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How Different Negative Emotions Affect Young and Older Adults' Arithmetic Performance in Addition and Multiplication Problems?

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Supplementary Materials: Data [see Index of Supplementary Materials]

Abstract

We examined how different types of negative emotional states (anger, disgust, sadness) influence arithmetic performance, and whether this influence is modulated by the types of arithmetic operations and moderated by adults' age. Younger and older adults verified addition and multiplication problems that were superimposed on emotionally negative (angry, disgust, sad) or neutral images. Emotionally negative images were matched on both arousal and valence. We found that different negative emotional stimuli had different effects on arithmetic performance. We also found that these effects differed for addition and multiplication problems, and were moderated by participants' age. More specifically: (a) younger adults were more impaired by sad stimuli than older adults while solving addition problems; (b) older adults but not younger adults solved multiplication problems more slowly following disgust and sad stimuli than emotionally neutral stimuli and (c) anger stimuli did not affect younger and older adults' performance while solving addition and multiplication problems. These findings shed important lights on how different negative emotional stimuli influence arithmetic performance and how this influence changes with age during adulthood.

Keywords

arithmetic, emotion, cognition, cognitive development

Non-Technical Summary

Why was this study done?

Previous research found that negative emotions impaired adults' arithmetic performance. This study examined if different negative emotions (anger, disgust, sadness) differ in their influence on adults' arithmetic performance. We asked if effects of these emotions' differ for addition and multiplication problems in younger and older adults.

What did the researchers do and find?

We examined younger and older adults while they were solving arithmetic problems of addition and multiplication problems. These arithmetic problems were superimposed on emotionally negative (anger, disgust, sadness) and neutral images. We found that sadness and disgust impaired adults' arithmetic performance, but anger had no effect. Sadness impaired both younger and older adults while they were solving addition problems. Sadness had stronger effects in younger than in older adults. Also, sadness and disgust impaired older but not younger adults while they were solving multiplication problems.

What do these findings mean?

Different negative emotions differ in how they influence arithmetic problem-solving. This influence stem from their specific effects on arithmetic processes (e.g. calculation for addition; fact recall for multiplication). This specificity is also clearly indicated age-related differences in how different emotion influence performance. Specifically, it is well-known that adults of different ages use different strategies while they are solving arithmetic problems of the same operation.

Highlights

- We found that different negative emotions have different effects on adults' arithmetic performance.
- While sadness and disgust impaired arithmetic performance, anger had not any effect.
- Effects of different negative emotions are not the same for addition and multiplication problems.
- Effects of different negative emotions were moderated by adults' age.

The goals of this study were to determine if arithmetic performance is influenced by different types of negative emotional images, and whether this influence is modulated by arithmetic operation and moderated by adults' age. Previous studies found that negative emotional states as triggered by emotional images lead adults to obtain poorer arithmetic performance (e.g., Fabre & Lemaire, 2019; Framorando & Gendolla, 2018, 2019; Kleinsorge, 2007, 2009; Lallement & Lemaire, 2021, 2023; Lemaire, 2024; Liu et al., 2021; Melani et al., 2024; Schimmack & Derryberry, 2005; Zhu et al., 2021, 2022). One important limitation of these previous studies is that most of them did not distinguish among different types of emotional stimuli, so that we do not know whether different types of negative emotional states have different effects while participants are solving arithmetic problems (see Fabre & Lemaire, 2019; Kleinsorge, 2007, 2009; Lallement & Lemaire, 2021, 2023; Lemaire, 2024; Melani et al., 2024; Schimmack & Derryberry, 2005). Also, no studies compared how stimuli triggering different types of emotions influence participants' performance while they are solving addition and multiplication problems (e.g., Framorando & Gendolla, 2018, 2019; Liu et al., 2021; Schimmack & Derryberry, 2005; Zhu et al., 2021, 2022). Further, only a few studies examined differences in effects of negative emotional states on young and older participants' arithmetic performance (Lallement & Lemaire, 2021, 2023; Melani et al., 2024), making it unclear as to whether effects of negative emotional states in arithmetic change with age. The present study aimed at filling these gaps by documenting how different types of negative emotional states (anger, disgust, sadness) influence arithmetic performance in young and older adults while solving addition and multiplication problems. Before outlining the logic of the present study, we review previous findings on effects of negative emotions on arithmetic performance and how these effects change during adulthood.

Effects of Negative Emotions on Arithmetic Performance

Emotions are "*episodic, relatively short-term biologically based pattern of perception, experience, physiology, action, and communication that occur in response to specifically physical and social challenges and opportunities*" (Keltner & Gross, 1999, p. 468). These patterns of perception and experience are subjectively valenced as pleasant (positive) or unpleasant (negative) (e.g., Kringelbach & Berridge, 2017). Numerous studies found that unpleasant (negative) emotions are associated with impaired arithmetic performance in adults whether effects of emotions are studied via emotional traits such as math anxiety or via experimental approaches using emotion induction procedures (Barroso et al., 2021; Cipora et al., 2022; Dowker et al., 2016; Mammarella et al., 2019, Zhang et al., 2019 for reviews; Fabre & Lemaire, 2019; Framorando & Gendolla, 2018, 2019; Kleinsorge, 2007, 2009; Lallement & Lemaire, 2021, 2023; Liu et al., 2021; Melani et al., 2024; Schimmack & Derryberry, 2005; Zhu et al., 2021, 2022).

Numerous correlational studies showed that individuals' emotional trait of "math anxiety" is associated with lower math performance (see Barroso et al., 2021; Cipora et al., 2022; Dowker et al., 2016; Mammarella et al., 2019, Zhang et al., 2019; for reviews). Math anxiety can be defined as "feeling of tension, apprehension, or fear that interferes with math performance" (e.g., Ashcraft, 2002, p. 181). These feelings are assumed to impair math performance in math anxious individuals by capturing working-memory processes necessary while individuals are solving the target math problem. Also, these feelings were found to lead math anxious individuals to avoid situations of mathematical learning. As a result, math anxious individuals usually obtain poorer math performance relative to non-math anxious individuals. Moreover, poorer math performance were found to trigger the development of math anxiety in individuals creating a vicious cycle over the long term (e.g., Aldrup et al., 2020; Carey et al., 2016; Gunderson et al., 2018; Pekrun et al., 2017).

Experimental studies manipulating participants' emotional states via different emotion induction procedures showed that relative to neutral emotions, negative emotions lead participants to obtain poorer arithmetic performance (Fabre & Lemaire, 2019; Framorando & Gendolla, 2018, 2019; Kleinsorge, 2007, 2009; Lallement & Lemaire, 2021, 2023; Liu et al., 2021; Melani et al., 2024; Schimmack & Derryberry, 2005; Zhu et al., 2021, 2022). For example, Lallement and Lemaire (2023) found that both younger and older participants obtained poorer performance while verifying addition problems (e.g., 8 + 4 = 13. True? False?) when problems were displayed superimposed on emotionally negative images (e.g., a burning house) relative to neutral images (e.g., a table).

Another relevant finding for the present study concerns the possibility that effects of emotions may differ when participants solve addition and multiplication problems. Thus, stronger group differences in performance were found between lower- and higher math-anxious individuals while participants solved addition problems compared with multiplication problems (e.g., Ashcraft & Faust, 1994; Fioriti et al., 2025; Huber & Artemenko, 2021). For example, Ashcraft and Faust (1994) found that highly math-anxious individuals were slower and less accurate while verifying addition (e.g., 3 + 4 = 12) compared to multiplication (e.g., 3 x 4 = 7) problems. Also, experimental studies found consistent deleterious effects of negative emotional states while participants were solving addition problems but somewhat inconsistent deleterious effects while solving multiplication problems. For example, whereas Fabre and Lemaire (2019) found that adults were faster under negative emotional states than under neutral emotional states while solving multiplication problems (e.g., 27 x 8 = 216, True?, False?), Lallement and Lemaire found that younger and older adults were slower under negative emotional states than under neutral emotional states while solving multiplication problems (e.g., which estimate —3200 or 4500— is closer to the correct product of 42 x 84?).

Also, a couple of studies suggest that different emotions may have different effects in arithmetic (Liu et al., 2021; Zhu et al., 2021). Liu et al. (2021) asked participants to choose the best product among two proposed products (1500 – 1200) for multiplication problems (e.g., for 24 x 57) under fear, anger, and neutral conditions. The authors found that, relative to neutral condition, adults performed more poorly under fear condition but performed equally well under anger condition. Also, using an emotional priming procedure, Zhu and colleagues (2021) found beneficial effects of fear conditions on young adults' arithmetic performance but no effects of anger, again in a task where participants had to select among two proposed product estimates (1500 or 1200) which one was closer to the correct one for two-digit multiplication problems (e.g., 24 x 57).

Previous research in arithmetic found that participants solve addition and multiplication problems with different strategies, using procedural strategies while solving addition problems and retrieval strategies to solve multiplication problems (e.g., Fayol & Thevenot, 2012; LeFevre et al., 1996; Metcalfe & Campbell, 2011; Roussel et al., 2002). For example, Metcalfe and Campbell (2011) found that participants used procedural strategies, like counting much more often (+ 68%) while solving simple addition problems relative to simple multiplication problems. Differences in relative use of procedural and declarative strategies may drive different effects of emotions in each of these operations, a possibility that we tested in the present study.

Effects of emotions on cognitive performance are usually accounted for by assuming that emotions capture participants' attention (e.g., Pessoa, 2022). When emotions are task irrelevant (e.g., as triggered by emotional images displayed prior/in parallel to the target task and that are completely unrelated to the target task), they grab participants' exogeneous attention and interrupt/slow down cognitive mechanisms involved in the target task, and/or generate a competition of resources between irrelevant emotional processing and relevant cognitive processing. The same mechanism was also found for math anxiety triggered by external (e.g., math task) and/or internal (e.g., thoughts on a upcoming math test) triggers (see Barroso et al., 2021; Cipora et al., 2022; Dowker et al., 2016; Mammarella et al., 2019; Zhang et al., 2019, for reviews). However, when emotions are task relevant (e.g., categorization of emotional and non-emotional words into "emotionally positive or negative words") emotions may enhance crucial cognitive mechanisms used to accomplish the target cognitive task.

In addition to capturing participants' attention, emotions can influence participants' motivation to engage in executing the target task (Pekrun, 2006, 2019; Pekrun & Linnenbrink-Garcia, 2012). Also, as postulated by Pekrun's Cognitive Value Theory (CVT, Pekrun, 2006, 2019; Pekrun & Linnenbrink-Garcia, 2012), the influence of negative emotions on participants' motivation may differ for so-called "deactivating" and "activating" negative emotions. More specifically, deactivating negative emotions such as sadness (see Pekrun, 2019) or (math)anxiety (see Barroso et al., 2021; Cipora et al., 2022; Dowker et al., 2016; Mammarella et al., 2019, Zhang et al., 2019; for reviews) can decrease participants' motivation to engage in cognitive (math) tasks (Pekrun, 2006). Activating negative emotions (e.g., anger) on participants' motivation, however, can have two types of effects. On the one hand, activating negative emotions can lead to lower cognitive performance via decreasing motivation to engage in the target task (Pekrun & Linnenbrink-Garcia, 2012). On the other hand, the activating nature of activating negative emotions may induce motivation to more quickly disengage from negative emotions and engage to target cognitive task (Pekrun & Linnenbrink-Garcia, 2012). Moreover, also as assumed by the Cognitive Value Theory, perceived controllability of the outcome (subjective expectation of success or failure in accomplishing the target task) may contribute to the influence of negative emotions on participants' performance. For instance, anxiety may decrease motivation to spend efforts in processing the target task if a successful task solution is seen as hopeless but may increase motivation to devote efforts in processing the target task if a successful task solution can be expected (e.g., Pekrun & Linnenbrink-Garcia, 2012).

How Effects of Emotions on Arithmetic Performance Change With Aging

Previous studies outside arithmetic found that effects of negative emotions tend to be smaller in older than in younger adults (e.g., see Carstensen & DeLiema, 2018; Gurera & Isaacowitz, 2019, for reviews). Such smaller deleterious effects in older adults are often assumed to result from increased efficiency in emotion regulation with age during adulthood.

Experimental studies in arithmetic found that effects of negative emotional states on arithmetic processing tend to be larger in younger than in older adults (Lallement & Lemaire, 2021, 2023; Melani et al., 2024). For example, Lallement and Lemaire (2021) asked younger and older adults to solve simple addition problems (e.g., 8 + 4 = 13. True? False?) in one experiment or to find approximate products to complex multiplication problems (e.g., which estimate —3200 or 4500— is closer to the correct product of 42 x 84?), in another experiment. In both experiments, problems were superimposed on emotionally negative or neutral pictures. The authors found larger deleterious effects in younger than in older adults while solving both addition and multiplication problems (see Melani et al., 2024, for similar results with complex multiplication problems like 5 x 41 = 201). Such age differences in effects of emotions during arithmetic problem solving were not found by Lallement and Lemaire (2023) while younger and older adults had to verify simple addition problems (e.g., 8 + 4 = 13). As the authors tested both positive and negative emotions in their study, they proposed that age differences in how negative emotions influence arithmetic performance may be modulated by emotional contexts (i.e., they may differ when negative emotions are tested alone and when they are tested with positive emotions). This led us to test younger and older adults with only neutral and negative emotions to investigate age-related differences in how different negative emotions affect younger and older adults while they are verifying addition and multiplication problems.

The Current Study

To further our understanding of how negative emotions influence arithmetic, we asked in the present study (a) whether different types of negative emotional states have different effects on arithmetic performance, (b) whether effects of emotions differ when adults solve addition and multiplication problems, and (c) how effects of different negative emotions on arithmetic performance and their modulations by arithmetic operations change with age during adulthood. Younger and older adults had to verify series of one-digit addition and multiplication problems (e.g., 4 + 8 = 13. True? False? and 4 x 8 = 31. True? False?) that were superimposed on images of adult faces expressing different negative (angry, sad, disgust) or neutral emotions.

First, following previous theoretical and empirical work in children and adolescents carried out by Pekrun and collaborators (see CVT of Pekrun, 2006, 2019), we expected that deactivating negative emotions, such as sadness, lead participants to obtain poorer arithmetic performance, and that activating negative emotions, such as anger or disgust, can lead to heterogenous effects. More specifically, in line with the CVT model (see Pekrun, 2006, 2019), activating negative emotions can either increase or decrease arithmetic performance in adults depending on further conditions (e.g., exception of controllability of the task outcome). Recall that Liu et al. (2021) and Zhu et al. (2021) both found no effects of anger on adults' arithmetic performance. Therefore, we expected either no effects or smaller effects of anger on adults' arithmetic performance. Regarding disgust, given its activating characteristics and its value for species survival (e.g., Söylemez & Kapucu, 2024), we hypothesized that disgust would strongly influence arithmetic. The present study enabled us to determine if fear and disgust had comparable strong effects on arithmetic performance. Like fearful stimuli (e.g., Liu et al., 2021), disgust stimuli were hypothesized to strongly capture participants' attention and, as a consequence, to impair their arithmetic performance.

Second, we expected stronger effects on performance in addition than in multiplication problems. More specifically, following previous findings showing that addition problems are solved mostly by with procedural strategies and multiplication problems mostly by a retrieval strategy (e.g., Fayol & Thevenot, 2012; LeFevre et al., 1996; Mathieu, Epinat-Duclos, Léone, et al., 2018; Mathieu, Epinat-Duclos, Sigovan, et al., 2018; Mathieu et al., 2016; Metcalfe & Campbell, 2011; Roussel et al., 2002), larger effects of emotions were expected for the former than the latter. This was expected as procedural strategies are known to be more resource demanding (e.g., Ashcraft & Faust, 1994; Fioriti et al., 2025; Huber & Artemenko, 2021).

Given its deactivating nature, sadness was expected to have deleterious effects on adults' arithmetic performance in both addition and multiplication problems. Further, recall that Liu et al. (2021) and Zhu et al. (2021) found no effects of anger on arithmetic performance. Multiplication problems were tested in these two studies. However, effects of anger on addition problem-solving performance have never been tested. Thus, we tested whether effects of anger interact with arithmetic operations and are found while solving addition but not multiplication problems (or are stronger in the former than in the latter).

The last set of hypotheses tested here concerned how effects of different emotions on arithmetic performance change with age during adulthood. Following previous works on emotional aging (see Kunzmann et al., 2014, for a review), varying age differences were expected in effects of sadness and anger. Previous works showed smaller sensitivity of anger in older than in younger adults and either age invariance or age increased sensitivity to sadness. This led us to hypothesize that anger might affect older adults' arithmetic performance less than younger adults'. Also, we expected smaller or no age-related differences in effects of sadness on arithmetic performance. Finally, given comparable sensitivity of younger and older adults to disgust (e.g., Curtis et al., 2004; Sarsony, 2018; Scheibe & Blanchard-Fields, 2009; Söylemez & Kapucu, 2024), we hypothesized that both younger and older adults would be similarly influenced by disgust while solving arithmetic problems.

Method

Participants

We recruited 100 participants online on Prolific, one group with younger adults (*n* = 50; mean age = 28.2; 20-35 y.o.; female = 44%) and one group with older adults (*n* = 50; mean age = 69.1; 65-76 y. o.; female = 52%). Any registered person on Prolific who mentioned being an English native speaker was allowed to participate independently of their country of origin. Native English speakers from the United Kingdom (*n* = 76), the United States (*n* = 4), Ireland (*n* = 2), Ethopia (*n* = 1), Lebanon (*n* = 1), Lithuania (*n* = 1), Germany (*n* = 1), India (*n* = 1), Italy (*n* = 1), Nepal (*n* = 1), Netherlands (*n* = 1), New Zealand (*n* = 1), Nigeria (*n* = 7), Sri Lanka (*n* = 1) and Uganda (*n* = 1) took part in the experiment. The sample size was determined based on previous research on effects of emotions in arithmetic using two groups ANOVA (e.g., Fabre et al., 2023; Lallement & Lemaire, 2023, 2021; Melani et al., 2024). Specifically, these studies compared groups of younger and older adults each including between 29 and 54 participants and found an effect size ranging between .25 and 40. Using a-priori G*Power analyses (G*Power; Faul et al., 2007) with an alpha = .05 for two groups ANOVAs, fixed effects, main effects and interactions, we calculated our sample size based on these studies. Specifically, we used a η_p^2 = .40 for our study design involving two repeated factors (Problem Type and Emotion) and one between-participants factor (Age) and achieved 75% power with 102 participants (51 per group). Based on theoretical work of statistical power of 2 x 2 repeated measures ANOVA (e.g., Brysbaert, 2019), our experiment was able to detect a main effect of one variable with d = .40 using a total sample size of 27 and interaction effects with d = .40 using a total sample size of 110.

Material

Arithmetic Problems

Each participant solved 96 addition and 96 multiplication problems (see Table 1). Specifically, participants had to verify whether a proposed answer that was presented to each problem was correct or incorrect. Both the 96 addition problems and the 96 multiplication problems were based on the same individual pairs of one-digit numbers (e.g., 4 + 8 and 4 x 8). Each of the 12 individual pairs of one-digit numbers was presented in the standard form $a + b$ (e.g., 4 + 8; 4 x 8) as well as in its $b + a$ version (e.g., 8 + 4; 8 x 4) and was presented with its correct sum (e.g., 4 + 8 = 12) or product (e.g., 4 x 8 = 32), as well as with an incorrect sum (e.g., 8 + 4 = 11) or an incorrect product (e.g., 8 x 4 = 31). Proposed answers in false problems had a deviation of -/+1 units from correct answers. The number of +1 and -1 deviations was equal, so that sum of splits was 0, for each smaller and larger addition and multiplication problems (e.g., 3 + 4 = 11; 3 x 4 = 23).

Table 1

Set of Addition and Multiplication Problems

	Addition Problems		Multiplication Problems	
Operands	**True**	**False**	**True**	**False**
3 4	7	6	12	11
3 6	9	8	18	19
3 7	10	9	21	22
3 8	11	12	24	23
4 6	10	11	24	23
4 7	11	12	–	27/29
4 8	12	13	32	31
6 7	13	14	42	43
6 8	14	13	48	47
6 9	15	14	54	53
7 8	15	16	56	57
8 9	17	16	72	73

Following previous findings in arithmetic (see Campbell, 2014; Cohen Kadosh & Dowker, 2015; Gilmore et al., 2018, for overviews), no tie problems (e.g., 3 + 3 = 6; 3 x 3 = 9) were included and none of the operands were equal to 0, 1, 2, or 5. Specifically, such problems are usually solved by fact retrieval from long-term memory or easy rule-based calculation strategies (e.g., $N + 0 = N$, $N \times 1 = N$, $N \times 0 = 0$). Further, false results for addition problems did not include one of the operands as a unit or decade digit (e.g., 3 + 9 = 13) and false results for multiplication problems did not include operation-related products (e.g., 8 x 4 = 12).

Emotional Stimuli

One-hundred-four (96 for experimental trials, 8 for practice trials) images with facial expressions of emotion from the NimStim Data Set (Tottenham et al., 2009) were used in our study (see Table 1). Half the images in the experimental trials had a negative emotional facial expression (n = 48), and half had a neutral facial expression. Negative emotional facial expressions included expression of anger, disgust, or sadness. One third of images displayed angry faces (n = 16), one third expressed disgust (n = 16) and one third showed sadness (n = 16).

Half the true and false addition and multiplication problems (each n = 24) were presented with emotional faces including eight images of each type of emotion (angry, disgust, and sad). The other half the true and false problems were presented with neutral faces (n = 24).

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To match the 48 emotional facial images of the three different types of emotions (angry, disgust, sad) on valence and arousal, we first conducted an online-rating study. First, we selected 96 emotional faces, 32 each showing anger, disgust, and sadness from the NimStim Data Set (Tottenham et al., 2009). Then, we asked 50 adults online on Prolific to judge valence (from 1 = negative to 9 = neutral) and arousal (from 1 = low to 9 = high) of the selected images using 9-point scales. Following this, for each type of angry, disgust, and sad emotions, we selected 16 emotional faces so as to match the three emotion faces of interest (angry, disgust, sad) on mean valence and arousal. Sixteen of the emotional faces expressed anger (*mean* valence = 3.27; *SD* = 0.47, and *mean* arousal = 5.29; *SD* = 0.48), sixteen of the emotion faces images expressed disgust (*mean* valence = 3.09; *SD* = 0.48, and *mean* arousal = 5.65; *SD* = 0.73), and sixteen of the emotion faces images expressed sadness (*mean* valence = 3.01; *SD* = 0.52, and *mean* arousal = 5.18; *SD* = 0.63). Mean valence (F = 2.056, p = .143) and arousal (F = .930, p = .404) for angry, disgust and sad faces did not differ (see Table 2).

Table 2

Mean Valence and Arousal of Emotional Facial Expression Images for True and False Problems (SDs in Parentheses)

Emotions	True problems	False Problems	*Fs*
Valence			
Anger	3.31 (0.46)	3.31 (0.46)	0.040
Disgust	3.14 (0.63)	3.05 (0.24)	0.063
Sadness	3.05 (0.60)	2.90 (0.81)	0.083
Arousal			
Anger	5.25 (0.25)	5.29 (0.61)	0.015
Disgust	5.55 (1.08)	5.67 (0.76)	0.027
Sadness	5.17 (0.43)	5.61 (1.13)	2.76e-4

Note. All *F*s are nonsignificant.

These 96 images with neutral and emotional facial expressions were paired with both addition and multiplication problems, such that the same pairs of operands for addition and multiplication problems were seen by each participant with the same neutral or emotional facial expression. Thus, for example, the true addition problem 3 + 4 = 7 and true multiplication problem 3 x 8 = 12 were shown with the exact same face (expressing the same emotion). Eight additional images with facial expressions were selected from the NimStim dataset for training trials, two each with anger, disgust, sad, and neutral emotional expressions.

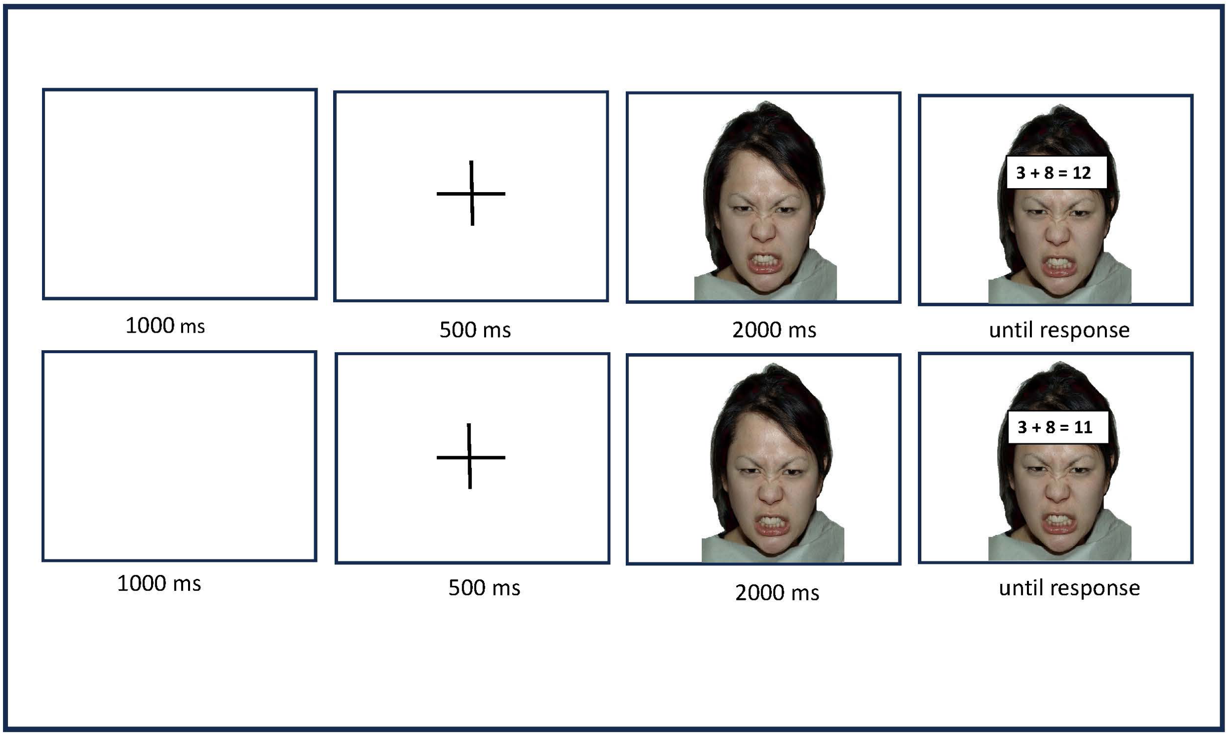
Procedure

The experiment was programmed with Gorilla Sc (Anwyl-Irvine et al., 2020) and carried out online on Prolific. Participants were told that they will see faces expressing different types of emotions (anger, disgust, sadness, or neutral emotions), and that they will complete an arithmetic problem verification task. Half the participants were told that they will first verify a series of addition equations (i.e., saying whether problems like 8 + 4 = 12 are true or false), and then a series of multiplication equations (i.e., saying whether problem like 8 x 4 = 32 are true or false). The other participants first verified multiplication problems and then addition problems.

Each experimental trial started with a 1000-ms blank screen followed by a 500-ms fixation cross in the center of the computer screen (see Figure 1), followed by a facial expression image (angry, disgusted, sad, or neutral) that was displayed for 2000 ms. Then, the arithmetic problem was displayed superimposed on the same facial expression image until participants' response. The problems appeared in the middle of forehead of the faces. Participants had to indicate if the proposed result is correct or not as quickly and as accurately as possible. We instructed half the participants to give answer by pressing the right L key on a keyboard if the proposed result was correct and the left S key if the proposed result was incorrect. The other half of the participants had to press the left S key for true problems and the right L key for false problems. The 96 problems were divided into two blocks of 48 problems each, matched on problem and image characteristics (e.g., mean valence and arousal values did not differ across blocks). Participants had a short break in-between the two blocks.

Figure 1

Illustration of the Procedure (Images Are Taken From NimStim; Tottenham et al., 2009)



Before the experiment starts in earnest, participants solved eight training (similar but different from experimental) addition problems prior to the experimental 96 addition problems and eight training multiplication problems prior to the experimental 96 multiplication problems. Six of these training problems were presented with an emotional face (two each with an angry, disgust, sad face) and two with a neutral face; half of these training problems were true problems and half were false problems. All problems for both arithmetic operation conditions were randomly presented to each participant.

Results

Mean response times and percent correct responses were analyzed with mixed-design ANOVAs including the following factors: 2 (Age: Younger adults, Older adults) × 2 (Arithmetic Operation: Addition, Multiplication) × 4 (Emotion: Anger, Disgust, Sadness, Neutral), with age as the only between-participants factor. Latencies larger than participant's *mean* + 2.5 *SD* were removed (2.7%). While the main effect of emotion ($F(3,255) = 9.916$, $p < .001$, $\eta_p^2 = .104$) was significant, the Emotion x Arithmetic Operation interaction was not significant ($F(3,255) = 2.140$, $p = .096$, $\eta_p^2 = .104$). However, contrast analyses showed that participants were slower under sad than under neutral conditions while solving either addition problems (3618 ms *vs.* 3470 ms; $t(508.91) = 3.82$; $p < .001$) or multiplication problems (3568 ms *vs.* 3488 ms; $t(508.91) = 2.19$; $p = .029$) (see Table 3 for means). Also, relative to neutral emotion condition, disgust led participants to slow down while solving multiplication problems (3588 ms *vs.* 3488 ms; $t(508.91) = 2.96$; $p = .003$), but not while solving addition problems (3509 ms vs. 3470ms; $t(508.91) = 1.12$; $p = .265$). Participants' latencies were comparable under neutral and anger emotions for both addition (3442 ms *vs.* 3470 ms; $t(508.91) = -0.54$; $p = .588$) and multiplication problems (3482 ms *vs.* 3488 ms; $t(508.91) = -0.14$; $p = .888$).

Table 3

Participants' Mean Response Times (in ms) and Percentages of Correct Responses (SDs in Parentheses) as a Function of Participants' Age Group (Younger, Older Adults), Arithmetic Operations (Addition, Multiplication), and Emotions (Anger, Disgust, Sadness, Neutral)

Problems	Anger	Disgust	Sadness	Neutral	*Means*	Anger – Neutral	Disgust-Neutral	Sadness – Neutral
Response Times (ms)								
All participants								
Addition	3442 (583)	3509 (682)	3618 (653)	3470 (598)	3510 (629)	-28	39	**148*****
Multiplication	3482 (857)	3588 (929)	3568 (921)	3488 (793)	3532 (875)	-6	**100****	**80***
Means	3462 (720)	3549 (806)	3593 (493)	3479 (696)	3521 (752)	-17	70	114
Younger adults								
Addition	3448 (705)	3584 (865)	3670 (774)	3510 (718)	3553 (767)	-62	74	**160****
Multiplication	3526 (980)	3609 (1014)	3575 (1026)	3596 (1007)	3576 (1007)	-70	13	-21
Means	3487 (843)	3597 (940)	3623 (900)	3553 (863)	3565 (887)	-66	44	70
Older adults								
Addition	3435 (427)	3432 (411)	3564 (499)	3429 (445)	3465 (446)	6	4	**135***
Multiplication	3285 (722)	3375 (845)	3377 (812)	3246 (484)	3486 (716)	57	**179*****	**178*****
Means	3360 (575)	3404 (628)	3471 (656)	3338 (465)	3476 (581)	22	66	133
Percentages of Correct Responses								
All participants								
Addition	91.6 (21.5)	90.0 (21.8)	90.5 (21.3)	90.7 (20.7)	90.7 (21.3)	.9	-.7	-.2
Multiplication	92.1 (17.8)	91.8 (17.5)	91.8 (17.8)	92.6 (17.1)	92.1 (17.6)	-.5	-.8	-.8
Means	91.9 (19.7)	90.9 (19.7)	91.2 (19.6)	91.7 (18.9)	91.4 (19.5)	.2	-.8	-.5
Younger adults								
Addition	92.1 (18.8)	90.3 (18.8)	90.3 (19.5)	90.9 (18.7)	90.9 (19)	1.2	-.6	-.6
Multiplication	88.6 (23.9)	86.9 (22.9)	88.6 (22.8)	89.2 (23.0)	88.3 (23.2)	-.6	**-2.3***	-.6
Means	90.4 (21.4)	88.6 (20.9)	89.5 (21.2)	90.1 (20.9)	89.7 (21.2)	.3	**-1.5***	-.6
Older adults								
Addition	91.0 (24.2)	89.7 (24.7)	90.7 (23.2)	90.5 (22.8)	90.5 (23.7)	-.5	-.8	.2
Multiplication	95.7 (5.7)	96.8 (6.0)	95.0 (9.8)	96.1 (5.6)	95.9 (6.8)	-.7	.7	-1.1
Means	93.4 (15.0)	93.3 (15.4)	92.9 (16.5)	93.3 (14.2)	93 (15)	.1	.0	-.4

The main effect of age, ($F(1,85) = 0.296$, $p = .588$, $\eta_p^2 = .003$) was not significant, but the Age x Arithmetic Operation x Emotion interactions ($F(3,255) = 2.947$, $p = .033$, $\eta_p^2 = .034$) was significant. Relative to neutral condition, sadness led younger adults to be slower while solving addition problems (3670 ms *vs.* 3510 ms; $t(257.92) = 3.17$; $p = .002$) but did not influence them while solving multiplication problems (3575 ms *vs.* 3596 ms; $t(257.92) = -0.54$; $p = .587$). Older adults were slower while solving addition (3564 ms *vs.* 3429 ms; $t(250.88) = 2.33$; $p = .021$) or multiplication problems (3377 ms *vs.* 3246 ms; $t(250.88) = 3.30$; $p < .001$) under sad compared to neutral condition. Also, older adults solved multiplication problems more slowly under disgust conditions than under neutral conditions (3375 ms *vs.* 3246 ms; $t(250.88) = 3.44$; $p < .001$). There was no effect of anger in younger and older adults for both addition problems (younger adults: 3448 ms *vs.* 3510 ms; $t(257.92) = -1.23$; $p = .214$; older adults: 3435 ms *vs.* 3429 ms; $t(250.88) = 0.33$; $p = .741$) and multiplication problems (younger adults: 3526 ms *vs.* 3596 ms; $t(257.92) = -1.71$; $p = .088$; older adults: 3285 ms *vs.* 3246 ms; $t(250.88) = 1.24$; $p = .216$).

Analyses of mean percent correct responses revealed neither significant main effects of emotion ($F(3,291) = 1.65$, $p = .177$; $\eta_p^2 = 3.720\times10^{-4}$) nor significant Arithmetic Operation x Emotion ($F(3,291) = 0.67$, $p = .573$; $\eta_p^2 = 1.927\times10^{-4}$) or Age x Emotion interaction ($F(3,291) = 1.27$, $p = .284$; $\eta_p^2 = .\ 2.862\times10^{-4}$). No other effects came out significant on latency or accuracy.

General Discussion

This study examined how varying negative emotions (anger, disgust, sadness) influence arithmetic performance while young and older adults are solving addition and multiplication problems. Participants had to verify series of one-digit addition and multiplication problems (e.g., 4 + 8 = 13. True? False? 4 x 8 = 31. True? False?). These problems were superimposed either on emotionally negative (anger, disgust, sadness) or neutral facial expressions. The main findings revealed that different negative emotions do not have the same effects on arithmetic performance. These emotional effects interacted with arithmetical operations (addition, multiplication) and participants' age. The present findings have important implications to further our understanding of how negative emotions influence arithmetic performance and how these influences change with aging.

How Negative Emotions Influence Arithmetic Performance

The present findings deepen our knowledge on deleterious effects of negative emotions. Previous studies found that negative emotions impair arithmetic performance. However, not all negative emotions influence arithmetic performance. We found that some negative emotions (sadness, disgust) had deleterious effects whereas anger did not influence adults' arithmetic performance. Moreover, and most interestingly, deleterious effects of negative emotions were not the same when participants solved addition and multiplication problems. Sadness influenced both addition and multiplication problems, whereas disgust affected only multiplication problems.

Following the CVT-Model (Pekrun 2006, 2019; Pekrun & Linnenbrink-Garcia, 2012), deactivating negative emotions such as sadness generally impair performance by undermining motivational engagement to perform the target task. The CVT and further proposals (Izard, 1993; Nabi, 1999; Weiner, 1985) agree that sadness leads generally to inaction, withdrawal, and/or decreased engagement in the target task processing. Our findings of deleterious effects of sadness on arithmetic performance are consistent with these proposals. Participants may have slowed down under sadness as a result of withdrawal or lowered engagement in the arithmetic problem-solving task quickly.

Interestingly, we found that disgust impaired adults' arithmetic performance only while solving multiplication problems but not while solving addition problems. This may be the result of addition and multiplication problems being solved via different strategies. Previous studies found that participants tend to use procedural strategies more often for addition problems and retrieval strategy more often for multiplication problems (e.g., Fayol & Thevenot, 2012; LeFevre et al., 1996; Metcalfe & Campbell, 2011; Roussel et al., 2002). It is possible that disgust influences participants' performance more while solving problems via a retrieval strategy relative to via a procedural strategy. The present study is limited in that we did not assess which strategy participants use on each trial. Future studies could test this possibility directly by comparing effects of disgust and other negative emotions while participants' strategies are assessed on a trial-by-trial basis (e.g., via verbal protocols) and/or while participants are instructed to use retrieval and non-retrieval strategies. In addition to further explaining how disgust influences addition and multiplication problem solving differently, such direct test would bring further evidence to previous findings that effects of emotions are mediating by strategic variations in younger and older adults (Lemaire, 2024). Moreover, it is even possible that the effect of negative emotions on (fact) retrieval processes and procedural processes generally differ, in arithmetic but also in many other math or cognitive tasks. Future studies could test this possibility in other domains or tasks, for example in episodic memory, attention, reasoning, decision making, or language processing.

Finally, we found no effects of anger on younger and older adults' performance while solving addition or multiplication problems. This replicates previous findings on multiplication problems (Liu et al., 2021; Zhu et al., 2021) and generalizes them to addition problems. Whether this lack of effects of anger is specific to our emotional stimuli (facial expressions of anger) or whether no effects of anger would also be found with other emotional induction procedures and/or stimuli as well as while participants accomplish other mathematical problem-solving tasks is to be tested before definitely concluding that anger as an emotional state does not influence arithmetic performance.

Age-Related Differences in Effects of Negative Emotions on Arithmetic Performance

Previous findings showed that negative emotions do not influence arithmetic performance to the same extent in younger and older adults, with stronger deleterious effects in younger than in older adults. Here, we found that negative emotions actually have sometimes different effects and sometimes similar effects in younger and older adults, and that such age differences or similarities depend on the type of arithmetic operation. More specifically, we found that sadness impaired older adults' performance while solving both addition and multiplication problems, whereas it influenced younger adults only while solving addition problems. Sadness had stronger effects in younger than in older adults while participants solved addition problems. We also found that disgust influenced older adults while solving multiplication (but not addition) problems and had no effects in younger adults.

That sadness influenced older adults' arithmetic problem-solving less than younger adults' was surprising as both age groups are usually found equally sensitive to sadness (Kunzmann et al., 2014). This suggests that the present smaller effects of sadness may not be the result of older adults' decreased sensitivity to sadness. One possibility is that increased automatization of procedural strategies for simple addition problems with aging (e.g., Chen & Campbell, 2018; Geary et al., 1993; Fayol & Thevenot, 2012; Thevenot et al., 2020; Uittenhove et al., 2016) led older adults to be less affected by sadness than younger adults while solving simple addition. This suggests that sadness may influence more not fully automatized procedural strategies. Similar results were found in a recent study comparing adults with higher and lower math anxiety (Fioriti et al., 2025). Repeated multiplication problems (a set of four three-digit x one-digit number problems (e.g., 189 x 4 = ?), that were repeated each 72 times) were designed to reflect retrieval learning and unrepeated multiplication problems (three-digit x one-digit number problems that were never repeated) to reflect procedural learning of arithmetic calculation. Fioriti et al. (2025) found that high-math anxious individuals were more impaired than low-math anxious individuals while solving problems with procedural strategies relative to problems solved with a retrieval strategy. This was explained by assuming that high math anxiety leads to decrease participants' motivation to spend extra effort in a math task (see also Choe et al., 2019; Jenifer et al., 2023). Procedural strategies are known to generally require more effort than retrieval strategies (e.g., Ashcraft & Faust, 1994; Fioriti et al., 2025; Huber & Artemenko, 2021). Finally, high math-anxiety is assumed to impair individuals' arithmetic performance particularly while they are solving tasks that require effortful, procedural strategies. Recall, that based on our findings we assumed that sadness would generally decrease participants' motivation to deploy effort in a target task. However, that these deleterious effects of sadness on addition problems were found to be larger in younger participants (who can be assumed to use procedural more often than retrieval strategies while solving addition problems) than for older participants (who can be assumed to use retrieval strategy more often than procedural strategies while solving addition problems) is in line with Fioriti et al. (2025)'s findings on math anxiety. Finally, we can speculate that the deleterious effects of sadness on participants' performance using procedural strategies results from a similar mechanism as the deleterious effects of math anxiety. This hypothesis can be tested in future studies by assessing precisely which strategies are used both younger and older adults under different negative emotions while solving addition problems.

Another interesting age differences found here concerns the fact that disgust and sadness influenced older (but not younger) adults while solving multiplication problems. Multiplication problems are known to be mostly solved by retrieval, especially in older adults (e.g., Geary et al., 1993; Roussel et al., 2002). One possibility is that disgust and sadness disrupts retrieval strategy used most often by older adults in multiplication problems. Such an effect was not seen in younger adults, possibly as a result of younger adults' using a mix of procedural (e.g., repeated additions) and retrieval strategies while solving multiplication problems. It can be speculated that disgust only impaired retrieval caused by the attention capture effect. Here again, assessing strategy used by each participant on each problem should help to determine if the type and frequencies of retrieval and non-retrieval strategies are key task components for effects of emotions to occur.

The present study includes several limitations. First, we tested only three negative emotions (anger, disgust, and sadness) and no positive emotions. A more exhaustive assessment of emotions would be useful to determine general characteristics of emotions that influence arithmetic performance and age-related differences in this influence. From a theoretical perspective, it would enable stronger tests of models like the CVT-model (Pekrun 2006, 2019; Pekrun & Linnenbrink-Garcia, 2012) that proposed to distinguish among different emotions on the basis of several characteristics such as their deactivating and activating nature. Second, how emotional states and emotional traits interact in arithmetic could not be documented in the present study, as we did not assess participants' emotionality characteristics. Determining how math anxiety, math enjoyment or boredom, as examples of individuals' characteristics, and experimentally induced emotional states would help determine how emotional states and traits interact while participants are solving arithmetic problems. Third, as already mentioned, by investigating how each emotion influences strategic aspects of arithmetic performance (including strategy repertoire, distribution, selection, and execution) and how age-related differences in effects of different emotions might be mediated by age-related differences in these strategic aspects. Finally, we only tested the effects of different negative emotions in arithmetic verification tasks but not in production tasks. Findings of negative emotion effects on participants performance while solving production problems would increase our understanding on how different negative emotions effect real life production set-ups such as work or school. However, our study was conducted in the domain of arithmetic. Previous research in arithmetic and particularly on the effects of emotions on arithmetic showed that findings are most often generalizable to different contexts. In two recent studies (e.g., Lemaire, 2024, 2025) negative emotion effects on arithmetic performance could be generalized from verification to production tasks in both adults and children. Future studies may expand on both Lemaire's studies (2024, 2025) and the present study by testing effects of different negative emotions on production tasks in arithmetic performance of both adults and children.

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Competing Interests: The authors declare that no competing interests exist.

Ethics Statement: This study was approved by the Aix-Marseille University Ethics Committee in France (Ref #: 2022-04-14-014).

Data Availability: The research data for this study is publicly available (see Viesel-Nordmeyer & Lemaire, 2025S).

Supplementary Materials

The Supplementary Materials contain the research data for this study (see Viesel-Nordmeyer & Lemaire, 2025S).

Index of Supplementary Materials

Viesel-Nordmeyer, N., & Lemaire, P. (2025S). *How different negative emotions affect young and older adults' arithmetic performance in addition and multiplication problems?* [Research data and codebook]. OSF. https://doi.org/10.17605/OSF.IO/MHJF2

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