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DOI
10.1007/s10608-023-10390-9
Publication date
2023
Document Version
Final published version
Published in
Cognitive Therapy and Research
License
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Link to publication

Citation for published version (APA):
Schmitz, E. A., Jansen, B. R. J., Wiers, R. W., & Salemink, E. (2023). Math-Failure Associations, Attentional Biases, and Avoidance Bias: The Relationship with Math Anxiety and Behaviour in Adolescents. *Cognitive Therapy and Research*, *47*(5), 788-801. Advance online publication. https://doi.org/10.1007/s10608-023-10390-9

Cognitive Therapy and Research (2023) 47:788–801
https://doi.org/10.1007/s10608-023-10390-9

ORIGINAL ARTICLE

Math-Failure Associations, Attentional Biases, and Avoidance Bias: The Relationship with Math Anxiety and Behaviour in Adolescents

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Accepted: 12 May 2023 / Published online: 20 June 2023

Abstract

Background Math anxiety in adolescence negatively affects learning math and careers. The current study investigated whether three cognitive biases, i.e. math-failure associations, attentional biases (engagement and disengagement), and avoidance bias for math, were related to math anxiety and math behaviour (math grade and math avoidance behaviour).

Methods In total, 500 secondary school students performed three cognitive bias tasks, questionnaires and a math performance task, and reported their grades.

Results Math-failure associations showed the most consistent associations with the outcome measures. They were associated with higher math anxiety above and beyond sex and education level. Those math-failure associations were also associated with lower grades and more avoidance behaviour, however, not above and beyond math anxiety. Engagement bias and avoidance tendency bias were associated with math avoidance behaviour, though the avoidance bias finding should be interpreted with care given the low reliability of the measure. Disengagement biases were not associated with any math anxiety nor behaviour outcome measure.

Conclusions Whereas a more reliable instrument for avoidance bias is necessary for conclusions on the relations with math performance and behaviour, the current results do suggest that math-failure associations, and not attentional bias, may play a role in the maintenance of math anxiety.

Keywords Math anxiety · Implicit associations · Attentional bias · Avoidance bias · Math behaviour

Background

Math anxiety can be defined as a negative emotional response that is evoked in math-related situations (see Suárez-Pellicioni et al., 2016) and is associated with avoidance behaviour, from rushing through difficult math items to avoiding math courses and even careers that involve math (Ashcraft & Faust, 1994; Hembree, 1990). Prevalence of math anxiety is hard to determine because of variability in instruments and cut-off criteria. According to an influential review study, prevalence rates vary between 2% and 68% in secondary school students (Dowker et al., 2016). As math anxiety can have significant negative effects in daily life functioning and choices for the future (e.g., math anxiety is associated with long-term learning difficulties and vocational choices, Luttenberger et al., 2018), even the lowest percentage indicates that math anxiety is a problem to take into account (Dowker et al., 2016). Given these negative outcomes, a better understanding of the underlying mechanisms driving math anxiety is crucial. A candidate underlying mechanism might be biased information processing (Beck & Clark, 1997). The aim of the current study was to investigate whether individual differences in three common cognitive biases (i.e., threat-related associations, attentional biases, and avoidance bias) play a role in math anxiety and math-related behaviour. The current study focusses

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on adolescents, because math anxiety has found to peak in adolescence (Hembree, 1990), a crucial period for learning math and choosing school subjects.

Cognitive models of anxiety posit that biases in processing threat-related stimuli contribute to the aetiology and maintenance of anxiety disorders (Beck & Clark, 1997). In an integrative multi-process model (Ouimet et al., 2009), different stages of processing threat-related stimuli are integrated. It is posited that encountering a given stimulus activates corresponding associated concepts (threat-related associations), that in turn activate attentional orientation as well as avoidance-related behavioural tendencies. Individual differences in these kinds of cognitive biases are believed to confer a vulnerability to anxiety. A large body of research provided robust empirical evidence for the role of these information processing biases in the development and maintenance of various types of anxiety (e.g., Abend et al., 2018; Cisler & Koster, 2010; Craske et al., 2009; Teachman et al., 2019). As biased information processing is extensively studied in anxiety, it seems surprising that these biases have received only minimal attention in math anxiety and behaviour (for a review see Suárez-Pellicioni et al., 2016).

Threat-related associations might play a role in math anxiety, similar to other types of anxieties. For example, it has been shown that students with spider (versus snake) fear were quicker to evaluate spiders as more threatening than snakes on an Implicit Association Task (IAT; Teachman et al., 2001) and that stronger self-anxiety associations were related to more anxiety after stress (Egloff & Schmukle, 2002; for a review see Teachman et al., 2019). Similarly, encountering math stimuli might activate threat-related associations in individuals scoring high on math anxiety. Recently, it was found that adolescents showed stronger implicitly measured math-anxiety associations, compared to math-calmness associations; however, the strength of the math-anxiety associations was not related to self-reported math anxiety or math behaviour (Schmitz et al., 2019). A possible explanation for the lack of a relationship with math anxiety might be that not the concept of anxiety but that failure is the threatening concept associated with math. Control-value theory proposes that anxiety is evoked by an expectancy of failure (Pekrun, 2006) implying strong implicit associations between math and failure. Furthermore, research in 1.327 children at grades 2–5 showed that there are two separable aspects of math anxiety: anxiety about math-related situations and anxiety about failure in mathematics (Sorvo et al., 2017). The current study investigated math-failure associations and whether these were associated with math anxiety and math behaviour.

Attentional biases towards math might be a second form of biased information processing related to math anxiety. A meta-analysis focussing on other types of anxiety concluded that anxious children and adolescents showed a robust pattern of threat-related attentional bias (Abend et al., 2018). There is evidence for both quicker orienting towards threat (engagement bias) as well as delayed disengagement from threat (disengagement bias; attention is held longer by the threatening information; Salemink et al., 2007) in anxiety (for a review see Cisler & Koster 2010). Recent studies have supported the role of attentional biases in the school context. Highly test-anxious (and not low test-anxious) individuals showed attentional biases towards school and exam-related stimuli (Mano et al., 2018; Putwain et al., 2011). Also, stronger school-related attentional biases in adolescents were associated with lower academic functioning (Scrimin et al., 2016, 2018). A few studies have investigated attentional biases in math anxiety. It has been found that highly math-anxious individuals have difficulties disengaging attention from math stimuli (Rubinsten et al., 2015). However, as math and neutral stimuli were never presented at the same time, these findings do not provide evidence for the preferential allocation of attention towards threat in the context of other stimuli (*selective* attention). In addition, as participants had to solve the equations, which were used as math stimuli, it is unclear whether response times only included attentional processes or calculation times as well. In a study with the Emotional Stroop Task, it was found that highly math-anxious (compared to low math-anxious) individuals took longer to respond to the colour of math words (compared to neutral words; Suárez-Pellicioni et al., 2015). However, it is debated whether the Stroop effect reflects attentional bias (de Ruiter & Brosschot, 1994; see also Hopko et al., 2002; Van Bockstaele et al., 2014). Thus, while there have been some studies investigating attentional biases in math anxiety, methodological aspects limit the interpretation of these findings. To address these limitations, a Math Visual Search Task (Math VST) was developed that allows differentiation of attentional engagement and disengagement, using a paradigm that is more reliable than the often used dot probe task (Schmukle, 2005; Van Bockstaele et al., 2019). This task will be used in the current study.

Lastly, avoidance biases away from math might play a role in math anxiety and behaviour. Using behavioural reaction time paradigms, such as the Approach Avoidance Task (AAT), it has been shown that, compared to non-anxious controls, socially anxious individuals have stronger avoidance tendencies for angry faces (Heuer et al., 2007) and spider fearful individuals have stronger avoidance tendencies for spiders (Rinck & Becker, 2007). And importantly, those spider avoidance tendencies were correlated with the speed of approaching a real spider, even when controlling for self-reported fear (Rinck & Becker, 2007, but see Effting et al., 2016). These findings indicate that an avoidance bias plays a role in anxiety and anxiety-related behaviour. Such avoidance biases likely play a role in math anxiety as well. While it has been suggested that highly math-anxious individuals avoid cognitive involvement in math tasks by rushing through the task, inferred from high speed and low accuracy in a math task (Ashcraft & Faust, 1994; Hembree, 1990), it remains unclear whether the sole processing of mathematical information, without the instruction to solve a math problem, is also biased. One experimental study has shown that reducing relatively implicit math-avoidance tendencies resulted in stronger math identification and more attempts on a math test (Kawakami et al., 2008), providing evidence for the role of math avoidance tendencies in math behaviour. In the current study, it was investigated whether stronger avoidance bias for math was associated with stronger math anxiety and math avoidance behaviour.

The current study investigated the role of three types of cognitive biases: math-failure associations, attentional (engagement and disengagement) biases, and math avoidance biases, in math anxiety and behaviour. The first aim was to test whether stronger cognitive biases were associated with stronger self-reported math anxiety. The second aim was to test whether stronger cognitive biases were associated with lower self-reported math grades (as an indication of math performance) and stronger math avoidance behaviour.

Methods

Participants

A total of 529 Dutch secondary school students, recruited through three schools, participated in the study. Passive informed consent from parents was obtained, and participants gave active informed consent. Participants received no reward. This study was approved by the Ethical Review Board of the Faculty of Social and Behavioural Sciences. Data from 29 participants were excluded from analyses (see Data Cleaning).

The final sample consisted of 500 participants ($M_{age} = 14.0$ years, $SD = 1.0$; 244 boys). Participants attended low (13.2% preparatory vocational), middle (58.6% senior general), or high (28.2% university preparation) education.

Materials

Cognitive Bias Tasks

Math-failure ST-IAT. The Single-Target Implicit Association Test (ST-IAT; cf. Karpinski & Steinman, 2006) was used to assess the strength of associations between *math* and *failure*, in comparison to *math* and *success*. It consisted of one practice block and two combination blocks (Fig. 1). In the practice block, participants learned the response keys (i.e., the left and right arrow keys) related to the categories *failure* and *success*, for which the labels were presented on the upper left and right corners of the screen (Fig. 1a). The label locations were randomized between participants. Next, the two combination blocks were presented in counterbalanced order. In the Math + Failure combination block, the labels *math* and *failure* were combined on one side of the screen, and *success* was presented on the other side (Fig. 1b). In the Math + Success combination block (Fig. 1c), the labels *math* and *success* were combined, and *failure* was presented on the other side.

Each category contained five stimuli; failure (e.g., ‘bad’), success (e.g., ‘proud’), and math (e.g., ‘graph’). The practice block consisted of 10 trials; all failure and success stimuli were presented once. Each combination block consisted of 60 trials. The five math stimuli were each presented five times in each block; the failure words were presented twice and the success words five times in the Math + Failure combination block; the failure words were presented five times and the success words two times in the Math + Success combination block. Stimuli were presented in random order (restriction: max. 2 per category successively). The

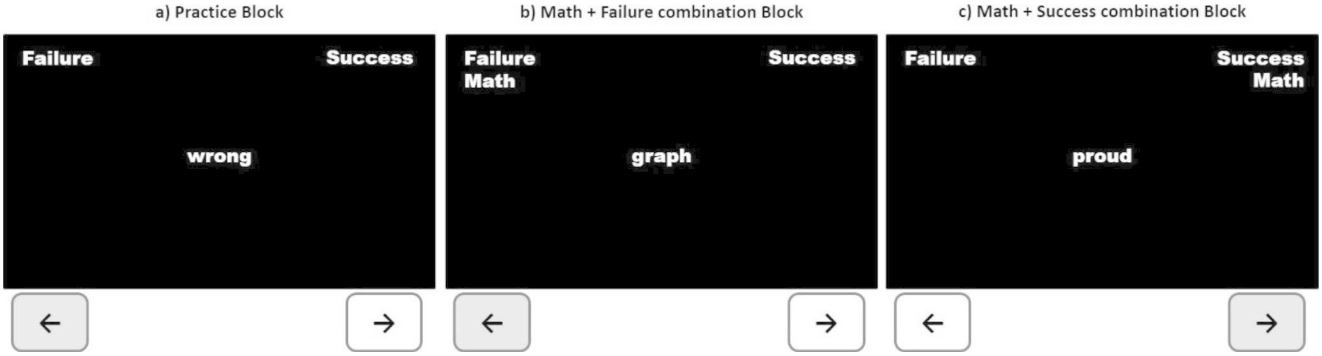

Fig. 1 Example trials of math-failure ST-IAT per block
Note. Correct responses are indicated by the grey arrow key. The label locations were counterbalanced across participants as well as the order of the combination blocks

word stimuli were matched on mean number of syllables per category.

Each trial started with an inter-trial interval (500–1000 ms), then a word was presented in the centre of the screen. Participants were instructed to classify the word by pressing the response key that corresponded to the label location as fast and accurate as possible. Stimuli remained on the screen until a response was given. When an error was made, a red cross was presented until the participant pressed the correct response. A time-out message and repetition of the instructions were presented after 10,000 ms, and the trial was repeated.

Following the improved scoring algorithm of Greenwald et al. (2003), *Math-failure association* D-scores were calculated including a built-in error penalty. More specifically, trials with latencies ≤ 300 ms and ≥ 10.000 ms responses were discarded. Then, the mean of correct response latencies was calculated for each combination block. As the IAT required participants to correct an incorrect response, the latency for the correct response includes the latency for the incorrect response (built-in error penalty). The difference in mean response latency between the two combinations blocks was calculated and divided by the pooled standard deviation resulting in the D-score. Higher D-scores represented faster responses in the Math + Failure than in the Math + Success combination block, indicating stronger math-failure associations (compared to math-success associations). The Spearman-Brown corrected split-half reliability calculated over ten randomly selected split-half sets (see Pronk et al., 2022) was good (*split-half reliability* = 0.85). The average error percentage was 6.6%.

Math VST. The Math Visual Search Task (Math VST; based on De Voogd et al., 2014) was developed to measure two components of attentional bias for math: engagement and disengagement bias. Each trial started with an inter-trial interval (500–1000 ms), after which a white fixation dot was presented in the centre of a black screen (500–1000 ms). Next, 8 white stimuli were presented in a circle, and participants were instructed to confirm whether a target stimulus was present. The 'yes' and 'no' response were randomly allocated between participants on the left and right arrow keys. When an error was made, a red cross was presented in the centre of the screen (1000 ms) and the trial was repeated.

The Math VST consisted of three blocks presented in counterbalanced order: Engagement block, Disengagement Formula block, Disengagement String block (Fig. 2). In the Engagement block (64 trials), participants needed to confirm whether a *formula* target was present amongst 7 *non-word* distractors (32 trials contained a formula; 32 trials a neutral *string* target). In the Disengagement Formula block (32 trials) and Disengagement String block (32 trials), participants needed to confirm whether a *word* target was present amongst either 7 *formula* or 7 neutral *string* distractors, respectively (in 16 trials a *word* was present and in 16 trials, it was not).

The Math VST started with an explanation of the four types of stimuli: (1) formulas (i.e., math equations; e.g., *3 y + 8 = 3 5*), (2) strings (i.e., random order of symbols (excluding the following math-related symbols /, +, -, x, =, ( )), e.g., *& : [? # { *), (3) words (i.e., Dutch words and punctuation marks; e.g., *(f r u i t ″*), and (4) non-words (i.e., random order of letters and punctuation marks; e.g., *l o q) m v“*). Each block was preceded by 4 practice trials (with unique stimuli), including feedback, that were repeated until ≥ 2 correct responses were given. Trials were presented in random order with the restriction of a maximum of three consecutive trials of the same target type and two at the same target position.

For calculation of scores, incorrect responses and trials with fast (< 200 ms) and slow (> individual's mean + 2 SD of correct trials of trial type) responses were discarded (De Voogd et al., 2014). The *engagement bias* score was calculated by subtracting the corrected mean RT of trials with a formula target from the corrected mean RT of trials with a string target in the Engagement block. Higher scores represented faster responses to finding a formula relative to string stimuli amongst neutral stimuli, indicating stronger engagement towards math. The *disengagement bias* score was calculated by subtracting the corrected mean RT of all trials in the Disengagement String Block from the corrected mean RT of all trials in the Disengagement Formula Block. Higher scores indicated slower responses when neutral stimuli were surrounded by formula than by string, indicating stronger difficulty to disengage from math. The Spearman-Brown corrected split-half reliabilities calculated over ten randomly selected split-half sets (see Pronk et al., 2022) were acceptable (engagement bias: *split-half reliability* = 0.78; disengagement bias: *split-half reliability* = 0.64). The average error percentage was 6.7%.

Math AAT. The Math Approach Avoidance Task (Math AAT; based on Peeters et al., 2013, 2012; Rinck & Becker, 2007) was used to measure math avoidance bias. Math stimuli (i.e., pictures of math problems or graphs) and neutral stimuli that visually resembled each math stimulus (i.e., schematic pictures of neutral objects) were used[1]. Each trial started with an inter-trial interval (500–1000 ms), after

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[1] To validate the stimuli, the valence of each stimulus was assessed by having participants indicate how they felt when they saw the picture, using a slider on a line, where 0 corresponded to strongest 'positive' valence on the left extreme and 100 to strongest 'negative' valence on the right extreme. Neutral stimuli were rated less negatively than math stimuli (respectively $M = 36.11$, $SD = 14.86$ versus $M = 56.91$, $SD = 19.48$), $t(483) = 19.54$, $p < .001$. Further, stronger negative valence of math stimuli was significantly related to higher math anxiety ($r = .40$, $p < .001$).

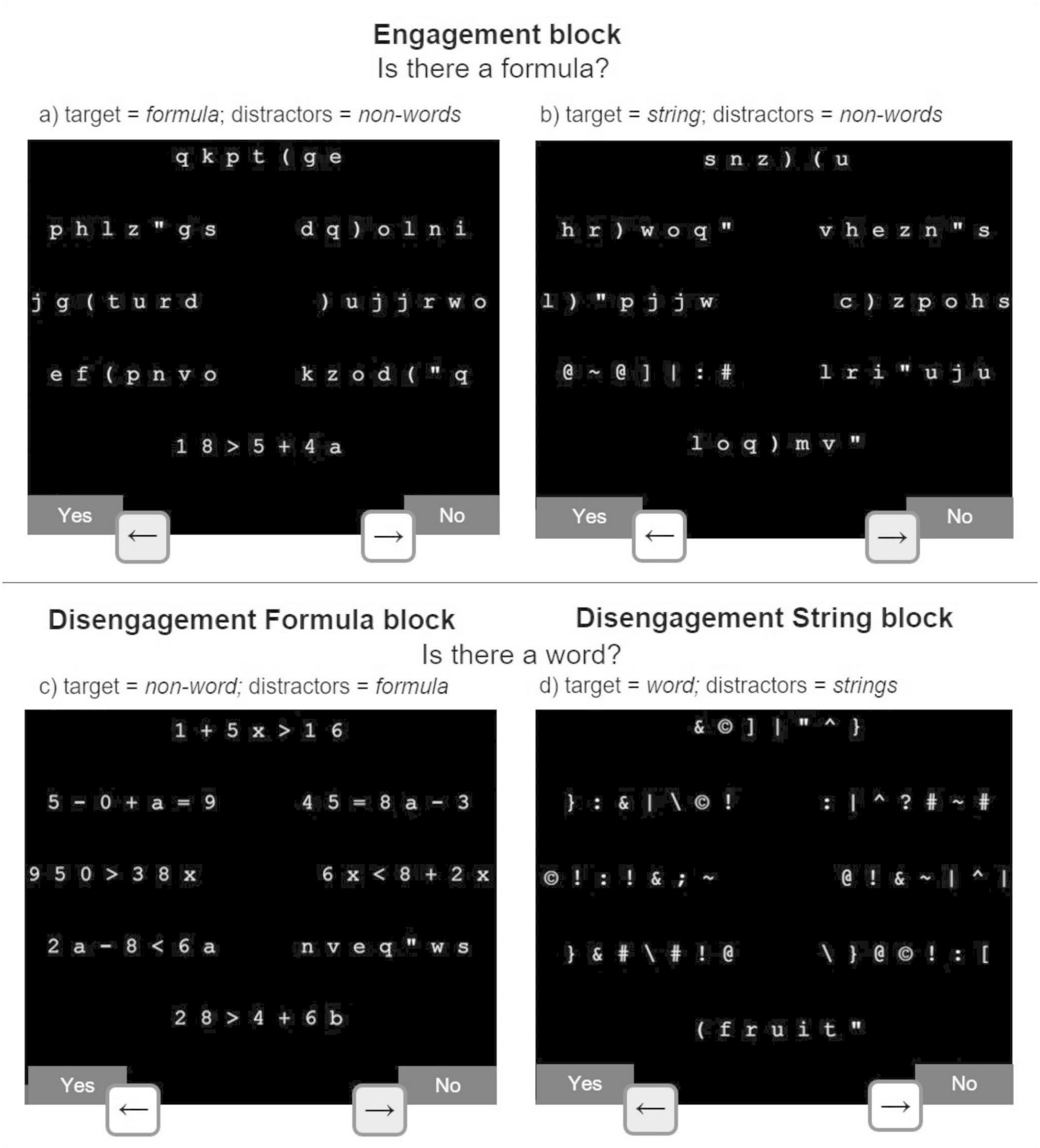

Fig. 2 Example trials of Math Visual Search Task per block
Note. Correct responses are indicated by the grey arrow key

which a white fixation dot was presented in the centre of a black screen (500–1000 ms). Next, a tilted stimulus was presented in the centre of the screen and participants were instructed to completely zoom out (i.e., avoidance response) or in (i.e., approach response), based on the direction in which it was tilted, until it disappeared. Participants were randomly allocated to the tilt–response key combination.

The Math AAT consisted of three blocks: a practice block and two critical blocks. In the practice block (10 trials), participants learned the keys corresponding to zooming in (e.g., downward arrow) and out (e.g., upward arrow), using a grey square stimulus. In the two critical blocks (40 trials each), 10 math and 10 neutral stimuli were used, which were all presented once tilted to the left and once tilted to the right. Different types of trials were presented in random order (restrictions: max. 3 consecutive trials of same type/category; max. 2 consecutive trials of same stimulus). When an error was made, instructions were presented again, and the trial was repeated. This was done to encourage providing correct answers.

The *math avoidance bias* and *neutral avoidance bias* scores were calculated following the improved algorithm of standardized D-scores (Greenwald et al., 2003), which was adapted for the AAT by Wiers et al. (2011; see also Lindgren et al., 2015). Trials with invalid, fast (<200 ms), slow (>2000 ms) and time-out (>4000 ms) responses were discarded. Reaction times of incorrect responses were replaced by an individual's mean RT + 2 SD for corrected responses. Next, *math avoidance bias* D-scores and *neutral avoidance* D-scores were calculated (i.e., corrected mean RT for approach responses - corrected mean RT for avoidance responses divided by the SD per category). Higher math avoidance bias D-scores indicated faster avoidance responses relative to approach responses to math-related stimuli, thus stronger avoidance bias. Similarly, higher neutral avoidance bias D-scores indicated faster avoidance responses relative to approach responses to neutral responses. The Spearman-Brown corrected split-half reliability calculated over ten randomly selected split-half sets (see Pronk et al., 2022) were low; 0.37 and 0.48 respectively for the math and neutral avoidance biases. The average error percentage was 8.2%. To control for general biases in approach and avoid action-tendencies, regression analyses with the math avoidance bias scores were conducted with the neutral avoidance bias score included as a covariate.

Math Behaviour

Self-reported math grade. As an indication of math performance, participants were asked to self-report the math grade of their latest report. Grades in the Dutch educational system range from 1.0 to 10.0, with higher grades representing better performance. A minimum of 5.5 is necessary to pass.

Math avoidance. The Amsterdam Math Anxiety Task (AMAT) was developed to assess math avoidance behaviour (and other math anxiety related processes, see Supplementary Materials for a full description of the AMAT). Participants had to solve 12 algebraic equations in a low anxiety condition (e.g., no anxiety inducing factors were added). The equations had three difficulty levels. At the start of each trial, participants chose the difficulty level of the to-be-solved equation out of two options represented by the number of stars (one, two or three stars). All combinations of difficulty levels were presented four times, resulting in 12 choices. Level 1 consisted of equations of the form $x + b = y$ and $x - b = y$, with b, x and y ranging from 11 to 99. Level 2 and 3 consisted of equations of the form $ax + b = y$ and $ax - b = y$, with $1 \leq x \leq 9$ and b and y ranging from 11 to 99 (Level 2: $2 \leq a \leq 5$; Level 3: $6 \leq a \leq 9$). All equations on Level 1 and 3, but none on Level 2, required a carry procedure. Equations did not concern decimal values, negative values, or multiples of ten.

Math avoidance behaviour was conceptualized as avoiding choosing the difficult equations, thus choosing the easier ones. As a result, choosing equations from Level 1 is indicative of avoidance and scored as three points; Level 2 = 2 points; Level 3 = 1 point. The total math avoidance score was calculated by summing up the points. It ranged from 16 to 32, with higher scores indicating avoidance of difficult items.

Self-reported math anxiety. The Components of Mathematics Anxiety Questionnaire was developed to measure self-reported math anxiety based on four components (i.e., affect & physiology, worry, avoidance, and effort) (Schmitz, 2020). Participants received 31 items (example item on worry: "I worry about maths tests", example item on avoidance: "I would rather not check my answers for maths") and indicated how much each statement applied to them on a 5-point Likert scale, ranging from 1 (*does not apply at all*) to 5 (*fully applies*). Mean total scores were computed with higher scores indicating higher math anxiety. Cronbach's alpha in the current sample was 0.94.

Procedure

The study was conducted at schools during regular school hours. After instruction and obtaining informed consent, individual assessment on computers started with questions on demographic characteristics and grades, followed by the task assessing math avoidance (AMAT). Next, participants performed two[2] cognitive bias tasks (randomly selected out of the three cognitive tasks) in random order. Each cognitive task was preceded by two equations (without choosing a level) to create a math context and activate math-related concepts. Bias tasks and questionnaires[3] were presented in an alternating sequence. At the end, participants were thanked, and received a written debriefing. The total assessment lasted approximately 35 min.

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[2] Due to time constraints, for 68 participants only one task was randomly selected.

[3] The following questions and questionnaires were not part of the current manuscript: English grade, math interest scale, math self-concept scale, teacher support scale, and contact with math and English teachers.

Data Cleaning

Data were excluded for one participant who withdrew from participation, and for two participants who completed the assessment within 20 min and for whom observations confirmed lack of motivation. Next, data on separate tasks were deleted if (1) data were incomplete ($n = 9$), (2) COMAQ was filled out within 60 s ($n = 3$), and (3) stimuli in the ST-IAT were presented in incorrect proportion ($n = 5$). In addition, following Greenwald et al. (2003), data for the ST-IAT were deleted if participants had $\geq 10\%$ fast (< 300 ms) responses ($n = 3$). For Math VST and AAT, data were deleted for participants with excessive percentages of errors (Math VST: $\geq 20\%$, $n = 12$; AAT: $\geq 25\%$, $n = 19$) or slow responses (AAT: $\geq 25\% > 2000$ ms, $n = 1$). Data of participants with missing data on all 3 cognitive bias tasks ($n = 14$) or COMAQ ($n = 12$) were deleted. The final sample consisted of 500 participants, of which 81.2% ($n = 406$) had complete data for two cognitive bias tasks. Number of participants per questionnaire and assessment task is presented in Table 1. There was a significant effect of Block order for the STIAT with stronger math-failure associations when the Math + Failure combination block was presented first, $t(304) = -14.26$, $p < .001$. Block order was therefore included in the analyses that involved the STIAT. There was a significant effect of allocation of response keys for the Neutral Avoidance bias D-score, $t(303) = -6.95$, $p < .001$, indicating lower scores when participants were instructed to give avoidance responses to pictures tilted to the left in comparison to the right. Therefore, response key allocation was taken into account in the regression analyses that involved the neutral avoidance bias D-scores.

With respect to sex differences, independent samples t-tests indicated that girls showed a stronger association between math and failure, $t(304) = -2.59$, $p = .010$, reported higher math anxiety, $t(498) = -3.35$, $p = .001$, and showed more math avoidance behaviour, $t(495) = -3.21$, $p = .001$, than boys. With respect to educational level, 3 Group (low, middle, high education level) ANOVA's indicated that the low education level was associated with the highest grades, $F(2, 497) = 9.84$, $p < .001$, $\eta_p^2 = 0.04$, and the strongest avoidance of difficult math equations, $F(2, 494) = 29.05$, $p < .001$, $\eta_p^2 = 0.07$. Therefore, sex and educational level were taken into account in the regression analyses.

Results

Zero-order Relationships

Zero-order correlations were calculated between the main variables (see Table 1). Higher math anxiety was related to lower math grades and stronger avoidance behaviour. In addition, a lower math grade was related to more avoidance behaviour. With respect to the cognitive biases, stronger math-failure associations were correlated with stronger math anxiety, lower math grades, and stronger math-avoidance behaviour. Both attentional bias indices were not significantly related to math anxiety nor math behaviour. Stronger math avoidance bias was, unexpectedly, associated with less avoidance behaviour. The neutral avoidance bias was neither correlated with math anxiety, math grade, nor math avoidance behaviour.

The Role of Cognitive Biases in Math Anxiety

The first aim was to test whether stronger cognitive biases for math were associated with stronger math anxiety, when controlling for sex and education level (dummy coded; and controlling for block order for math-failure associations and controlling for response key allocation and neutral avoidance bias for math avoidance bias). Hierarchical regression analyses were performed with math anxiety as the dependent variable, and sex and educational level (Step 1), and specific cognitive biases (Step 2) as the independent variables (see Table 2). The results can be summarized as following: adding cognitive biases in Step 2 significantly improved the model for math-failure associations, but not

Table 1 Correlations between math-related measures (anxiety, grade and avoidance) and cognitive biases and descriptive statistics

	1.	2.	3.	4.	5.	6.	7.	Mean (SD)	Range	N
1. Math anxiety	-	-	-	-	-	-	-	2.10 (0.65)	1.00–4.65	500
2. Math grade	−0.45***	-	-	-	-	-	-	6.58 (1.20)	3.50–10.00	500
3. Math avoidance behaviour	0.31***	−0.18***	-	-	-	-	-	21.53 (5.58)	16–32	497
4. Math-failure associations	0.21***	−0.12*	0.16**	-	-	-	-	−0.05 (0.42)	-1.06 −0.91	306
5. Engagement bias	−0.01	0.05	0.10	0.13	-	-	-	561.75 (482.23)	-1046.73–2982.89	298
6. Disengagement bias	−0.04	−0.08	−0.02	0.14	0.02	-	-	147.54 (413.40)	-1446.55–2417.23	298
7. Math avoidance bias	−0.02	−0.03	−0.12*	0.06	−0.05	−0.12	-	−0.02 (0.39)	-1.10–1.02	305
8. Neutral avoidance bias	0.04	0.03	−0.002	0.16	−0.08	−0.17*	0.29***	0.002 (0.43)	-1.17–1.18	305

Note. $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$

for engagement bias, disengagement bias, nor avoidance bias. Thus, only stronger math-failure associations were associated with stronger math anxiety (independent of sex, educational level, and block order). In most models, girls reported significantly more math anxiety than boys. Education level was not significantly related to math anxiety.

Sex: 0 = boys, 1 = girls. Dummy variables for educational level, with the low educational level being the reference category. Response Key is the allocation of approach or avoid responses to the tilt of the picture in the AAT. There are some slight differences in participant numbers per experimental task analysis.

Table 2 Hierarchical regression analyses with sex, education level, and cognitive bias as the independent variables and math anxiety as the dependent variable

			Math Anxiety	
			Step 1	Step 2
Math-failure associations	Model	ΔR^2	0.03	0.04
		ΔF	1.9	12.4**
	Variable (β)	Sex	0.13*	0.09
		Education Middle	−0.09	−0.09
		Education High	−0.09	−0.09
		Block order	0.07	−0.10
		Bias		0.26**
Engagement bias	Model	ΔR^2	0.04	0.00
		ΔF	3.6*	0.1
	Variable (β)	Sex	0.18**	0.19**
		Education Middle	0.01	0.01
		Education High	0.04	0.04
		Bias		−0.02
Disengagement bias	Model	ΔR^2	0.04	0.001
		ΔF	3.6*	0.41
	Variable (β)	Sex	0.18**	0.18**
		Education Middle	0.01	0.02
		Education High	0.04	0.04
		Bias		−0.04
Avoidance bias	Model	ΔR^2	0.02	0.01
		ΔF	1.7	1.2
	Variable (β)	Sex	0.10	0.11
		Education Middle	−0.008	−0.02
		Education High	−0.04	−0.04
		Response Key	−0.11	−0.14*
		Neutral Bias		0.10
		Bias		−0.04

$^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$

The Role of Cognitive Biases in Math Behaviour

The second aim was to investigate whether math-related cognitive biases were associated with math behaviour, controlling for sex and education level (controlling for block order for math-failure associations and controlling for response key allocation and neutral avoidance bias for math avoidance bias), and on top of self-reported math anxiety. Hierarchical regression analyses were performed with math grade and math avoidance behaviour as the dependent variables, and sex and educational level (dummy coded) (Step 1), a specific cognitive bias (Step 2), and math anxiety (Step 3) as the independent variables (see Table 3).

The results for math grade can be summarized as following. Adding cognitive biases in Step 2 significantly improved the model for math-failure associations, but not for engagement bias, disengagement bias, nor avoidance bias. Thus with respect to cognitive biases in Step 2, only stronger math-failure associations were associated with lower math grades (independent of sex, educational level, and block order). The model including math anxiety (Step 3 in the analyses) is consistently the best model with math anxious individuals having lower math grades, above and beyond the other variables in the model. In addition, girls tend to have better math grades than boys (though not in all regression models). There is no significant association between the four different biases and math grade when math anxiety is part of the model. The low education level was associated with the highest math grades.

The results for math avoidance can be summarized as following. Math failure associations significantly improved the model in Step 2. Consistent with our expectations, stronger math failure associations were associated with more math avoidance behaviour (independent of sex, educational level, and block order). While Step 2 with avoidance biases did not significantly improve the model, stronger math avoidance biases were associated with less math avoidance behaviour (contrary to expectations). The model including math anxiety (Step 3) is, again, consistently the best model with higher math anxiety being associated with more avoidance behaviour in all models. In Step 3, also engagement bias and avoidance bias are significantly associated with math avoidance. The finding for engagement bias is consistent with our hypotheses, individuals with stronger attentional engagement bias for math show stronger avoidance of difficult math equations than individuals with weaker engagement bias. Contrary to expectations, stronger math avoidance biases were associated with less math avoidance behaviour while controlling for neutral avoidance biases. Math failure associations and disengagement biases were not associated with math avoidance behaviour in Step 3. In addition, individuals from the high education level showed

Table 3 Hierarchical regression analyses with sex, education level, cognitive bias, and math anxiety as the independent variables and math grade and math avoidance behaviour as the dependent variables

			Math Grade			Math Avoidance Behaviour		
			Step 1	Step 2	Step 3	Step 1	Step 2	Step 3
Math-failure associations	Model	ΔR^2	0.04	0.03	0.22	0.14	0.02	0.07
		ΔF	3.0*	9.8**	93.0***	12.6***	5.6*	28.4***
	Variable (β)	Sex	0.09	0.13*	0.17**	0.23***	0.20***	0.18**
		Education Middle	−0.24**	−0.25**	−0.29***	−0.35***	−0.35***	−0.32***
		Education High	−0.12	−0.12	−0.17*	−0.48***	−0.48***	−0.46***
		Block order	0.001	0.15*	0.10	0.05	−0.06	−0.03
		Bias		−0.23**	−0.10		0.17*	0.09
		Math Anxiety			−0.49***			0.28***
Engagement bias	Model	ΔR^2	0.03	0.002	0.19	0.05	0.01	0.09
		ΔF	3.0*	0.52	69.0***	5.2**	3.3	29.6***
	Variable (β)	Sex	0.03	0.03	0.11*	0.10	0.19	0.04
		Education Middle	−0.28**	−0.28**	−0.27**	−0.16	−0.15	−0.16
		Education High	−0.21*	−0.21*	−0.19*	−0.31**	−0.31**	−0.32**
		Bias		0.04	0.03		0.10	0.11*
		Math Anxiety			−0.44***			0.30***
Disengagement bias	Model	ΔR^2	0.03	0.004	0.19	0.05	0.00	0.09
		ΔF	3.0*	1.2	70.5***	5.2**	0.04	28.8***
	Variable (β)	Sex	0.04	0.04	0.11*	0.10	0.10	0.05
		Education Middle	−0.28**	−0.27**	−0.26**	−0.16	−0.16	−0.17
		Education High	−0.21*	−0.21*	−0.19*	−0.31**	−0.31**	−0.32**
		Bias		−0.06	−0.08		−0.01	0.00
		Math Anxiety			−0.44***			0.30***
Avoidance bias	Model	ΔR^2	0.03	0.001	0.22	0.05	0.02	0.11
		ΔF	2.4	0.22	88.1***	3.7**	2.3	39.1***
	Variable (β)	Sex	0.01	0.01	0.06	0.09	0.10	0.06
		Education Middle	−0.25*	−0.25*	−0.26**	−0.32**	−0.31**	−0.30**
		Education High	−0.12	−0.12	−0.14	−0.35***	−0.34***	−0.33***
		Response Key	0.07	0.06	−0.01	−0.02	−0.02	0.02
		Neutral Bias		0.03	0.08		0.05	0.01
		Bias		−0.03	−0.05		−0.13*	−0.11*
		Math Anxiety			−0.48***			0.34***

$^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$

Sex: 0 = boys, 1 = girls. Dummy variables for educational level, with the low educational level being the reference category. Response Key is the allocation of approach or avoid responses to the tilt of the picture in the AAT

less avoidance of difficult math items than individuals from the low education level (and a similar, though less consistent pattern was observed for middle versus low education levels). In one model, girls showed more avoidance of difficult items than boys.

Exploratory Mediation Analyses

The finding that math-failure associations were associated with math anxiety (aim 1) and that the relationship between math-failure associations and math behaviour was no longer significant when taking math anxiety into account (aim 2), could suggest that math anxiety mediates the relationship between math-failure associations and math behaviour. As this is in line with current theories (Pekrun, 2006), exploratory mediation analyses were performed using PROCESS macro V4.1 in SPSS (Hayes, 2022). Math-failure associations (independent), math anxiety (mediator), as well as sex and dummy variables for educational level (covariates) were entered in the models predicting math grade and math avoidance behaviour (dependent variables). Results revealed a significant full mediation effect for both analyses: math anxiety mediated the relation between math-failure associations and math grade (indirect effect: B = -0.28; 95% bootstrap CI [-0.46, -0.12]) and between such associations and math avoidance behaviour (indirect effect: B = 0.74; 95% bootstrap CI [0.27, 1.31], see Fig. 3, Panel A and B respectively). Stronger math-failure associations were associated with stronger math anxiety, which in turn was associated with lower math grades and more math avoidance.

Discussion

The current study investigated the role of three types of cognitive biases: math-failure associations, attentional biases (both engagement and disengagement), and avoidance bias, in math anxiety and math behaviour (math grade and math avoidance). Of these three biases, math-failure associations showed the most consistent associations with the various outcome measures. That is, math-failure associations were associated with higher math anxiety above and beyond sex and education level. Those math-failure associations were also associated with lower grades and more avoidance behaviour, however, not above and beyond math anxiety. Engagement biases and avoidance biases were only associated with math avoidance behaviour (while controlling for math anxiety). Disengagement biases were not associated with any outcome measure.

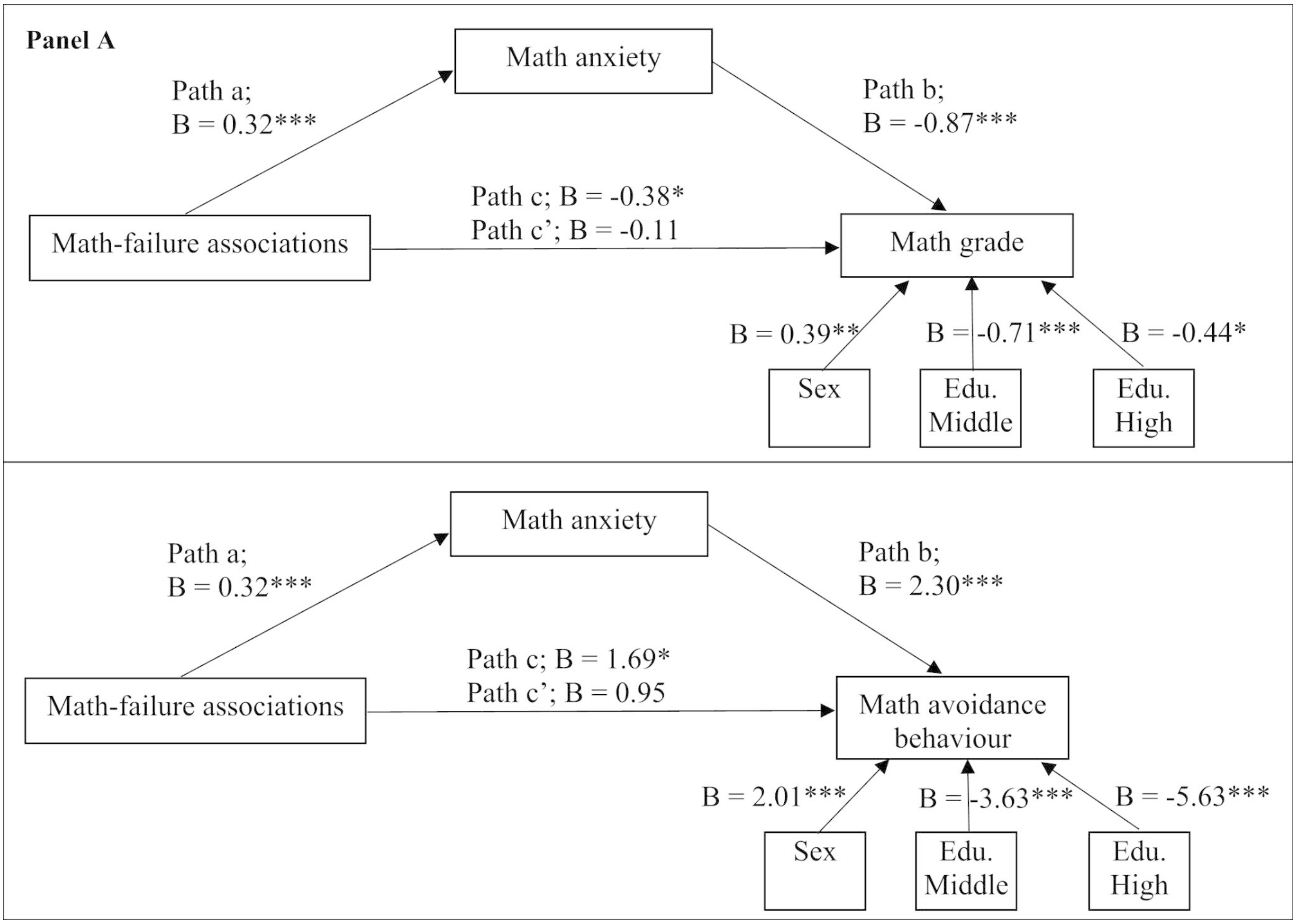

Fig. 3 Full mediation effect of math anxiety in the relation between math-failure associations and math behavior (grade and math avoidance behaviour)

Note. Panel A, Math grade: the indirect effect: B = -0.28; 95% bootstrap CI based on 5.000 samples [-0.46, -0.12]); Panel B, Math avoidance behavior: the indirect effect B = 0.74; 95% bootstrap CI based on 5.000 samples [0.27, 1.31]; B = unstandardized coefficients. Sex: 0 = boys, 1 = girls. Edu. Middle = dummy coded variable for middle educational level, with the low level being the refence category. Edu. High = dummy coded variable for high educational level, with the low level being the refence category. Covariates sex, Edu. Middle, and Edu. High were not significant in models with Math Anxiety as the dependent variable. * $p < .05$. ** $p < .01$. *** $p < .001$

Implicit math-failure associations correlated with math anxiety, math grade and avoidance behaviour. While the correlation between more implicit associations and anxiety has been studied and shown consistently in other anxiety domains (Teachman et al., 2019), it has received less attention in the field of math anxiety. The current finding is thus consistent with the broader anxiety literature and also adds to the math anxiety literature specifically, as it highlights the crucial role of math-failure associations instead of math-anxiety associations. A previous study (Schmitz et al., 2019) did not observe math-anxiety associations playing a role in math anxiety. Based on the control-value theory of (math) anxiety that proposes that anxiety is evoked by an expectancy of failure (Pekrun, 2006), we hypothesised that for math anxious individuals failure would be the core problematic implicit association with math, and not anxiety. Our findings provide some first empirical support for this hypothesis and more general for the role of implicit associations in math anxiety.

Implicit math-failure associations did not add to the explanation of math behaviours on top of self-reported math anxiety. The exploratory mediational analyses provide a tentative explanation consistent with theoretical models of math anxiety (Pekrun, 2006). For individuals who associate math with failure, exposure to math stimuli, such as math words or equations during math exams, may trigger associations of failure that may activate feelings of math anxiety. Such anxiety is likely to disturb the math problem solving process leading to lower math grades. And those lower grade might be a failure experience that then strengthens the math-failure associations resulting in a vicious, maintaining cycle. In addition, stronger math-failure assocations and stronger math anxiety likely results in math avoidance behaviour, such as avoiding difficult math items. The correlational design of the current study does not permit any causal inferences, though the current findings support the hypothesis that math-failure associations play a role in math anxiety and math behaviour. Future studies with a longitudinal or an experimental design (where implicit associations are manipulated) are warranted to shed more light on the role of implicit associations as mechanisms in math anxiety.

The current study also showed that biased attentional engagement plays a role in math-related avoidance behaviour. While this finding reinforces the findings from an earlier study regarding a role of attentional bias in math anxiety (Suárez-Pellicioni et al., 2015), there are some notable differences and more detailed insights obtained in the current study. That is, the current findings highlighted differences between attentional engagement and disengagement with attentional disengagement not playing a role in any of the math anxiety outcome measures (which is inconsistent with Rubinsten et al., 2015). Biased attentional engagement was not associated with math anxiety or math grade, but only to math avoidance behaviour, and above and beyond sex, education level, and math anxiety. Given the central, maintaining role of avoidance behaviour in anxiety (Craske et al., 2009), gaining more insight into the processes that play a role in such avoidance behaviour is crucial. Thus, independent of the role of math anxiety, the tendency to selectively engage one's attention towards math stimuli is associated with more avoidance of math. Important next steps are replicating these findings and testing whether biased attentional processes play a causal role in math avoidance behaviour. An experimental study where attentional bias for math stimuli is manipulated (for example using the EVST task, De Voogd et al., 2014) would allow one to test whether this process plays a driving, causal role in math avoidance.

Contrary to expectations, math avoidance biases were not associated with math anxiety and math grade in the current study. They were associated with math avoidance behaviour, however in the opposite direction than hypothesised; stronger tendencies to avoid math stimuli were associated with less avoidance of difficult math exercises on a math task. It is unlikely that this finding is due to the math task (AMAT). While that test was a newly developed task to measure math avoidance behaviour (and other math-related processes, see Supplementary Materials), it is a promising task as the obtained measure of math behavioural avoidance was correlated with math anxiety, math grade, and math failure-associations in the expected direction. It seems more likely that those unexpected findings might be due to the (mis)match between the AAT and the AMAT, or specific task features and limitations of the AAT. With respect to the match; within the AAT, participants are approaching or avoiding math-related stimuli as well as neutral stimuli that are unrelated to math. In contrast, avoidance was operationalized as the tendency to select easier rather than difficult math equations in the AMAT. As such, the AMAT measures avoidance of difficult math problems and not the avoidance of math altogether. This difference between the operationalization of avoidance within the AAT and AMAT could be a potential explanation of the unexpected direction of effects. It would be very interesting for future research to test this, for example by having a task that includes a choice between doing math equations or doing something else that is unrelated to math. With respect to the AAT task itself, analyses indicated that the reliability of the avoidance bias index was poor, and this puts also the reliability of these findings into question. Some features of the current AAT task might be improved. We used an indirect version of the AAT task (i.e., participants responded to picture-tilt, unrelated to picture content), whereas a meta-analysis only found effects using more direct versions in which participants respond to the contents of stimuli (e.g., math or neutral) (Phaf et al., 2014).

However, others have found effects using an indirect AAT in anxiety (Rinck & Becker, 2007). Another explanation might be that the math stimuli used in the AAT task were not threatening enough to trigger avoidance tendencies. The ratings of the valence of the math stimuli in the current study provide some support for this possibility. Although the rated negativity of the math stimuli was related to math anxiety, the average rating was nearly neutral. It might be necessary to include the (expectation of) interacting with the math stimuli (e.g., solving some equations) to activate failure expectations, negative evaluation of the stimuli, and avoidance tendency biases. To conclude, it seems likely that limitations of the current AAT task might explain the unexpected findings for math avoidance biases.

The current study is not without limitations. First, the current sample consisted of a regular secondary school population, wherein most students might have low levels of math anxiety. The conclusions drawn in the current study are mainly based on lower levels of math anxiety and cannot be directly generalized to high levels of math anxiety. To optimally examine math-anxiety related implicit information processing biases, the full range of math-anxiety levels is necessary with enough students having high levels of math anxiety. This might require actively searching and including highly math-anxious individuals. Secondly, the AAT task used to measure biased avoidance tendencies showed poor reliability. Using a direct version of this task (Rinck & Becker, 2007) and/or including math stimuli that are evaluated as more threatening might improve the task. Alternatively, a different task could be used to measure avoidance tendencies, for example the manikin task as it proved to be more sensitive than the AAT in assessing avoidance tendencies towards spiders and was more strongly related to self-reported fear (Krieglmeyer & Deutsch, 2010). Thirdly, the Math VST that was used to measure attentional engagement and disengagement, might not be well-suited to disentangle these two processes. For example, in the disengagement formula block, slower response latencies to identify a word (target) stimulus in the presence of math formula stimuli could be the result of delayed disengagement from formula stimuli once they have been attended to during the search, or could be the result of a greater tendency to have attention drawn towards the formula stimuli during the search (see for an elaborate discussion Clarke et al., 2013). This is a limitation of these attentional bias indices derived from the current Math VST and limited the conclusions that can be drawn. Future studies that aim to differentiate between these two types of attentional processes should use a task that ensures that attention is on a predetermined initial focus (see Clarke et al., 2013 for three criteria). Finally, the study had a correlational design. While this is an important first step to start understanding which implicit biases in information processes play a role in math anxiety, important next steps include prospective studies with a longitudinal design to examine whether biases predict later development of math anxiety (cf. Price et al., 2016) and experimental studies to stringently examine the causal role. The latter has already been done for approach avoidance tendencies in the context of math; training individuals to approach math (instead of avoiding it) strengthened women's implicit identification with math (Batailler et al., 2021; Kawakami et al., 2008).

Overall, the current results highlight the important role of math failure associations in math anxious adolescents. In addition, (engagement) attentional biases might be associated with math behaviour, but so far not with math anxiety, and conclusions on avoidance bias cannot be drawn yet. Follow-up research, with improved instruments that integrate math and failure, may provide more insights. Practically, the study results give reason to break the association between math and failure in education, for example by having students practice at their own level and thereby increase their level of success in math. Adaptive online education offers possibilities to do so (Jansen et al., 2013). After all, although students can learn from failure, success is the basis for their confidence.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10608-023-10390-9.

Acknowledgements We thank Thomas Pronk for programming the cognitive bias tasks. We thank all adolescents, parents and schools for their participation, and all undergraduate students for their assistance in school recruitment and data collection. And thank prof. Colin Macleod for the inspiring conversation about anxiety versus failure in the context of implicit math-related associations.

Funding This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Declarations

Conflict of Interest The authors declare that they have no conflict of interest.

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