeared where a negative picture did. In symbols trials, HMA participants were slightly slower when the target appeared in the location in which a math stimulus was presented than when the target appeared in the neutral-symbol locus. This marginal interaction was interpreted as attentional avoidance of math. However, this interpretation is problematic: (1) they did not analyze whether the smaller difference in RT depending on target position in symbol trials differed from zero, therefore, that interaction may arise from an AB for negative pictures and no AB for math, and (2) the long exposure duration of the task-irrelevant pairs of stimuli in the dot probe makes it impossible to determine the type of bias. Therefore, although the different attentional behavior in the HMA population when presented with innate threat vs. math-related threat is very interesting, their results provide no clear conclusions on the influence of math in selection. Pizzie and Kraemer's results could be explained by attentional avoidance of math occurring after unbiased engagement, as the authors claim; engagement bias towards math; or no AB for math.

Therefore, previous research shows inconsistencies in whether math stimuli bias HMA's attentional selectivity or not. None of the methodologies previously used in the field of math anxiety can offer a valid measure of AB, nor can they properly distinguish which specific component of AB would be associated with math anxiety. The main aim of our study was to explore whether there is, or not, any component of AB for math that modulates attentional selectivity in the HMA population and whether conclusions that come from the AB observed with improved methods in general and specific anxieties (e.g., Grafton and Macleod, 2016) apply to math anxiety or not. To explore this issue, two groups with extreme levels of math anxiety were asked to perform an adaptation of the ARDPEI task. Apart from using a methodology that can distinguish modulations in engagement and disengagement, a second novelty in the field of math anxiety was the use of brief symbol exposure durations to prevent several shifts in spatial attention during their presentation. Individual differences in the indices scores were analyzed to determine whether math anxiety is associated with facilitated engagement with math stimuli, with delayed disengagement from them, with attentional avoidance of them or with no AB (as in McLaughlin, 1996, Hopko et al., 2002, and Shi et al., 2022). An AB may require an actual state of anxiety (e.g., Fox et al., 2001). Therefore, in the present study, participants were asked about the level of state anxiety generated by the adapted ARDPEI task. Moreover, as in other AB studies (e.g., Fox et al., 2002), state anxiety was previously induced. Group differences in state anxiety were ensured by generating state-math anxiety: participants were asked to solve a timed arithmetic task just before performing the ARDPEI task. To confirm that a higher level of experienced anxiety in the HMA group was sufficiently sustained throughout the attentional task, state anxiety was measured at the end of the ARDPEI task and compared with state anxiety reported before performing the arithmetic task. The HMA group was expected to maintain a larger increment of state anxiety than the low math-anxious (LMA) group.

As stated previously, a secondary aim of this study was to study attentional control. Several studies have suggested impaired control in the HMA population (e.g., Núñez-Peña et al., 2021), which could be due to either an anxiety-independent deficit that characterizes the HMA population, an attentional consequence of anxiety, as suggested by ACT (Eysenck et al., 2007), or both. However, HMAs' impaired attentional control does not appear to be a generic trait that affects all types of cognitive tasks (e.g., Di Lonardo Burr & LeFevre, 2021). Considering ACT, it should be expected that HMA individuals would less efficiently control their goal-directed attention than LMA individuals, if they perform any working-memory demanding task while experiencing a higher level of state anxiety than the former. In fact, reduced attentional control is usually observed while HMA participants are solving numerical tasks (e.g., Pletzer et al., 2015; Shi et al., 2022), spatial tasks (e.g., Núñez-Peña et al., 2019), or cognitive processes that may resemble mathematical processing (Colomé et al., 2022), and thus are probably experiencing state anxiety. As the ARDPEI task is a working-memory demanding task in which the brief appearance of symbols between the anchor and the target causes distraction, and state-math anxiety was induced, less efficient control in the HMA group was hypothesized. We predicted that HMA individuals would need more time to overcome distraction (and therefore to perform the task) than LMA individuals. Moreover, as two stimulus onset asynchronies (SOA) between distractors and target were used, we expected faster responses in the longer SOA than in the shortest in the LMA group, since efficient attentional control would use the longer duration to shift the attentional focus (probably captured by the distractors) back to the task goal before the target appears. By contrast, it was predicted that the longer duration would not be enough for individuals with less efficient attentional control (i.e., HMA participants) to start overcoming distraction: we predicted no differences between both SOAs in this group[1]. Likewise, group differences in RT were expected to be observed, especially in the longer SOA.

Methods

Participants

Forty-two volunteers (28 women and 14 men) took part in this study. All participants signed an informed consent form before the start of the experiment and were paid for their participation. They were selected from a larger sample of 1096 college students, who were recruited both online and at the university. A Qualtrics survey assessing math anxiety, age, gender, laterality, education, knowledge of Cyrillic languages and medication use was prepared and shared through social media. The 230 responses obtained in the online survey were added to those obtained in a previous sample of 866 students who completed the survey in the classroom as part of a larger project. Twenty-one respondents who had scored below the first quartile ($Q_1 = 53$) of the larger sample distribution on the *Shortened Mathematics Anxiety Rating Scale* (Alexander & Martray, 1989), and 21 participants who had scored above the third quartile ($Q_3 = 78$) were selected. This resulted in two groups (the LMA and the HMA groups) that differed in math anxiety ($t(40) = 14.74$, $p < .001$). Participants had also been asked to complete the subscale of the *State-Trait Anxiety Inventory* that measures trait anxiety (STAI-T, Spielberger et al., 2008) and were selected in such a way that the groups did not differ in trait anxiety ($t(40) = 0.20$, $p = .839$). Considering that trait and math anxiety are highly correlated and that the former is also likely to influence attentional control (Eysenck et al., 2007) and attentional selectivity (e.g., Grafton & MacLeod, 2014), we could thereby dismiss the effect of this factor on group differences. Additionally, to prevent extreme values of trait anxiety from affecting attentional control, we excluded respondents who scored over the third quartile ($Q_3 = 31$) of the aforementioned larger sample distribution on the STAI-T. Moreover, because depression and dysphoria have been also found to be associated with an AB to negative stimuli, our participants scored in the minimal rank of depression on the *Beck Depression Inventory-Second Edition* (i.e., from 0 to 13; Sanz & Vázquez, 2011). In addition, to control for any noise due to different associations between the responding hand and laterality in the ARDPEI task (anchor target congruency should be answered with the right hand), only right-handed people were included during the selection process. Lastly, to avoid individual differences in familiarity

[1] It may be considered that the appearance of distractors acts as a preparatory cue that anticipates the target and that the random alternation of two intervals between the distractors and the target (i.e., SOA or "foreperiod") may generate a foreperiod effect (Niemi & Näätänen, 1981). This consists of faster responses in the longer SOA because (1) the expectancy of target appearance is increased, and (2) the use of top-down attentional control for increasing the attentional resources devoted as target expectancy rises (i.e., temporal orienting) needs time (e.g., Weinbach & Henik, 2012). If this was the case, we would expect this effect to contribute to the same group difference: less efficiency of attentional control in HMA individuals would lead to an absence of the foreperiod effect in this group.

with symbols influencing attentional selectivity, volunteers from higher studies with a high mathematical content (e.g., STEM degrees) and volunteers who could read Cyrillic languages (or had any previous knowledge of these languages) were excluded. The two final groups did not differ in depression ($t(40) = 0.24$, $p = .813$), age ($t(40) = 0.94$, $p = .353$) or gender (14 women in each group). More detailed information is provided in Table 1.

Material

Shortened Mathematics anxiety rating scale (sMARS; Alexander & Martray, 1989)

The sMARS was used to assess participants' math anxiety. In this questionnaire, respondents are asked to indicate the level of anxiety that they would experience in 25 situations that might cause math anxiety (e.g., "Opening a math or stat book and seeing a page full of problems"). Answers must be given on a 5-point Likert-type scale ranging from 1 (no anxiety) to 5 (high anxiety), with total score ranging from 25 to 125 points. The Spanish version of sMARS (Núñez-Peña et al., 2013) was used. It has shown good psychometric properties (Cronbach's alpha was 0.94 and the intra-class correlation coefficient for 7-week test-retest reliability was 0.72). Cronbach's alpha for the present data was 0.97.

State-trait anxiety inventory (STAI) (Spielberger et al., 2008)

The STAI comprises 40 items, half of which are used to evaluate state anxiety (STAI-S), while the other half measure trait anxiety (STAI-T).

During the stage process of selecting participants, the STAI-T subscale was used. It assesses a rather stable tendency to experience anxiety. Its 20 statements express different feelings that respondents must rate using a 4-point Likert-type scale, reporting how they feel "in general" (e.g., "I worry too much over something that really doesn't matter"). Answers range from 0 (almost never) to 3 (almost always). The total score on this subscale therefore ranges from 0 to 60. We used the Spanish version of the STAI (Spielberger et al., 2008), which has excellent psychometric properties (Cronbach's alpha = 0.95 and 20-day test-retest reliability with college students = 0.86). The scores of the STAI-T in the present study had a good alpha coefficient (Cronbach's alpha = 0.73).

During the experimental session, two measures were obtained to quickly evaluate the level of state anxiety of participants in different moments. First, the short-form version of the STAI-S subscale by Fioravanti-Bastos et al. (2011) was used to measure participants' state anxiety scores before starting the experimental session and after finishing the attentional task. This scale measures a transitory state of anxiety by asking about emotions at a particular moment (e.g., "I am worried") and it also responded by using a 4-point Likert-type scale, ranging from 0 (not at all) to 3 (very much). The Spanish version of this scale was used (Buela-Casal & Guillén-Riquelme, 2017), which has good psychometric properties (e.g., Polychoric Ordinal Alpha = 0.89). Second, to assess the level of anxiety specifically generated by the attentional task, we selected four items (3, 5, 12, and 17) from the short version of the STAI-S subscale by Fioravanti-Bastos et al. (2011). At the end of each item statement, we added "due to the task I am doing" (e.g., "I am worried due to the task I am doing"). Participants were asked to respond to these items after answering the STAI-S subscale, at the end of the ARDPEI task. The internal consistency of the scores on the scale that measures state anxiety specifically associated with the task in the present study was good (Cronbach's alpha = 0.86).

Table 1 Means and SEM (in brackets) for math anxiety, trait anxiety, depression and age for low math-anxious (LMA) and highly math-anxious (HMA) groups. The number of women is also shown

	Math anxiety	Trait anxiety	Depression	Age	
LMA	44.09 (1.84)	18.14 (1.64)	5.43 (0.75)	23.19 (0.84)	14
HMA	90.33 (2.54)	18.57 (1.31)	5.14 (0.94)	24.33 (0.88)	14

Beck Depression Inventory-Second Edition (BDI-II; Beck et al., 2011)

The BDI-II is a 21-item questionnaire that evaluates symptoms of depression. It is frequently used in the field of psychopathology-related AB. Each item indicates a specific symptom (e.g., irritability) and provides different answers associated with a four-point scale ranging from 0 to 3. The total score therefore varies from 0 to 63. The Spanish version (Sanz & Vázquez, 2011) was used as it has shown good psychometric properties for college students (Cronbach's alpha was 0.89). Cronbach's alpha for the present data was 0.72.

French kit (French et al., 1963)

This is a set of timed pen-and-paper arithmetic tests, which was used with the goal of generating state anxiety in the HMA group prior to the attentional task. Ten participants from each group were asked to solve the first part of the Additions test, which consists of sixty additions of three numbers of one and two digits. Eleven participants from each group were asked to perform the Verification test on a list of solved additions and subtractions. In both tasks, they were requested to accurately solve as many operations as possible in two minutes.[2]

Attentional response to distal vs. proximal emotional information (ARDPEI) task (Grafton & MacLeod, 2014)

The ARDPEI task was adapted (see Fig. 1). The threatening aspect of stimuli was manipulated by presenting two categories of symbolic expressions: mathematical and neutral. Each symbolic expression consisted of a single-line set of symbols (14-point Calibri font size; 6.6 cm length and 1 cm height). The neutral category consisted of 16 meaningless random groupings of 9–10 Cyrillic characters. Linguistic symbols were used, as Pizzie and Kraemer (2017) did, to present stimuli that were equivalent in complexity and visual salience to math symbols and devoid of meaning, mathematical connotation or valence. The math category consisted of 16 math expressions (see Appendix I in the Supplementary Information).

The stimuli were presented inside two boxes (2-point size gray square outlines of 8.4 cm × 8.4 cm) that were constantly displayed throughout the block, one centered 6 cm to the left from the screen center, and the other 6 cm to the right. The distance between the inner edge of each box and the center of the screen was 1.8 cm. Each trial started with a smaller yellow square outline (1.2 cm × 1.2 cm), presented for 300 ms in the horizontal center and slightly below the vertical center of one of the boxes. Participants were instructed to direct attention to this smaller yellow square. An anchor triangle then appeared inside this smaller square. The anchor and the target were empty or filled triangles (▲ or △), measuring about 7 mm in radius, obtained from https://es.piliapp.com/symbol/. The small square and the anchor disappeared 200 ms later. After an interstimulus interval (hereinafter, ISI) of 20 ms, a symbolic expression was presented in the horizontal center and slightly above the vertical center of one of the boxes, either proximally (in the same box as the anchor) or distally (in the other one) to the initial attentional focus, for 130 or 280 ms. The distance between the center of the anchor and the center of the symbolic expression that was presented proximally was 6 mm, subtending a vertical visual angle of 0.57º. Trials in which the symbolic expression was presented proximal to the initial attentional focus were used to measure differences in disengagement of attention as a function of the type of symbolic expression (math or neutral). Trials in which the symbolic expression was presented distally to the initial attentional focus were used to study differences in engagement. Inside the remaining box, another stimulus was displayed so that two stimuli could compete for selective attention. This consisted of a set of 14-point Calibri font size vertical lines and dots (|•|•|•|•|•|). After an ISI of 20 ms, the target triangle appeared. Therefore, SOAs (i.e., the interval from the appearance of the irrelevant stimuli to the appearance of the target) were 150 ms and 300 ms. The target was presented in the horizontal center and slightly below the vertical center (the same vertical position as the anchor) of the same or the opposite box to the symbolic expression that just appeared. Participants were told to press a button on the mouse with their right thumb if both triangles (anchor and target) were equal and the other with their left thumb if they were different, and to do this as quickly and accurately as possible. The target was presented until response or for a maximum of 3 s. During an inter-trial interval of 1000 ms, the two empty boxes remained on the screen.

The four variables that were manipulated (i.e., SOA, anchor-symbolic expression relative position, type of symbolic expression, and relative position between the symbolic expression and the target) yielded 16 (2^4) experimental conditions. The 16 neutral Cyrillic symbolic expressions were presented in all neutral conditions and each specific neutral symbolic expression was never repeated in the same condition. Likewise, all math symbolic expressions were presented in all math conditions and a specific math symbolic expression was never repeated in the same condition. To study whether MA is associated with an engagement bias or a disengagement bias to math stimuli, an Engagement Bias Index and a Disengagement Bias Index were calculated as proposed by Grafton and MacLeod (2014). When each type of bias index was calculated, according to their methodology, first, the selective attentional processing of each category of symbolic expression (i.e., neutral and math categories) must be computed as the difference between RT when the target appeared in the opposite box to the symbolic expression and RT when it appeared in the same box. Second, to assess whether there is a bias towards math symbols, an index must compare the selective attentional processing of the math symbols category with the selective attentional processing of the neutral symbols category (i.e., the difference value between the differences in RT for each symbol category must be calculated). Importantly, to specifically study the engagement component, only trials in which the symbolic expression was presented far from the anchor, that is, distally to the initial attentional spatial locus (hereinafter, distal trials), were considered. Difference values were

[2] Apart from the adapted ARDPEI task, participants were asked to perform another short non-mathematical attentional task in the framework of a larger project. As we wanted to induce state-math anxiety before the two main tasks, an arithmetic test was performed before each of them. The order of testing of both main tasks was counterbalanced between subjects in each group, while the order of the arithmetic tests presented before each task remained the same. In this way we were able to ensure that the effects measured in the main tasks were independent of the task order and of the specific arithmetic test performed immediately beforehand.

calculated in such a way that a higher Engagement Bias Index score reflects facilitated attentional capture by the math symbols category:

Engagement Bias Index =
(RT for targets in same loci as neutral symbols -
RT for targets in loci opposite to neutral symbols) -
(RT for targets in same loci as math symbols -
RT for targets in loci opposite to math symbols)

Likewise, to specifically evaluate the disengagement component, only trials in which the symbolic expression was presented proximally to the initial attentional spatial locus (hereinafter, proximal trials) were entered in the calculation. The more positive the Disengagement Bias Index is, the harder it was for the participant to disengage attentional focus from the locus in which the math symbols had appeared, as compared to the neutral symbols. Although attentional avoidance is not considered in the original article, following the methodology's logic of the ARDPEI, significantly negative Disengagement Bias Index scores would reflect a pattern of attentional avoidance of the math symbol category.

Disengagement Bias Index =
(RT for targets in loci opposite to math symbols -
RT for targets in the same loci as math symbols) -
(RT for targets in loci opposite to neutral symbols -
RT for targets in the same loci as neutral symbols)

Procedure

When participants arrived at the laboratory, they filled in the short-form version of the STAI-S scale. Next, they performed the two-minute task of the French Kit. As stated before, this task was used with the goal of generating state anxiety in the HMA group prior to the attentional task (HMA individuals experience higher state anxiety than LMA individuals after performing arithmetic; e.g., Di Lonardo Burr & LeFevre, 2021; González-Gómez et al., 2023). Then, participants were seated at approximately 60 cm from the computer screen and were asked to keep their posture centered and at the same distance from the screen during the blocks. They carried out the ARDPEI task, in which 256 trials were presented in 4 blocks of 64 trials. In each block, trials of the 16 experimental conditions that resulted from combining the four manipulated variables (4 trials of each condition) were randomly displayed. Participants were allowed breaks between blocks of the duration that they needed. Once the task was finished, they responded to the short-form version of the STAI-S scale again, and to the questionnaire asking about task-specific state anxiety.

E-Prime 2.0 software (Psychology Software Tools Inc., Pittsburgh, PA, United States) was used to design and present the task. Stimuli were displayed in white on a black background using an AOC AMD Freesync Gaming monitor (53.5 cm width and 30 cm height), with a pixel resolution of 1920 × 1080 and a refresh rate of 144 Hz.

Data analysis

RT was measured as the time between target appearance and the participant's response. Medians of RT for accurate trials of each condition for each participant were calculated, as the median is a central tendency measure that is less skewed by outliers than the mean (Maxwell & Delaney, 2004).

To analyze whether there were differences between the groups regarding AB for math, the bias index scores were computed (see the Material section) and submitted to an analysis of variance (ANOVA), taking Group (LMA vs. HMA) as the between-subjects factor, and SOA (150-ms vs. 300-ms) and Attentional Bias Index (Engagement Bias Index vs. Disengagement Bias Index) as the within-subject factors. In addition to this, in order to study whether there was a significant bias for math symbols (i.e., different from zero) in engagement or in disengagement in each group, we planned to use one-sample t-tests for both attentional bias indices within each group.

To evaluate attentional control, we analyzed RT. First, we conducted an ANOVA with Group (LMA vs. HMA) as the between-subjects factor, and SOA (150-ms vs. 300-ms), Trial Type (Distal vs. Proximal), Anchor Target Location (Same vs. Opposite)[3] and Symbol Type (Neutral vs. Mathematical) as the within-subject factors. Second, to test our predictions about groups (i.e., the LMA group being faster in SOA 300-ms than in SOA 150-ms and the HMA group showing no SOA effect), we conducted separate ANOVAs in each group. Third, to test the prediction that LMA would be faster than HMA in the longer SOA, we computed the mean RT for each participant in each SOA and carried out an independent t-test for each SOA to compare group means.

Finally, to evaluate whether there were differences between groups in the level of state anxiety experienced

[3] The levels of this factor were grouped considering the position of the target relative to the initial attentional focus, because it was expected that a general IOR effect might affect response time in this task: as the anchor location has been mandatorily focused on previously, when the target appears in the same location as the anchor, a slower response might be found. Note that the words "distal/proximal" are used to refer to the relative position of the task-irrelevant symbolic expression (math vs. neutral), while "same/opposite loci" are always used for talking about the relative position of the target (in both cases, compared to the anchor's position).

throughout the task, we calculated the increase in state anxiety for each participant as the difference value between participant's score in the short-form version of the STAI-S scale after performing the ARDPEI task minus his/her score before starting the experiment. We then analyzed this difference value using a t-test. Group differences in the level of state anxiety specifically generated by the task were also analyzed by a t-test.

For the sake of clarity and readability, only significant results are reported in the text. For ANOVAs, the *F* value, the degrees of freedom, the probability level, and the η_p^2 effect size index are given. As suggested by Dienes (2014), whenever conclusions require testing a theoretically important null hypothesis (e.g., in the exploratory analysis of bias index scores, where both the presence and absence of effect are relevant for assessment, and to evaluate the prediction of absence of an SOA effect in RT for the HMA group), Bayesian analyses are computed. The Bayes factor BF_{01} is given, as it indicates the relative strength of evidence in favor of the null hypothesis (how many times the null hypothesis is more likely than the alternative hypothesis to explain data). Usually, $BF_{01} > 1$ but < 3 is considered weak evidence for the null hypothesis, $BF_{01} \geq 3$ is considered substantial evidence, and $BF_{01} \geq 10$ is considered strong evidence. The Bayesian analyses provided by the computer software JASP (Version 0.16; JASP Team, 2021, https://jasp-stats.org/) were used. For interactions, Bayes factors (*BFexcl*) were obtained by selecting the effects across matched models, as suggested by Mathôt (2017).

Results

In the present study, we evaluated whether there is evidence to reject or to accept the hypotheses that LMA and HMA individuals do not differ in the following: (1) in biases in attentional engagement or disengagement for math vs. neutral stimuli; (2) in attentional control during a working memory demanding non-mathematical task; and (3) in state anxiety associated with this task. As for attentional biases, no predictions were made since the antecedents were inconsistent. As for attentional control, we predicted that groups would differ in RT, particularly when the SOA was 300 ms, and that the HMA group would not show the SOA effect that the LMA group was expected to show (i.e., faster responses when the SOA was 300 ms). Finally, since we have induced state-math anxiety prior to the ARDPEI task, we expected HMA participants to report a higher increase in state anxiety at the end of this attentional task (compared to their state before performing any task), and explored whether they reported a higher level of state anxiety specifically generated by the ARDPEI task.

Bias index scores

The ANOVA taking bias index scores as the dependent variable yielded no significant effects for any factor or interaction. Hence, there was no main effect of Group, nor interactions with this factor (the descriptive data for each condition and the ANOVA results can be found in Appendix II in the Supplementary Information). Therefore, a Bayesian ANOVA was run (homoscedasticity was met, p-value of the Levene's test > .05). Data provided evidence in favor of the absence of group differences in attentional selectivity (main effect of Group: $BF_{01} = 4.71$; Group x SOA: $BF_{excl} = 2.84$; Group x Attentional Bias Index: $BF_{excl} = 2.88$; Group x SOA x Attentional Bias Index: $BF_{excl} = 3.22$). To rule out that the absence of group differences was due to the two groups showing the same AB towards one of the symbol categories, we examined whether any index differed from zero by conducting a two-sided t-test for each index in both groups, as planned. Since in the previous analysis there were no significant effects regarding SOA, both levels were collapsed. Student's t-test assumptions were met (the Shapiro-Wilks test was run for each index in both groups and all p-values > .05). No index differed significantly from zero in any of the groups. Bayesian two-sided Student's t-tests (null hypothesis, the AB index does not differ from zero vs. alternative hypothesis, the AB index does differ from zero) confirmed the lack of effects. For the LMA group, the engagement bias index had a mean score of 4.59 (SEM = 14.25; 95% CI, from −25.14 to 34.33; $BF_{01} = 4.19$) and the disengagement bias had a mean score of -7.62 (SEM = 13.29; 95% CI, from −35.34 to 20.11; $BF_{01} = 3.79$). For the HMA group, the engagement bias had a mean score of -5.68 (SEM = 13.02; 95% CI, -32.84 to 21.48; $BF_{01} = 4.03$) and the disengagement bias had a mean score of 11.29 (SEM = 19.95; 95% CI, from −30.33 to 52.91; $BF_{01} = 3.81$). Moreover, scores on the bias indices were not associated with the participants' scores on the sMARS, on the increase in state anxiety or on the level of anxiety specifically generated by the task (see the correlation matrix in Appendix II in the Supplementary Information).

Response time

A significant main effect of SOA was found, $F(1,40) = 15.18$, $p < .001$, $\eta_p^2 = 0.27$. Participants were faster in the longer SOA (M = 630.55 ms, SEM = 14.03) than in the shorter one (M = 645.84 ms, SEM = 12.88), which was modulated by an SOA x Trial Type interaction, $F(1,40) = 5.80$, $p = .021$, $\eta_p^2 = 0.13$. There was also a main effect of Anchor Target Location, $F(1,40) = 3.99$, $p = .053$, $\eta_p^2 = 0.09$. Participants were faster when the target appeared in the location opposite the previous anchor's location (631.93 ms, SEM = 13.97) than when the target appeared in the anchor location (M = 644.45 ms, SEM = 13.40), modulated by a marginal Group x Anchor Target Location interaction, $F(1,40) = 3.42$, $p = .072$, $\eta_p^2 = 0.08$. This was explained by the presence of an Anchor Target Location effect in the LMA group but not in the HMA group (see below further analysis within each group). Moreover, there was a marginal Group effect, $F(1,40) = 3.61$, $p = .064$, $\eta_p^2 = 0.08$, with HMA participants taking longer to answer (M = 663.51 ms, SEM = 18.84) than their LMA peers (M = 612.88 ms, SEM = 18.84). To study the interaction with the factor Group and to evaluate our predictions, we conducted separate ANOVAs for each group.

In the LMA group, a significant main effect of SOA was found, $F(1,20) = 30.95$, $p < .001$, $\eta_p^2 = 0.61$. LMA participants were faster in the longer SOA (M = 602.17 ms, SEM = 18.56) than in the shorter one (M = 623.59 ms, SEM = 18.74). Additionally, there was a main effect of Anchor Target Location, $F(1,20) = 8.78$, $p = .008$, $\eta_p^2 = 0.30$. LMA participants were faster when the target appeared in the location opposite to the anchor location (M = 600.82 ms, SEM = 19.75) than when it appeared in the anchor location (M = 624.94 ms, SEM = 18.96).

Regarding the HMA group, only a significant main effect of Trial Type, $F(1,20) = 4.88$, $p = .039$, $\eta_p^2 = 0.20$, was found. The proximal trials had slower RT (M = 670.39 ms, SEM = 20.58) than the distal trials (M = 656.63 ms, SEM = 18.11). Neither SOA nor Anchor Target Location reached significance. As the absence of an SOA effect in this group was a prediction that was relevant theoretically, a Bayes factor was computed to determine whether the data were consistent with the null hypothesis. Likewise, as it might be of theoretical interest that the HMA group did not present the Anchor Target Location effect shown in the LMA group, a Bayes factor was obtained to assess this non-significant result. Bayesian analysis showed evidence in favor of the null hypothesis for the SOA effect ($BF_{01} = 3.41$) and for the Anchor Target Location effect ($BF_{01} = 8.48$). HMA participants took 668.10 ms (SEM = 17.70) to respond when SOA was 150 ms and 658.92 ms (SEM = 21.04) when SOA was 300 ms. Their RT was 663.97 ms (SEM = 18.56) when the anchor and target loci were the same, and 663.05 ms (SEM = 20.81) when they appeared in opposite loci. Since one of the possible explanations for the absence of an Anchor Target Location effect in the HMA group proposes a strategy to compensate for the reduced attentional control (see the Discussion section), we carried out an additional analysis. First, we calculated the difference value between the RT when the anchor and the target were the same and the RT in the opposite location for each participant, as this probably reflects an IOR effect. Then, a Pearson's correlation between this difference value and participant's total hit rate was conducted within each group. While the correlation was negligible in the LMA group ($r = .17$; $p = .473$), a significant correlation ($r = -.49$; $p = .024$) was found in the HMA group, with HMA participants who did not show IOR (or even showed faster responses when the target appeared in the anchored location) achieving a better hit rate.[4]

Finally, we performed independent t-tests to evaluate group differences in RT separately for each SOA. Groups differed significantly when the SOA was 300 ms ($t(40) = 2.02$, $p = .050$, $d = 0.624$), as predicted. The effect of group was smaller and not significant when the SOA was 150 ms ($t(40) = 1.73$, $p = .092$, $d = 0.533$).

RT results for both SOAs in each group are illustrated in Fig. 2. RT results on the spatial location of the target with reference to the initial location of attention for both groups are shown in Fig. 3.

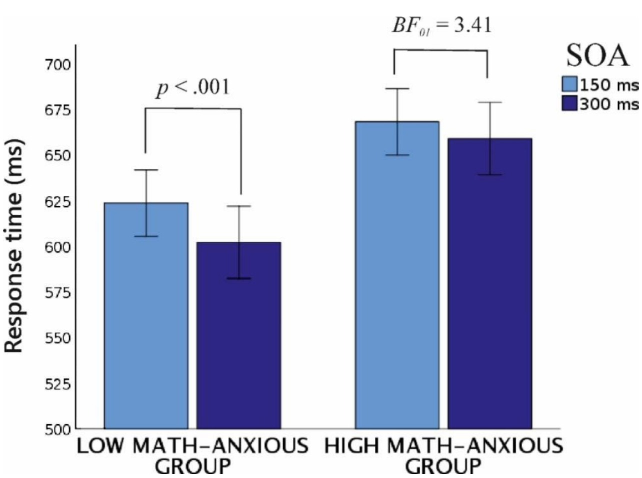


Fig. 2 Mean response time (and SEM) for each SOA and group. Only low math-anxious individuals respond faster when a longer SOA is provided

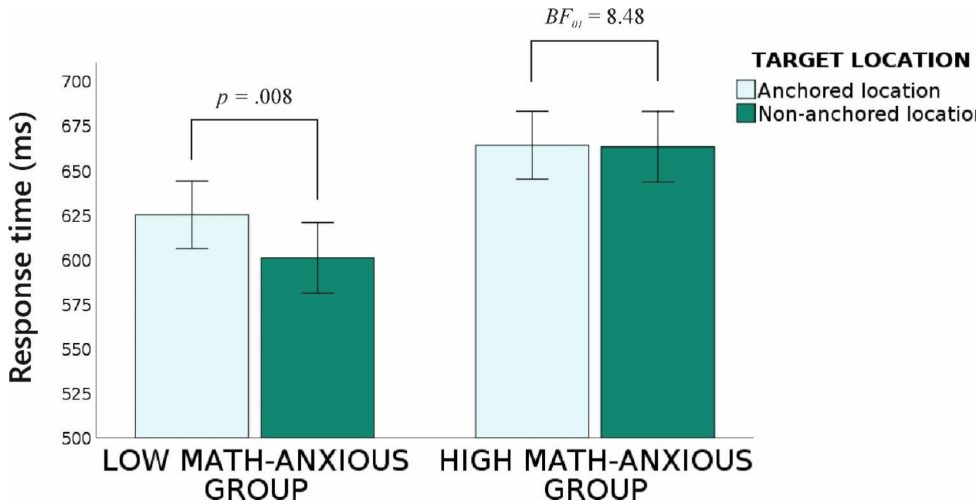
State anxiety

Groups differed in the increase in state anxiety measured after the task with respect to their initial state, $t(40) = 2.07$, $p = .045$, with HMA participants experiencing a larger increase (M = 3.43, SEM = 1.18) than LMA participants (M = 0.76, SEM = 0.52). This increase in state anxiety was significantly different from zero in the HMA group, $t(20) = 2.90$, $p = .009$, but not in the LMA group.

Groups also differed in the level of state anxiety specifically generated by the task, $t(40) = 2.32$, $p = .029$, with HMA participants reporting a higher level of state anxiety

[4] Groups did not differ in accuracy ($t(40) = 0.04$, $p = .968$): both groups had a hit rate of 0.93, which indicates that both groups achieved the same performance effectiveness, but also that they followed the instruction regarding the initial allocation of attention to the anchor position.

Fig. 3 Mean response time (and SEM) for each Anchor Target Location and group. Only low math-anxious individuals show IOR (slower responses in the anchored location)



(M = 2.95, SEM = 0.68) than their LMA peers (M = 1.28, SEM = 0.23).

The level of state anxiety specifically generated by the task was positively and strongly associated with the increase in state anxiety. Furthermore, both measures of state anxiety were positively correlated with the level of math anxiety (i.e., sMARS scores). These data are provided in Appendix II in the Supplementary Information.

Discussion

The main objective of the present study was to evaluate whether task-irrelevant math stimuli generate a bias in attentional engagement or disengagement in the HMA population. This has been proposed as an important factor that might be involved in originating, maintaining and aggravating math anxiety. A secondary objective was to study whether math anxiety is associated with less efficient attentional control, provided that state-math anxiety was previously induced. This may be a main factor that contributes to explaining HMA's difficulties when performing maths.

Regarding AB, the results provided evidence that populations with extreme math anxiety do not differ in either the Engagement Bias or the Disengagement Bias Index. There was also evidence that none of the indices differed from zero in either group. This suggests that HMA individuals do not display facilitated engagement with math stimuli, impaired disengagement from them or attentional avoidance of them. Unlike what has been suggested with other kinds of anxiety when threatening stimuli are presented (e.g., Grafton & MacLeod, 2016), math anxiety is not linked to any AB to swiftly presented math stimuli. Instead, math anxiety was found to share with general anxiety the association with less efficiency of attentional control. This can be added to previous evidence in the math anxiety field (e.g., De Agostini, 2020; González-Gómez et al., 2023; Pletzer et al., 2015) and concur with ACT. Several findings in the present study suggest this diminished efficiency of attentional control.

First, HMA individuals tend to be slower than their LMA peers, even in this non-mathematical and fairly simple (but attentional control demanding) task, which suggests greater susceptibility to distraction of HMA individuals, at least when they are experiencing higher state anxiety. Moreover, group differences were significant when more time was allowed from the appearance of the distractors until the presentation of the target. As expected, LMA participants could improve their performance when SOA was 300 ms (vs. 150 ms), using the longer time available to start shifting their attentional focus (probably stolen by distractors) back to the task goal. In contrast, HMA participants could not gain leverage of the extra time to increase their readiness to discriminate the target after distraction. HMA individuals have been shown to shift between arithmetical mental sets less efficiently than LMA individuals when an interval for executing proactive task-goal shifting is provided (González-Gómez et al., 2023). The present results suggest that they also show less efficient proactive shifting to the task goal (i.e., getting ready to discriminate the target) when the attentional focus has been allocated on task-irrelevant stimuli. According to ACT, and considering that executive functions related to attentional control - and specifically shifting - are required during math processing, this less efficient shifting of attentional focus (e.g., to shift back from the task-irrelevant data of a math problem or from the distracting worrisome thoughts that usually show up when anxiety is experienced) can contribute to explaining HMAs' difficulties during math performance (particularly, the longer time they usually need to achieve similar math achievement to their LMA peers, e.g., Faust et al., 1996).

Second, LMA individuals showed faster RT when the target was displayed in the location opposite to their initial focus. At the beginning of each trial, participants focused on the anchored region. Then, two stimuli were simultaneously presented in the previously anchored region and in the non-anchored region. Finally, the target could appear with equal probability in either region. Thus, both regions were non-predictively cued, but the anchored region had been cued previously and mandatorily attended to. The effect shown in LMA individuals was then probably due to an IOR effect in the anchored location, which is usually interpreted as a cost of orienting attention to a recently attended location, a mechanism that encourages orienting towards novel locations (Klein, 2000). According to this traditional conception (but see Lupiáñez, 2010), IOR occurs when attention has been disengaged from the previously attended region. Thus, our results probably indicate that LMA participants oriented their attention to the stimulus in the non-anchored region in most trials, showing slower RT in the previously attended location and faster RT when the target appeared in the non-anchored region. By contrast, HMA individuals did not show any difference in RT regarding the location of the target. They did not show IOR, nor benefit in the anchored region.

Under the assumption that IOR requires previous disengagement and considering that irrelevant visual stimuli that are displayed to interrupt the task tend to attract visual attention (e.g., Hakim et al., 2020), this group difference suggests that HMA participants were effortfully trying to avoid attending to the stimulus that appeared in the non-anchored region and held their spatial attention in the anchored region more frequently than their LMA peers. This might be understood as a compensation strategy: ACT predicts that individuals who experience difficulties in overcoming distraction and concentrating on the task often try to effortfully compensate it to reduce the impact of distraction on task accuracy. There are several plausible explanations for this strategy. It may be based on diminished probabilities of distraction if participants attend only to one task-irrelevant stimulus (it is assumed that the irrelevant stimulus presented close to fixation is inevitably attended to, Fox et al., 2001, Grafton and MacLeod, 2014) and avoid engaging with the second one. The strategy may also draw on the benefit of holding spatial attention where the anchor had just appeared, to facilitate maintenance of the visual representation of the feature (i.e., filled or empty triangle) in working memory (e.g., Williams et al., 2013).

Alternatively, the lack of IOR in the HMA group might not reflect a group difference in orienting during the presentation of task-irrelevant stimuli. Instead, it may suggest that HMA individuals do not exhibit IOR when they are experiencing anxiety because inhibiting a location might be counterproductive to better locate a threat (i.e., this would be in line with anxiety favoring the stimulus-driven attentional system, and thus also consistent with ACT). To further evaluate whether this result was more probably due to HMA participants exerting a compensation strategy or to a state anxiety-linked absence of IOR, we ran a correlation between IOR and hit rate in both groups. The correlation was negligible in the LMA group. In the HMA group, a significant correlation indicated that HMA participants who did not show IOR had a better hit rate. This suggests that the more plausible interpretation is that several HMA participants displayed a compensation strategy to reduce the effect of their impaired attentional control over accuracy. Likewise, some previous studies showed that HMA individuals use compensatory strategies (e.g., more attentional resources allocated to a cognitive task; Núñez-Peña et al., 2019).

To facilitate that math-anxiety-linked modulations over the attentional system occurred and could be measured (Eysenck et al., 2007; Macleod et al., 2019) in the present study, state-math anxiety was intentionally generated in the HMA group by asking participants to perform an arithmetic task just before the attentional task. As expected, the HMA group reported a higher increase in state anxiety after finishing the ARDPEI task (compared to their original state anxiety when they arrived at the lab) than the LMA group. This indicates that the HMA group maintained a higher degree of state anxiety until the end of the attentional task than their LMA peers. In addition, the HMA group reported a higher level of anxiety when asked about the response specifically generated by the ARDPEI task. This might suggest that math stimuli, despite the very fast presentation and the irrelevance, were able to trigger an anxiety response, as Pizzie and Kraemer (2017) found with a longer presentation time. However, other factors, such as the fact that the task goal was threatened to a greater extent in the HMA group because of their impaired attentional control, might have contributed to maintaining a higher level of state anxiety in HMA participants while they performed the ARDPEI task (Power & Dalgleish, 1997) and to perceiving this task as a source of anxiety.

The higher state anxiety during the attentional task probably explains the reduction in attentional control observed in HMA individuals. According to ACT, when an individual experiences anxiety, it is dangerous to concentrate on a cognitive task. This emotional response leads to a reduction in top-down attentional control. Therefore, response time results in the present study are likely to be a consequence of state anxiety and are consistent with ACT and with previous studies (e.g., Li et al., 2022). Nevertheless, we cannot rule out from these results that HMA individuals have a trait deficit in attentional control that is independent of the state of anxiety.

In contrast, the higher state/trait math anxiety did not lead to a biased attentional selection of math symbols. Therefore, the absence of a bias for math symbols on HMA individuals' attentional selectivity may indicate a difference with general anxiety and specific phobias, which may also be of interest beyond the realm of math anxiety. This difference does not question that task-irrelevant math stimuli trigger a threat response, as indicated by the stronger amygdala reactivity found by Pizzie and Kraemer (2017). By contrast, it suggests that (1) the mathematical nature of symbols cannot be perceived as threatening as fast as the negative nature of other stimuli associated with danger for survival (remember that we used symbol exposure durations shorter than those used by Pizzie and Kraemer); (2) the threat response triggered by irrelevant math stimuli differs from the threat response triggered by other threatening stimuli (e.g., it might not be intense enough as to bias attention, Hopko et al., 2002), or (3) once math stimuli have triggered the threat response, this leads to an AB only for stimuli that the brain easily recognize as dangerous (i.e., when threat mechanisms are activated, attention is oriented towards innately threatening stimuli, even if they are not threatening survival at the present moment, but this is not the case of math stimuli). Any of the three explanations may be linked to the lack of biological preparedness of math symbols. Studies that address AB linked to general and specific types of anxiety and phobias mostly use stimuli with attributes that have been related with danger during evolutionary history (e.g., dangerous animals, angry faces, etc.). However, math symbols have not threatened survival and thus it is unlikely that math attributes of stimuli had been prioritized during evolution so to be rapidly encoded as intense threats and preferentially attended when experiencing anxiety, despite their task irrelevance, as seems to happen with innately threatening stimuli (Okon-Singer, 2018).

Nevertheless, certain limitations of the present study should be mentioned. The first is the nature of the neutral symbols used. It was difficult to select symbols that were similar in salience and only differed from math symbols in the absence of valence, since many symbols may be associated with math to some extent. Following Pizzie and Kraemer (2017), we decided to use linguistic symbols from a foreign alphabet. More specifically, we presented sets of Cyrillic symbols that had no meaning for participants. Although it has been reported that some individuals may experience foreign language anxiety when learning a foreign language (Djafri & Wimbarti, 2018), we prevented this type of anxiety (or any individual differences due to familiarity with Cyrillic symbols) from influencing attentional selectivity by only including individuals who had no previous experience of Cyrillic languages. Therefore, it is unlikely that foreign language anxiety was triggered by the neutral symbols and that this could have influenced the results. Second, while the present results show evidence of an absence of math-anxiety-linked AB for math vs. neutral stimuli, this evidence is considered to be substantial but not strong, since the Bayes factors were below 10 (Jeffreys, 1961). Although it cannot be ruled out that the absence of effects might be due to a lack of power (especially considering that AB for threat might not be a stable feature of high anxious individuals, MacLeod et al., 2019), it is worth noting that our sample size was similar to the one used in the study of Grafton and MacLeod (2014), who found significant evidence for biases in engagement and disengagement in trait-anxious individuals in the ARDPEI task, and equal or larger than those used by all the previous studies on math anxiety and AB for math (e.g., Rubinsten et al., 2015; Suárez-Pellicioni et al., 2015). However, future replications would be useful to strengthen the evidence regarding the lack of relation between math anxiety and AB for task-irrelevant math stimuli. Third, a few studies have suggested that gender might influence anxiety-linked AB to threat (e.g., Waters et al., 2007). Unfortunately, since the groups were composed of female and male participants, gender-specific effects cannot be examined by means of the present data, and so future studies are needed.

Last, the present results cannot rule out that the math nature of task-relevant stimuli that are being attended and processed for a cognitive task (e.g., Rubinsten et al., 2015) might generate delayed disengagement from that math information or attentional avoidance of it in HMA individuals. Nevertheless, any anxiety-linked disengagement bias, although relevant in maintaining anxiety, is believed by many researchers to be mediated by attentional control (e.g., Cisler & Koster, 2010; Lonigan et al., 2004), and specifically by reduced shifting function (e.g., Taylor et al., 2016). Attentional control is likely to underly anxious individuals' biases in attentional selectivity directly, in the case of difficulties in disengaging, or in the case of avoidance, by means of emotion regulation, which is in turn related to attentional control, also in HMA individuals (Lyons & Beilock, 2012). In this line, recent reviews conclude that research and interventions in anxiety should focus on attentional control (e.g., see the integrative framework of Mogg & Bradley, 2018), which is consistent with the results obtained in the present study regarding math anxiety.

To summarize, the present study provides evidence of HMA individuals not having an AB to math and suggests that it is unlikely that a biased selection of irrelevant math (vs. neutral) information may originate or worsen math anxiety. However, the results do support ACT and swell existing evidence about math anxiety impairing executive control, even when no numerical calculation or mathematical processing is required, at least when HMA individuals experience an increased level of state anxiety. Therefore, research should keep focusing on math anxiety effects over attentional control, and integrative interventions should be designed to diminish the evaluation of the threat level of mathematical information (and the consequent worry and reward of avoiding math courses, e.g., Pizzie et al., 2020) and to enhance attentional control (Mogg & Bradley, 2018), in order to improve HMA individuals' lives.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s12144-023-04828-2.

Acknowledgements We thank Mireya Roca and Nuria García for their collaboration during the preprocessing of data.

Authors' contributions All authors contributed to the study design. According to CRediT (Contributor Roles Taxonomy), the contributions were as follows:
Conceptualization, Software, Data Curation, Formal analysis, Investigation, Writing - original draft preparation, Visualization: [Belén González-Gómez]; Methodology, Funding acquisition, Project administration, Resources, Writing - review and editing: [Belén González-Gómez], [Àngels Colomé] and [M. Isabel Núñez-Peña]; Supervision: [Àngels Colomé] and [M. Isabel Núñez-Peña].

Funding Open Access funding provided thanks to the CRUE-CSIC agreement with Springer Nature. This study was supported by grants PID2020-117140GB-I00/AEI/10.13039/501100011033 from the Spanish Ministry of Science and Innovation. Funding was also provided by the Catalan Government under grants SGR2017-974, SGR2017-48, 2019FI_B1-00016, and 2020FI_B2-00009.

Data Availability Mathematical and neutral symbols used in this experiment are provided in the Supplementary material. The datasets generated and analyzed during the current study are available from the corresponding author on request.

Declarations

Ethics approval This study forms part of a broader research project that has been approved by the Ethics Committee of the University of Barcelona.

Consent All participants signed an informed consent form before starting the experiment and were paid for their participation.

Competing interests The authors declare that they have no conflicts of interest.

References

Alexander, L., & Martray, C. (1989). The development of an abbreviated version of the Mathematics anxiety rating scale. *Measurement and Evaluation in Counseling and Development*, *22*, 143–150.

Ashcraft, M. H., & Ridley, K. (2005). Math anxiety and its cognitive consequences: A tutorial review. In J. I. D. Campbell (Ed.), *Handbook of mathematical cognition* (pp. 315–325). Psychology Press.

Beck, A. T., Steer, R. A., & Brown, G. K. (2011). *Manual. BDI-II. Inventario de Depresión de Beck-II.* Pearson.

Buela-Casal, G., & Guillén-Riquelme, A. (2017). Short form of the spanish adaptation of the state-trait anxiety inventory. *International Journal of Clinical and Health Psychology*, *17*(3), 261–268. https://doi.org/10.1016/j.ijchp.2017.07.003

Cisler, J. M., & Koster, E. H. W. (2010). Mechanisms of attentional biases towards threat in anxiety disorders: An integrative review. *Clinical Psychology Review*, *30*(2), 203–216. https://doi.org/10.1016/j.cpr.2009.11.003

Clements, D. H., & Sarama, J. (2019). Executive function and early mathematical learning difficulties. In A. Fritz, V.G. Haase, & P. Räsänen (Eds.), *International handbook of mathematical learning difficulties* (pp. 755–771). Springer. https://doi.org/10.1007/978-3-319-97148-3_43

Colomé, À., Núñez-Peña, M. I., & González-Gómez, B. (2022). Proactive control of attention in math–anxious individuals. *Psychological Research Psychologische Forschung*. https://doi.org/10.1007/s00426-022-01750-3

De Agostini, R. (2020). *The role of working memory and inhibition efficiency in mathematics anxiety* [Doctoral dissertation, University of York].

Di Burr, L., S. M., & LeFevre, J. A. (2021). The subject matters: Relations among types of anxiety, ADHD symptoms, math performance, and literacy performance. *Cognition and Emotion*, *35*(7), 1334–1349. https://doi.org/10.1080/02699931.2021.1955243

Dienes, Z. (2014). Using bayes to get the most out of non-significant results. *Frontiers in Psychology*, *5*, 1–17. https://doi.org/10.3389/fpsyg.2014.00781

Djafri, F., & Wimbarti, S. (2018). Measuring foreign language anxiety among learners of different foreign languages: In relation to motivation and perception of teacher's behaviors. *Asian-Pacific Journal of Second and Foreign Language Education*, *3*(1), 1–15. https://doi.org/10.1186/s40862-018-0058-y

Eysenck, M. W., Derakshan, N., Santos, R., & Calvo, M. G. (2007). Anxiety and cognitive performance: Attentional control theory. *Emotion*, *7*(2), 336–353. https://doi.org/10.1037/1528-3542.7.2.336

Faust, M. W., Ashcraft, M. H., & Fleck, D. E. (1996). Mathematics anxiety Effects in simple and complex addition. *Mathematical Cognition*, *2*, 25–62.

Fioravanti-Bastos, A. C. M., Cheniaux, E., & Landeira-Fernandez, J. (2011). Development and validation of a short-form version of the brazilian state-trait anxiety inventory. *Psicologia: Reflexão e Critica*, *24*, 485–494. https://doi.org/10.1590/S0102-79722011000300009

Fox, E., Russo, R., Bowles, R., & Dutton, K. (2001). Do threatening stimuli draw or hold visual attention in subclinical anxiety? *Journal of Experimental Psychology: General*, *130*(4), 681–700. https://doi.org/10.1037/0096-3445.130.4.681

Fox, E., Russo, R., & Dutton, K. (2002). Attentional bias for threat: Evidence for delayed disengagement from emotional faces. *Cognition and Emotion*, *16*(3), 355–379. https://doi.org/10.1080/02699930143000527

French, J. W., Ekstrom, R. B., & Price, L. A. (1963). *Manual for kit of reference tests for cognitive factors (revised 1963)*. Educational Testing Service Princeton NJ.

González-Gómez, B., Núñez-Peña, M. I., & Colomé, À. (2023). Math anxiety and the shifting function: An event-related potential study of arithmetic task switching. *European Journal of Neuroscience,57*(11), 1848–1869. https://doi.org/10.1111/ejn.15984

Grafton, B., & MacLeod, C. (2014). Enhanced probing of attentional bias: The independence of anxiety-linked selectivity in attentional engagement with and disengagement from negative information. *Cognition and Emotion*, *28*(7), 1287–1302. https://doi.org/10.1080/02699931.2014.881326

Grafton, B., & Macleod, C. (2016). Engaging with the wrong people: The basis of selective attention to negative faces in social anxiety. *Clinical Psychological Science*, *4*(5), 793–804. https://doi.org/10.1177/2167702615616344

Hakim, N., Feldmann-Wüstefeld, T., Awh, E., & Vogel, E. K. (2020). Perturbing neural representations of working memory with task-irrelevant interruption. *Journal of Cognitive Neuroscience*, *32*(3), 558–569. https://doi.org/10.1162/jocn_a_01481

Hopko, D. R., McNeil, D. W., Gleason, P. J., & Rabalais, A. E. (2002). The emotional stroop paradigm: Performance as a function of stimulus properties and self-reported mathematics anxiety. *Cognitive Therapy and Research*, *26*(2), 157–166. https://doi.org/10.1023/A:1014578218041

Jeffreys, H. (1961). *Theory of probability*. Oxford University Press.

Klein, R. M. (2000). Inhibition of return. *Trends in Cognitive Sciences*, *4*(4), 138–147. https://doi.org/10.1016/s1364-6613(00)01452-2

Koster, E. H. W., Crombez, G., Verschuere, B., Van Damme, S., & Wiersema, J. R. (2006). Components of attentional bias to threat in high trait anxiety: Facilitated engagement, impaired disengagement, and attentional avoidance. *Behaviour Research and Therapy*, *44*(12), 1757–1771. https://doi.org/10.1016/j.brat.2005.12.011

Li, T., Quintero, M., Galvan, M., Shanafelt, S., Hasty, L. M., Spangler, D. P., Lyons, I. M., Mazzocco, M. M. M., Brockmole, J. R., Hart, S. A., & Wang, Z. (2022). The mediating role of attention in the Association between Math anxiety and Math Performance: An Eye-Tracking Study. *Journal of Educational Psychology*. https://doi.org/10.1037/edu0000759

Lonigan, C. J., Vasey, M. W., Phillips, B. M., & Hazen, R. A. (2004). Temperament, anxiety, and the Processing of threat-relevant Stimuli. *Journal of Clinical Child & Adolescent Psychology*, *33*(1), 8–20. https://doi.org/10.1207/S15374424JCCP3301

Lupiáñez, J. (2010). Inhibition of return. In A. C. Nobre, K. Nobre, & J. T. Coull (Eds.), *Attention and time* (pp. 17–34). Oxford University Press.

Lyons, I. M., & Beilock, S. L. (2012). Mathematics anxiety: Separating the math from the anxiety. *Cerebral cortex*, *22*(9), 2102–2110. https://doi.org/10.1093/cercor/bhr289

MacLeod, C., Mathews, A., & Tata, P. (1986). Attentional bias in emotional disorders. *Journal of Abnormal Psychology*, *95*, 15–20.

Macleod, C., Grafton, B., & Notebaert, L. (2019). Anxiety-linked attentional Bias: Is it Reliable? *Annual Review of Clinical Psychology*, *15*, 529–554. https://doi.org/10.1146/annurev-clinpsy-050718-095505

Mathews, A., & MacLeod, C. (2002). Induced processing biases have causal effects on anxiety. *Cognition and Emotion*, *16*(3), 331–354. https://doi-org.sire.ub.edu/10.1080/02699930143000518

Mathôt, S. (2017, May 15). *Bayes like a Baws: Interpreting Bayesian Repeated Measures in JASP* Cognitive science and more. https://www.cogsci.nl/blog/interpreting-bayesian-repeated-measures-in-jasp

Maxwell, S. E., & Delaney, H. D. (2004). *Designing experiments and analyzing data: A model comparison perspective*. Lawrence Erlbaum Associates.

McNally, R. J. (2019). Attentional bias for threat: Crisis or opportunity? *Clinical Psychology Review*, *69*, 4–13. https://doi.org/10.1016/j.cpr.2018.05.005

McLaughlin, M. S. (1996). *Comparison of a self-report questionnaire and a Stroop color-naming task.* [Unpublished senior thesis]. Oklahoma State University.

Mogg, K., & Bradley, B. P. (2018). Anxiety and threat-related attention: Cognitive-motivational Framework and Treatment. *Trends in Cognitive Sciences*, *22*(3), 225–240. https://doi.org/10.1016/j.tics.2018.01.001

Mogg, K., Holmes, A., Garner, M., & Bradley, B. P. (2008). Effects of threat cues on attentional shifting, disengagement and response slowing in anxious individuals. *Behaviour Research and Therapy*, *46*(5), 656–667. https://doi.org/10.1016/j.brat.2008.02.011

Niemi, P., & Näätänen, R. (1981). Foreperiod and simple reaction time. *Psychological Bulletin*, *89*(1), 133. https://doi.org/10.1037/0033-2909.89.1.133

Núñez-Peña, M. I., Suárez-Pellicioni, M., Guilera, G., & Mercadé-Carranza, C. (2013). A spanish version of the short Mathematics Anxiety Rating Scale (sMARS). *Learning and Individual Differences*, *24*, 204–210. https://doi.org/10.1016/j.lindif.2012.12.009.

Núñez-Peña, M. I., González-Gómez, B., & Colomé, À. (2019). Spatial processing in a mental rotation task: Differences between high and low math-anxiety individuals. *Biological Psychology*, *146*, 107727. https://doi.org/10.1016/j.biopsycho.2019.107727

Núñez-Peña, M. I., Colomé, À., & González-Gómez, B. (2021). The Spatial-Numerical Association of Response Codes (SNARC) effect in highly math-anxious individuals: An ERP study. *Biological Psychology*, *161*, 108062. https://doi.org/10.1016/j.biopsycho.2021.108062

Okon-Singer, H. (2018). The role of attention bias to threat in anxiety: Mechanisms, modulators and open questions. *Current Opinion in Behavioral Sciences*, *19*, 26–30. https://doi.org/10.1016/j.cobeha.2017.09.008

Pérez-Dueñas, C., Acosta, A., & Lupiáñez, J. (2009). Attentional capture and trait anxiety: Evidence from inhibition of return. *Journal of Anxiety Disorders*, *23*(6), 782–790. https://doi.org/10.1016/j.janxdis.2009.03.002

Pizzie, R. G., & Kraemer, D. J. M. (2017). Brain and cognition avoiding math on a rapid timescale: Emotional responsivity and anxious attention in math anxiety. *Brain and Cognition*, *118*, 100–107. https://doi.org/10.1016/j.bandc.2017.08.004

Pizzie, R. G., McDermott, C. L., Salem, T. G., & Kraemer, D. J. M. (2020). Neural evidence for cognitive reappraisal as a strategy to alleviate the effects of math anxiety. *Social Cognitive and Affective Neuroscience*, *15*(12), 1271–1287. https://doi.org/10.1093/scan/nsaa161

Pletzer, B., Kronbichler, M., Nuerk, H. C., & Kerschbaum, H. H. (2015). Mathematics anxiety reduces default mode network deactivation in response to numerical tasks. *Frontiers in Human Neuroscience*, *9*, 1–12. https://doi.org/10.3389/fnhum.2015.00202

Power, M. J., & Dalgleish, T. (1997). *Cognition and emotion: From order to disorder*. Psychology Press.

Ray, C. (1979). Examination stress and performance on a color-word interference test. *Perceptual and Motor Skills*, *49*(2), 400–402. https://doi.org/10.2466/pms.1979.49.2.400

Rubinsten, O., Eidlin, H., Wohl, H., & Akibli, O. (2015). Attentional bias in math anxiety. *Frontiers in Psychology*, *6*, 1–9. https://doi.org/10.3389/fpsyg.2015.01539

Sanz, J., & Vázquez, C. (2011). *Adaptación española del Inventario para Depresión de Beck-II (BDI-II)* [Spanish adaptation of the Beck depression inventory—II (BDI-II)]. Manual. Pearson.

Shi, X., Xu, J., Wang, F., & Cai, D. (2022). Cognitive processing features of elementary school children with mathematical anxiety: Attentional control theory-based explanation. *Journal of Experimental Child Psychology*, *224*, 105513. https://doi.org/10.1016/j.jecp.2022.105513
Spielberger, C. D., Gorsuch, R., & Lushene, R. (2008). *Cuestionario de ansiedad estado-rasgo, STAI*. TEA Ediciones.
Suárez-Pellicioni, M., Núñez-Peña, M. I., & Colomé, À. (2015). Attentional bias in high math-anxious individuals: Evidence from an emotional Stroop task. *Frontiers in Psychology*, *6*. https://doi.org/10.3389/fpsyg.2015.01577
Suárez-Pellicioni, M., Núñez-Peña, M. I., & Colomé, À. (2016). Math anxiety: A review of its cognitive consequences, psychophysiological correlates, and brain bases. *Cognitive Affective and Behavioral Neuroscience*, *16*(1), 3–22. https://doi.org/10.3758/s13415-015-0370-7
Taylor, C. T., Cross, K., & Amir, N. (2016). Attentional control moderates the relationship between social anxiety symptoms and attentional disengagement from threatening information. *Journal of Behavior Therapy and Experimental Psychiatry*, *50*, 68–76. https://doi.org/10.1016/j.jbtep.2015.05.008
Waters, A. M., Nitz, A. B., Craske, M. G., & Johnson, C. (2007). The effects of anxiety upon attention allocation to affective stimuli. *Behaviour Research and Therapy*, *45*(4), 763–774. https://doi.org/10.1016/j.brat.2006.07.002
Weinbach, N., & Henik, A. (2012). Temporal orienting and alerting–the same or different? *Frontiers in Psychology*, *3*, 236. https://doi.org/10.3389/fpsyg.2012.00236
Williams, M., Pouget, P., Boucher, L., & Woodman, G. F. (2013). Visual-spatial attention aids the maintenance of object representations in visual working memory. *Memory and Cognition*, *41*(5), 698–715. https://doi.org/10.3758/s13421-013-0296-7
Yiend, J. (2010). The effects of emotion on attention: A review of attentional processing of emotional information. *Cognition and Emotion*, *24*(1), 3–47. https://doi.org/10.1080/02699930903205698