Mental arithmetic performance, physiological reactivity and mathematics anxiety amongst U.K primary school children

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Abstract

A mixed experimental design was employed in which 77 U.K primary school children performed mental arithmetic problems of increasing difficulty. Psychophysiological measures of heart rate, systolic blood pressure (BP) and diastolic BP were taken along with behavioral measures of response time and error rate. Results demonstrated a significant effect of problem type, such that systolic BP increased significantly between baseline and presentation of three-digit mental arithmetic problems. Further to this, self-reported math anxiety was found to be significantly positively correlated with physiological reactivity to more difficult mental arithmetic. Findings suggest that mental arithmetic may act as a stressor among children in a similar way to adults and indicate that an increase in problem size may induce heightened blood pressure among children. Furthermore, results highlight the potentially negative psychological and physiological reactions that pupils experience, particularly among children who are math anxious.

Keywords: math anxiety; mental arithmetic; blood pressure; children

1. Introduction

Mathematics remains a core subject throughout primary and secondary education across the world and acquiring basic math skills is essential for success in both school and everyday life. There is a growing body of research that has furthered our understanding of anxiety towards math and, in recent years, empirical work has begun to explore the development of math anxiety.

Research has demonstrated that children as young as five to seven years in the U.S. experience anxiety towards math and this is negatively related to math performance (Ramirez, Gunderson, Levine & Beilock, 2013). In a study of 106 first grade children in the U.S., Harari, Vukovic & Bailey (2013) found math anxiety was significantly negatively correlated with computation skills, counting skills and math concepts. Further, math anxiety was significantly negatively correlated with attitude towards math. Similarly, in a qualitative study of four to seven year olds in the U.K., Petronzi, Staples, Sheffield and Fitton-Wilde (in prep.) identified polarised attitudes towards numeracy within this age group, with some children describing all aspects of numeracy negatively. Such findings may have important implications, for example in predicting children's future engagement with math. Indeed, research has highlighted a significant negative correlation between children's math anxiety and intention to take more math (Meece, Wigfield & Eccles, 1990; Hembree, 1990).

Research has also shown that, among seven to nine year-olds, math anxiety has a pronounced effect on performance in response to more demanding math problems and that this effect is unrelated to trait anxiety (Wu, Barth, Amin, Malcarne & Menon, 2012). These findings highlight the early stage at which math anxiety appears to be present, as well as the relationships with math performance. Interestingly, there is empirical evidence that demonstrates a relationship between math anxiety in children and increased activation in right amygdala regions (Young, Wu & Menon, 2012) thus highlighting a neurodevelopmental basis for math anxiety. This is particularly important given the role of those regions in processing negative stimuli (Maratos, Mogg, Bradley, Rippon & Senior, 2009).

It is an established protocol to incorporate mental arithmetic tasks, for example Paced Auditory Serial Addition Test (PASAT; Tombaugh, 2006), in the study of stress and related physiological reactivity in adults. For instance, Ushiyama *et al*. (1991) observed an increase in heart rate and diastolic and systolic blood pressure among healthy adults in response to performing mental arithmetic. Also, blood samples showed a significant increase in norepinephrine and epinephrine after initiation of the arithmetic test. Reims *et al*. (2004) also observed an increase in blood pressure among adults in response to a mental arithmetic test. In addition, they found poorer recovery following the test among those displaying high screening blood pressure; the authors emphasise the potential importance of this result in relation to delayed blood pressure recovery to mental stress predicting future blood pressure in young adult borderline hypertensives (Borghi, Costa, Boschi, Mussi, & Ambrosioni, 1986) and children (Matthews, Woodall, & Allen, 1993). Furthermore, mental task load has been shown to impact blood pressure, with blood pressure increasing as mental task load increases (Willemsen, Ring, McKeever & Carroll, 2000; Yoshino & Matsuoka, 2005).

Whilst it is clear that math anxiety exists amongst young children, the consequences are not fully understood. In particular, few studies have examined the relationship between anxiety and physiological reactivity in children (Dobkin, Treiber, & Tremblay, 2000) and, to date, no published study has measured young children's physiological reactivity to performing mental arithmetic of increasing difficulty in relation to math anxiety. In this study, it was hypothesised that physiological arousal, as measured by heart rate, and systolic and diastolic blood pressure, would increase as a function of problem difficulty. Moreover, it was predicted that self-reported math anxiety would be positively related to physiological reactions to mental arithmetic.

2. Method

2.1 Participants

Participants consisted of an opportunity sample of 77 (male, *n*=42 and female, *n*=35) children from a primary school in the Midlands, U.K. Children in two year groups were tested: year 5, consisting of children who were 9 or 10 years of age, and year 6, consisting of children who were 10 or 11 years of age.

2.2 Design

An experimental, mixed design was employed in which all participants completed two sets of mental arithmetic problems. Between-subjects factors were year group and gender. Response times and accuracy levels on the math problems were recorded along with measures of systolic blood pressure, diastolic blood pressure and heart rate recorded at three intervals: baseline, presentation of the two-digit mental arithmetic task, and presentation of the three-digit mental arithmetic task.

2.3 Materials

A Boso Medicus Prestige blood pressure (BP) monitor was used in order to enable participants' physiological reactivity to be measured whilst they were completing the mental arithmetic task.

To measure self-reported mathematics anxiety, the study employed a modified version of the Mathematics Anxiety Scale for children (MASC), developed by Chiu and Henry (1990). Consistent with the original version, the modified version of the MASC adopted a 4-point scale (1= not nervous, 2= little bit nervous, 3= very nervous and 4= very very nervous) and participants were required to decide how nervous they felt in certain scenarios related to the subject of mathematics. The scale consisted of 22 questions, for example how nervous they would be when "buying a new math textbook". However, some questions were changed in order for children being tested in the present study to fully understand and interpret them, for example, one question on the MASC asked children how nervous they would be in calculating the following math question: "If I spend $3.87 at the store how much change would I get from a $5 bill?". This question was altered to how nervous they would feel when working out a math question such as "If I spend £3.87 at the shop, how much change would I get from a £5 note?".

The mathematics task was created using Macromedia Authorware 6.5 (educational version) software and consisted of 40 (20 2-digit and 20 3-digit) problems presented as a verification task on a laptop computer; this provided sufficient data to measure arithmetic performance without the task becoming too onerous for the children involved. The selected problems are commensurate with the requirements for Key Stage 2 within the national curriculum in England (Department for Education, 2013). Problems were presented in size 72, black Arial style font. For 2-digit problems addends were randomly selected from a range of 10 to 89, ensuring the proposed solution remained lower than 100. Similarly, for 3-digit problems, addends were randomly selected, and reselected as necessary, to ensure the proposed solution remained below 1000. Problems that involved the addition of the same number were avoided. Inclusion of a carry term was roughly equal for 2-digit problems (40% carry, 60% no-carry) and equal for 3-digit problems (50% carry, 50% no-carry). In order to minimise strategies for responding to false problems, the level of split for proposed solutions varied from 2 to 10 and ranged from negative to positive.

2.4 Procedure

Following parental and participant consent, participants were tested individually in a quiet corner of their classroom. First, participants completed the modified MASC, followed by baseline measures of heart rate and blood pressure. A series of 20 2-digit problems and then 20 3-digit problems were presented, individually, in a random order in the centre of the screen.

Following brief verbal instructions of what was required in order to complete the task, on-screen instructions consisted of: “if the sum is correct, click on the button with a tick. If the sum is not correct, click on the button with a cross”. Subsequently, the math problems were presented. Below each problem tick and cross symbols were displayed, representing correct and incorrect solutions, respectively.

After they had completed the task the BP monitor cuff was carefully removed from the arm of the participant and they were then asked whether they had any questions about the study and whether they enjoyed participating. Children were verbally debriefed and a copy of the parent/carer debrief form was given to each child to take home to their caregivers. Finally, each child received a sticker and was thanked for participating.

3. Results

Previous research has demonstrated differing neurophysiological responses as a function of incorrect versus correct solutions in arithmetic verification tasks (e.g. Jost, Hennighausen & Rosler, 2004b) and others have found math anxiety effects on performance as a function of level of split in the proposed solution (Faust, Ashcraft & Fleck, 1996). As such, only data relating to problems with correctly proposed solutions were analysed. Response time data were analysed using a 2 (year group) x 2 (gender) x 2 (problem type) mixed ANOVA. There was no significant main effect of year group, $F(1, 73) = 0.43$, $p = .51$, $\eta^2 = .004$, and no significant main effect of gender, $F(1, 73) = 1.10$, $p = .30$, $\eta^2 = .01$. However, there was a significant main effect of problem type, $F(1, 73) = 14.39$, $p < .001$, $\eta^2 = .05$, whereby children took longer to respond to three-digit problems (M = 11.67s, SD = 4.90s) than two-digit problems (M = 9.71s, SD = 3.65s). There were no significant interactions between the independent variables. Adding math anxiety as a covariate eliminated the main effect of problem type ($p = .21$). Follow-up analysis showed no significant correlation between math anxiety and response time to 2-digit problems (r (75) = .21, $p = .07$), but math anxiety was significantly positively correlated with response time to 3-digit problems (r (75) = .48, $p <$ .001).

Following this, the proportion of correct responses was analysed. There was no significant main effect of year group, $F(1, 73) = 2.57$, $p = .11$, $\eta^2 = .02$, and no significant main effect of gender, $F(1, 73) = 0.05$, $p = .82$, $\eta^2 < .001$. However, there was a significant main effect of problem type, $F(1, 73) = 140.04$, $p < .001$, $\eta^2 = .30$, whereby children gave a greater proportion of correct responses to two-digit problems (89.61, SD = 12.08) than three-digit problems (M = 74.03, SD = 11.98). No significant interactions were observed. Adding math anxiety as a covariate had no impact on the observed effects.

After establishing an effect of problem type on arithmetic performance, but no effect of gender or year group, a series of one-way repeated measures ANOVAs were then conducted to test heart rate, systolic BP and diastolic BP across the three stages of the task: baseline, presentation of two-digit problems, and presentation of three-digit problems. The sphericity assumption was not met so all results are based on a Greenhouse-Geisser adjustment. There was a significant effect of stage of task on heart rate, $F(1.54, 117.15) = 3.76$, $p = .04$, $\eta^2 = .01$. Also, systolic BP significantly differed between the stages of the task, $F(1.69, 128.64) = 4.29$, $p = .02$, $\eta^2 = .01$. Further, results demonstrated a significant effect of task stage on diastolic BP, $F(1.38, 104.76) = 13.48$, $p < .001$, $\eta^2 = .05$.

Subsequently, planned comparisons were conducted using repeated measures t-tests for each physiological measure. To reduce the risk of a type I error, alpha was adjusted to .025. Heart rate decreased significantly between baseline and presentation of two-digit problems, $t(76) = 3.18$, $p < .01$, $d = 0.18$, but did not change significantly between baseline and presentation of three-digit problems, $t(76) = 1.67$, $p = .10$, $d = 0.14$. No significant difference in systolic BP was observed between baseline and presentation of two-digit problems, $t(76) = .05$, $p = .96$, $d = 0.003$ but a significant increase was found between baseline and presentation of three-digit problems, $t(76) = 2.35$, $p = .02$, $d = 0.23$. Similarly, there was no significant difference in diastolic BP between baseline and presentation of two-digit problems, $t(76) = 1.86$, $p = .07$, $d = 0.11$, but diastolic BP significantly increased from baseline to presentation of three-digit problems, $t(76) = 4.05$, $p < .001$, $d = 0.51$. See Table 1 for means and standard deviations.

		Baseline	2-digit problems	3-digit problems
Measure	Heart rate	92.00 (15.63)	89.18 (13.17)	89.75 (12.97)
	SysBP	105.51 (16.82)	105.56 (17.29)	109.36 (17.01)
	DiaBP	72.26 (16.98)	74.19 (14.21)	80.87 (17.00)

Table 1. Means (and SDs) of heart rate, sysBP and diaBP as a function of problem type

Reactivity scores were calculated for heart rate, systolic BP and diastolic BP between baseline and presentation of two-digit problems and between baseline and presentation of three-digit problems. These were then correlated with math anxiety. No significant correlations were observed between math anxiety and baseline-two-digit change in heart rate, $r = .01$, $p = .45$, and baseline-three-digit change in heart rate, $r = .05$, $p = .34$. However, significant positive correlations were found between math anxiety and baseline-two-digit change in systolic BP, $r = .20$, $p = .04$, and baseline-three-digit change in systolic BP, $r = .24$, $p = .02$. No significant correlations were observed between math anxiety and baseline-two-digit change in diastolic BP, $r = .11$, $p = .18$, and baseline-three-digit change in diastolic BP, $r = .14$, $p = .12$.

4. Discussion

The current study assessed children's physiological reactivity to arithmetic problems that increased in difficulty. Performance analyses validated problem difficulty; three-digit addition problems were responded to more slowly and with more errors than two-digit problems. In particular, math anxiety was related to longer response times on 3-digit problems. Also, as predicted, problem difficulty affected physiological responses, such that systolic blood pressure and diastolic blood pressure increased statistically significantly between baseline and presentation of three-digit problems. Furthermore, as predicted, physiological reactivity was shown to correlate with self-reported math anxiety: changes in systolic blood pressure between baseline and presentation of arithmetic problems were positively related to math anxiety.

The heightened physiological response to mental arithmetic seen in the present study is consistent with previous research findings (Ushiyama *et al*., 1991; Reims *et al*., 2004; Willemsen *et al*., 2000) and suggests that mental arithmetic may act as a stressor among children in a similar way to adults. Much previous work into math anxiety effects has focused on the role of carry terms and the impact they have on working memory processes, in particular the negative relationship often observed between math anxiety and performance (e.g. Faust, Ashcraft & Fleck, 1996). In the present study, half of the 3-digit problems included a carry term. The total number of problems needed to remain quite low to ensure the task was not too taxing given the age group studied. As such, analysis as a function of whether a carry term was included would not be meaningful. Our findings indicate that an increase in problem size may induce heightened blood pressure among children, although further research is required that assesses the impact of carry operations in the context of psychophysiological reactivity and math anxiety.

The non-statutory guidance for Key Stage Two within the national curriculum (Department for Education, 2013) refers to the practising of mental calculations with increasingly large numbers to aid fluency. The example provided includes four- and five-digit problems, yet the three-digit problems presented in the current study were sufficient to induce a statistically significant increase in physiological activity. Thus, the findings indicate that standard mental arithmetic, even outside of a typical classroom testing context, might be a stressful experience for some children. Furthermore, pupils who are math anxious are more likely to experience heightened physiological reactivity to more difficult mental arithmetic, suggesting greater awareness is needed of the individual, affective differences that influence the way children react to mental arithmetic. These findings accord with the stress responses to mental arithmetic observed in adults (Ushiyama *et al*., 1991, Reims, 2004). The increases observed were sufficiently large to elevate BP levels to those expected in children (mean diaBP = 80.7). We did not assess how long BP levels were elevated, but even brief task-related physiological reactivity has been prospectively related to higher resting blood pressure several years later in children (Matthews et al., 1993). Future studies could examine if the BP elevations in relation to math anxiety observed in the current study provide prognostic information about the development of hypertension (Light et al., 1999; Everson et al., 1997; Lynch, Everson, Kaplan, Salonen & Salonen, 1998).

One way that children may cope with stress and the feelings of anxiety associated with math is to avoid it (Hembree, 1990). However, math anxiety is mutable and so interventions should target how children cope in situations involving math that are perceived as stressful, particularly test situations.

The findings from the current study need to be considered in light of the cross-sectional experimental nature of the design. Similarly, future work should ideally include a random sample of children from a wider pool in naturalistic conditions, for example during school tests. Also, the need to develop mathematical resilience in children should be noted; math anxiety may be an antecedent to such resilience (Kooken, Welsh, McCoach, Johnston-Wilder & Lee, 2015). Nevertheless, the results of the present study provide useful insight into how children respond to mental arithmetic within the classroom and highlight the potentially negative psychological and physiological reactions that pupils experience.

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