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Working memory, worry, and algebraic ability

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ABSTRACT

Math anxiety (MA)–working memory (WM) relationships have typically been examined in the context of arithmetic problem solving, and little research has examined the relationship in other math domains (e.g., algebra). Moreover, researchers have tended to examine MA/worry separate from math problem solving activities and have used general WM tasks rather than domain-relevant WM measures. Furthermore, it seems to have been assumed that MA affects all areas of math. It is possible, however, that MA is restricted to particular math domains. To examine these issues, the current research assessed claims about the impact on algebraic problem solving of differences in WM and algebraic worry. A sample of 80 14-year-old female students completed algebraic worry, algebraic WM, algebraic problem solving, nonverbal IQ, and general math ability tasks. Latent profile analysis of worry and WM measures identified four performance profiles (subgroups) that differed in worry level and WM capacity. Consistent with expectations, subgroup membership was associated with algebraic problem solving performance: high WM/low worry > moderate WM/low worry = moderate WM/high worry > low WM/high worry. Findings are discussed in terms of the conceptual relationship between emotion and cognition in mathematics and implications for the MA–WM–performance relationship.

Introduction

Interest in the impact of emotional states on learning and cognition has a long history in developmental psychology (Fletcher, 1934; Mandler & Sarason, 1952). A widely held view is that emotional states (e.g., anxiety) are relatively stable within a learning domain (e.g., math) and affect problem

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solving similarly across the domain (i.e., emotion is a trait) (see Pnevmatikos & Trikkaliotis, 2013). In the context of math problem solving specifically, it has also been argued that math anxiety (MA) affects working memory (WM), which together affect math problem solving (Ashcraft & Krause, 2007). Nonetheless, others suggest that emotional states (anxiety), cognition, and learning relationships may differ within and across learning domains (i.e., emotion is a state) (Pnevmatikos & Trikkaliotis, 2013; Punaro & Reeve, 2012;). One difficulty in deciding between state/trait interpretations, as well as MA/WM relationships, in math is that previous relevant research has focused on arithmetic problem solving (Ashcraft & Faust, 1994; Friso-van den Bos, van der Ven, Kroesbergen, & van Luit, 2013; Miller & Bichsel, 2004; Raghubar, Barnes, & Hecht, 2010). It is possible that MA/WM problem solving relationships may differ as a function of math domain (e.g., algebra). In the current study, we investigated the relationships among 14-year-olds' algebraic anxiety/worry, algebraic WM, and algebraic problem solving abilities.

Although algebra is often considered as the generalization of arithmetic, it is also different from arithmetic cognitively. Algebra involves working with unknown values and requires a structural, rather than a procedural, understanding of mathematical expressions (Alibali, Knuth, Hattikudur, McNeil, & Stephens, 2007; Christou & Vosniadou, 2012; Humberstone & Reeve, 2008; Kieran, 1992; Knuth, Stephens, McNeil, & Alibali, 2006). The absence of research examining the relationship between WM and MA in algebra is problematic for at least three reasons. First, claims for a link between MA and problem solving may have been overstated (i.e., claims may be restricted to arithmetic). Second, we have little understanding of how anxiety and/or cognitive factors interact to affect problem solving in complex/abstract mathematical domains. Third, from an applied perspective, algebra is typically introduced early in high school, and failure to grasp its intricacies may be a stumbling block to the acquisition of higher level math (Alibali et al., 2007; Stacey & MacGregor, 1999).

Math anxiety

Some studies that have examined the MA–arithmetic association found that individuals with high MA are less accurate and slower at solving problems compared with students with low MA (Ashcraft & Faust, 1994; Ashcraft & Kirk, 2001; Faust, Ashcraft, & Fleck, 1996), whereas other studies found no difference in problem solving accuracy between high and low MA groups (Cates & Rhymer, 2003). However, findings are difficult to reconcile because these studies used different MA and arithmetic problem solving measures. For example, Ashcraft and Faust (1994) used a true/false verification of addition, multiplication, and mixed arithmetic problems, Ashcraft and Kirk (2001) used solving addition problems within a dual task paradigm, and Cates and Rhymer (2003) required participants to solve complex arithmetic and simple algebraic equations. Indeed, the findings of Cates and Rhymer suggest that MA might not impair advanced mathematics problem solving. Moreover, Wu, Barth, Amin, Malcarne, and Menon (2012) examined math performance on a standardized general abilities test and found that MA has a pronounced effect on math reasoning but not on arithmetic computation subtasks. In sum, research suggests that MA may impair simple arithmetic performance; however, the relationship between MA and more advanced mathematics is unclear.

Nearly all indexes of MA are based on responses to questions about anxiety experienced solving math problems (e.g., "How stressed do you feel solving math problems?"; see Capraro, Capraro, & Henson, 2001) rather than the anxiety that occurs *while* solving math problems. The interpretation of questionnaire responses may be problematic for at least five reasons. First, assessing general perceptions of competence is open to influences (e.g., self-concept, gender stereotypes; see Bull, Espy, & Wiebe, 2008; Monti, Parsons, & Osherson, 2012). Second, commonly used MA measures (e.g., Mathematics Anxiety Rating Scale; Richardson & Suinn, 1972) assess math *test* anxiety and not MA per se. Third, items on MA scales focus on arithmetic referents and do not refer to more complex mathematical problems (e.g., algebraic problems) (Capraro et al., 2001). Fourth, few studies assess cognitive factors (e.g., memory, attention) that might affect self-reports. Fifth, MA questionnaires tend to tacitly assume that MA is an enduring anxiety (trait) rather than an anxiety state experienced solving particular problems. These limitations suggest that retrospective and global self-report measures should be interpreted with caution and that more proximal indexes of anxiety would be desirable (i.e., assessing anxiety while solving problems).

Attentional control theory

The claim that MA negatively affects problem solving is partially consistent with attentional control theory (ACT) proposed by Eysenck and colleagues (Eysenck & Calvo, 1992; Eysenck & Derakshan, 2011; Eysenck, Derakshan, Santos, & Calvo, 2007). ACT focuses on the effects of state anxiety and worry. Worry has traditionally been identified as the cognitive component of anxiety and is thought to be the aspect of anxiety that affects WM and performance (Deffenbacher, 1980; Eysenck & Calvo, 1992; Hayes, Hirsch, & Mathews, 2008; Liebert & Morris, 1967). In ACT, it is proposed that worry reduces WM capacity, which in turn negatively affects problem solving ability (Eysenck & Calvo, 1992; Eysenck & Derakshan, 2011; Eysenck et al., 2007). Worry is also claimed to have a facilitative effect (sometimes referred to as a motivation or arousal effect), resulting in more effortful processing that limits the impairment effect of worry and may increase performance effectiveness (Eysenck & Calvo, 1992; Eysenck & Derakshan, 2011; Eysenck et al., 2007). The inhibitory and facilitative effects of worry suggest a U-shaped function in performance. ACT also suggests that when WM capacity is reduced by task demands, the negative effects of anxiety on performance increase. In other words, worry, WM, and task demands interact to affect problem solving ability.

However, findings in support of ACT are mixed (Ashcraft & Kirk, 2001; Hoffman, 2010; Hopko, Ashcraft, Gute, Ruggiero, & Lewis, 1998; Miller & Bichsel, 2004). Mattarella-Micke, Mateo, Kozak, Foster, and Beilock (2011), for example, found that only high WM individuals, compared with those with low WM, are affected by MA. Miller and Bichsel (2004), in contrast, found that problem solving accuracy (assessed by math subtasks of the Woodcock–Johnson III Tests of Achievement) had a negative relationship with MA. In a second analysis, they found that problem solving accuracy was associated with high WM (compared with low WM), but this was examined only in high MA individuals. In contrast, Owens, Stevenson, Hadwin, and Norgate (2014) found that the effects of trait anxiety on performance of a combined math and general reasoning measure differed depending on WM capacity. High trait anxiety was associated with (a) impaired reasoning performance for low WM individuals, (b) no effect for moderate WM individuals, and (c) improved performance for high WM individuals (Owens et al., 2014). Differences in findings may be due to variation in the WM tests used in the studies; Miller and Bichsel (2004) assessed verbal and visual WM using language and paper folding tasks, Hoffman (2010) measured WM with an operation span task that involved a mathematical equation component (Turner & Engle, 1989; Unsworth & Engle, 2005), and Owens and colleagues (2014) used a battery of WM tests.

Math and working memory

Although WM is hypothesized to affect all aspects of math problem solving (LeFevre, DeStefano, Coleman, & Shanahan, 2005), there is disagreement about how to define and/or assess WM (Libertus, Brannon, & Pelphrey, 2009). It has been argued that the concept of WM in math research needs to be better defined (Hicks, Von Baeyer, Spafford, Van Korlaar, & Goodenough, 2001; Raghubar et al., 2010). WM in math research is hypothesized to comprise visual–spatial and verbal components and a domain-general central executive component (Andersson & Lyxell, 2007; Gathercole, Pickering, Ambridge, & Wearing, 2004; Holmes & Adams, 2006; Imbo & Vandierendonck, 2007; Swanson, 2006; Wilson & Swanson, 2001; Zheng, Swanson, & Marcoulides, 2011). However, evidence suggests that WM may include more domain-specific abilities (Knops, Nuerk, Fimm, Vohn, & Willmes, 2006; Libertus et al., 2009). Indeed, Libertus and colleagues (2009), Oberauer, Süß, Schulze, Wilhelm, and Wittmann (2000), and Zheng and colleagues (2011) have all proposed that WM may have number/math-specific components. These domain-specific components may be less evident in children but appear in adolescents and adults (Libertus et al., 2009), suggesting possible age-related changes in domain-specific WM.

Raghubar and colleagues (2010) suggested that WM resources in math reasoning depend on several factors. First, the math domain itself may affect WM; standardized math tasks (e.g., the Applied Problems subtest from the Woodcock-Johnson III Tests of Achievement) often cover a broad range of math skills to assess mathematical cognition but are likely to be too general to assess math–WM relationships (Raghubar et al., 2010). Second, the strategies used to solve math problems may also affect WM because they place different demands on WM. For example, counting and performing operations in complex addition are more WM dependent than tasks such as multiplication, which involves recall from long-term memory (De Rammelaere, Stuyven, & Vandierendonck, 1999; Imbo & Vandierendonck, 2007; Raghubar et al., 2010). Third, individuals' skill level in a math domain may affect WM. For example, arithmetic is associated with visual–spatial WM in young children but tends to be associated with verbal WM in adolescents and adults. Raghubar and colleagues (2010) suggested that the acquisition of new math skills may depend on visual–spatial WM initially but become dependent on verbal WM with the acquisition of expertise.

Algebra

Compared with arithmetic, algebraic competence depends more on abstract reasoning and is thought to reflect formal reasoning ability (Piaget & Inhelder, 1969; Tolar, Lederberg, & Fletcher, 2009). Arithmetic problem solving largely involves numerical operations; algebra, by contrast, is an abstract structural representation of numerical relations that partly builds on arithmetic principles (Knops et al., 2006; Tolar et al., 2009).

The concept of equivalence differs in algebra and arithmetic—a possible reason for the negative transfer between arithmetic and algebra (Humberstone & Reeve, 2008; Jones, Inglis, Gilmore, & Dowens, 2012; McNeil & Alibali, 2005; McNeil, Rittle-Johnson, Hattikudur, & Petersen, 2010). Studies of algebra have identified difficulties with the equivalence sign, symbolized as "=", as a major stumbling block in the acquisition of algebra (Alibali et al., 2007; Kuchemann, 1981). There are two interpretations of the meaning of the equivalence sign; one is *operational* and the other is *relational* (Alibali et al., 2007; Kieran, 1981). An operational view of the equivalence sign indicates the answer or the end of the problem (Humberstone & Reeve, 2008; Kieran, 1981; Kuchemann, 1981; McNeil & Alibali, 2005). In relational understanding, the sign suggests that the left side of the problem is equivalent to the right side (Humberstone & Reeve, 2008; Kieran, 1981; Kuchemann, 1981). Students with an operational understanding tend to read equations from left to right, which is less sophisticated and is similar to arithmetic processing (Humberstone & Reeve, 2008; Kuchemann, 1981; McNeil & Alibali, 2005). Conversely, the relational understanding of equivalence is recognized as more advanced algebraic thinking (Kieran, 1981; Kuchemann, 1981). Students' algebraic ability can be assessed using these properties of the equivalence sign. Equations that have properties that favor an operational or relational view would be recognized as "easy" or "hard" algebraic equations, respectively.

The current study

The current study examined the role of WM and worry in algebraic problem solving. A sample of 14-year-old female students completed algebraic judgment/worry, algebra problem solving, and algebraic WM tasks. MA appears to be uniformly higher in females than in males (see Kargar, Tarmizi, & Bayat, 2010; Ma, 1999; Ma & Xu, 2004). Indeed, Devine, Fawcett, Szűcs, and Dowker (2012) found that after controlling for test anxiety, the association between MA and math performance disappears for males but not for females.

In an algebraic judgment/worry task, students made same/different judgments about pairs of algebraic problems that differed from each other in their equation form, after which they rated how *worried* they felt while making judgments. In the algebraic problem solving task, students mentally solved algebraic problems that varied in difficulty. To avoid issues associated with domain-relevant math–WM relationships, an algebraic span task assessed algebraic WM. Basic reaction time (RT), nonverbal IQ (Raven's matrices), and standardized math ability (Woodcock–Johnson III Tests of Achievement) were also assessed. Several studies have found that RT is related to arithmetic abilities (Bull & Johnston, 1997; Floyd, Evans, & McGrew, 2003; Kail, 2007). In addition, general intelligence has been found to be associated with math performance (Rohde & Thompson, 2007) as well as with working memory span (Conway, Kane, & Engle, 2003).

We used latent profile analysis to identify different worry–WM subgroups to examine claims from ACT. We were interested in how algebraic problem solving performance differed among identified groups to assess the relationships among worry, WM, and algebra performance. We anticipated that we would identify four subgroups (high/low WM $\times$ high/low worry) using latent profile analysis. We hypothesized that the WM–worry profiles would predict algebraic problem solving accuracy. According to ACT, the effect of worry on performance varies depending on WM capacity, so we expected that low WM with high worry would be associated with low/poor algebraic performance compared with profiles characterized by low WM with low worry. High WM profiles, with low or high worry, were predicted to be associated with high algebraic performance. Finally, we hypothesized that these worry–WM profiles would predict algebraic performance even after we statistically controlled for processing speed, nonverbal IQ, and general math performance.

Method

Participants

A sample of 80 female students (mean age = 14 years 7 months, *SD* = 8 months) attending girls' schools in a large Australian city participated. The sample consisted of students from diverse multicultural and socioeconomic backgrounds, as is typical of Australian urban high schools. According to school personnel, none of the students had identified learning difficulties, and all had normal or corrected-to-normal vision. Participants were excluded from analyses if they performed below chance accuracy on the WM task (3 of 80). The research was approved by, and conducted in accordance with the requirements of, the human research ethics committee of the authors' university. Approximately 70% of students invited to participate in the research agreed to do so.

Materials and procedure

Students completed algebraic problem solving, algebraic judgment worry, and algebraic WM tasks. They also completed the Raven's Standard Progressive Matrices (Raven, Raven, & Court, 1998), mathematical computation and problem solving tests from the Woodcock–Johnson III Tests of Achievement, and a basic RT test. Tasks were completed on 2 successive days. The three algebraic tasks were completed in a randomized order on Day 1 and took approximately 30 min to complete; the remaining tasks were completed on Day 2 and took approximately 40 min to complete. With the exception of the Raven's matrices and the Woodcock–Johnson tests, tasks were presented on a 15-inch laptop computer running E-Prime software (Version 2.0).

The *algebra problem solving task* assessed students' algebraic problem solving ability. Students were presented with linear algebra equations that they solve mentally (i.e., without using pencil/pen and paper to help work out solutions) (see Fig. 1 for example problems). Students were instructed as follows: "In a moment, you will see a series of algebraic equations appear on-screen. As fast and as accurately as you can, solve the equations. Type your answer, and then press Enter." The task consisted of eight easy and eight hard equations presented in random order. Problems were presented one at a time. Easy equations comprised three-term problems with a variable, a coefficient, and a constant on the left side of the equivalence sign and a constant on the right side (e.g., $mx + c_1 = c_2$). Hard equations comprised four-term problems with a variable, a coefficient, and a constant on the left and right sides of the equivalence sign (e.g., $m_1x + c_1 = m_2x + c_2$) (Alibali et al., 2007; Humberstone & Reeve, 2008; Knuth et al., 2006). Solutions ranged between −9 and +12. The time taken to type answers and answer correctness were recorded.

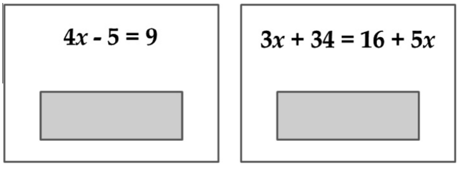

Fig. 1. Schematic of the algebraic problem solving task for easy and hard items.

The *algebraic worry task* assessed worry associated with judging the correctness of pairs of algebraic problems. Students were shown pairs of algebra equations of the form $mx + c_1 = c_2$ (see Table 1 and Fig. 2 for example problems) and judged whether the value of the variable in the two equations had the same value (equivalent equations) or different values (nonequivalent equations) by pressing either the left or right control key on the computer keyboard. Although students were encouraged to make judgments as quickly as possible, equations remained on the screen for 15 s. Immediately after each judgment, the Faces Anxiety Scale (Bieri, Reeve, Champion, Addicoat, & Ziegler, 1990; Punaro & Reeve, 2012) appeared on the screen and students rated their worry about the correctness of their answers. The Faces Anxiety Scale consisted of six faces depicting increasing worry (neutral to extremely worried) (see Fig. 2). The scale is widely used to examine anxiety/worry and has previously been used to examine math worries in school children (Howard & Freeman, 2007; Punaro & Reeve, 2012).

The algebraic worry task consisted of eight easy and eight difficult equation pairs, half of which were equivalent equations and half of which were nonequivalent equations. Easy problems comprised equation pairs in which only one operation was required to determine equivalence; difficult problems required two operations (see Fig. 2 for example problems). To introduce the algebraic worry task, students completed three practice trials in which procedural requirements were described. Stimulus presentation times were based on pilot work showing that approximately 80% of students could complete easy judgments within 15 s, but only 55% of students could complete difficult judgments within 15 s. Judgment accuracy, response times, and worry ratings were recorded.

The *algebra WM task* was based on Turner and Engle's (1989) operation span task and was modified to use algebraic stimuli. Participants needed to both solve algebraic problems and remember algebraic terms (see Fig. 3). The algebraic problem solving component required students to decide whether the answer to a simple equation was correct or incorrect (e.g., $3y + 2 = 20$; $y = 2$) by pressing a key on the computer keyboard. Participants were given 15 s to respond. Following judgments, an algebraic term (e.g., $4x$) appeared on the screen for 1600 ms. After three, four, or five problem solving–algebraic term trials, participants attempted to recall the algebraic terms that had appeared on the screen by typing their answers. Students completed two blocks of three, four, or five span trials in which the different span sizes were presented in a random order. Of interest was algebraic problem solving correctness and span. Following Turner and Engle, span was determined by the highest span correct across the two blocks.

Students completed the Calculations and Applied Problems subtests from the Woodcock–Johnson III Tests of Achievement; these are formal tests of math computation and problem solving ability. The subtests were administered and scored according to test requirements. The task was included to determine the general validity of the algebraic problem solving task (which would be demonstrated by a significant correlation between the two tasks).

The Raven's Standard Progressive Matrices test (De Lemos & Raven, 1989; Raven et al., 1998) is a standardized measure of nonverbal reasoning ability and was administered and scored according to the Raven's matrices test protocol.

The basic RT test consisted of 36 trials. A black orienting cross appeared in the center of the screen, after which either a red or blue dot appeared (500, 1000, or 1500 ms after the black cross). Participants were instructed to press a computer key as quickly as possible only if a red dot appeared.

Rationale for data analysis

Groups are often formed by dichotomizing continuous MA measures by a median split (Cates & Rhymer, 2003), quartiles (Ashcraft & Faust, 1994; Faust et al., 1996), or extreme groups design

Table 1
Example stimuli used in the algebraic judgment task.

	Equivalent	Nonequivalent
Easy	$x + 4 = 7$	$x + 2 = 14$
	$2x + 8 = 14$	$4x + 8 = 14$
Hard	$3x - 6 = 12$	$2x + 2 = 16$
	$8x - 16 = 32$	$6x + 8 = 56$

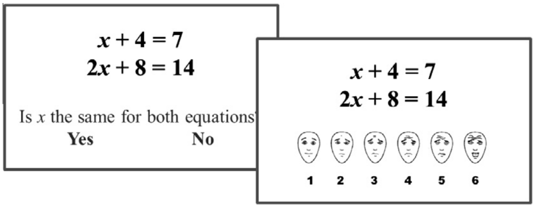

Fig. 2. The algebraic judgment task.

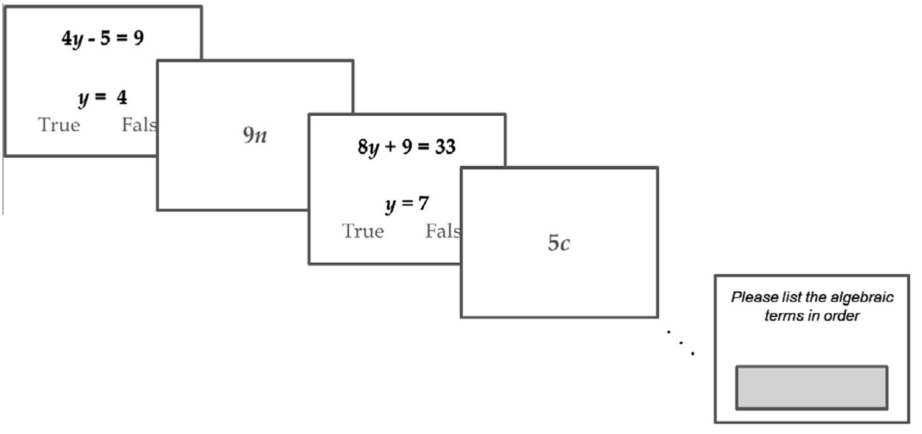

Fig. 3. Example stimuli used in the algebra working memory task.

(Ashcraft & Kirk, 2001). This practice may result in loss of information about individual differences and may also cause spurious statistical significance and overestimation of effect size (see MacCallum, Zhang, Preacher, & Rucker, 2002; Preacher, Rucker, MacCallum, & Nicewander, 2005). Given the potentially complex relationships among MA, WM, and math performance, dichotomizing MA scales may result in a distorted picture of the relationships among these three constructs.

We used latent variable analysis to isolate possible worry/WM subgroups. Latent profile analysis (LPA) is a form of latent variable analysis that identifies discrete mutually exclusive classes of individuals based on their responses to a set of continuous variables (Collins & Lanza, 2010). It does not require some of the assumptions of many other forms of analysis (e.g., traditional modeling) such as normal distribution and homogeneity; therefore, it is less prone to biases (Magidson & Vermunt, 2003). The number and characteristics of the profiles are not predetermined but are identified after the analyses to determine the best fitting model (Fletcher, Marks, & Hine, 2012; Pastor, Barron, Miller, & Davis, 2007). The analyses involve testing a number of profiles (e.g., two to six). For each number of profiles, the analysis creates groups based on probabilities of shared characteristics, accounting for uncertainty (Fletcher et al., 2012). LPA assumes that members of one subgroup share a pattern of response probabilities that distinguishes them from other groups (Collins & Lanza, 2010). The various profiles and response probabilities are compared for statistical fit, theoretical significance, and parsimony to select the optimal number of profiles (Fletcher et al., 2012). The procedure has been used to identify core number competency subgroups (Reeve, Reynolds, Humberstone, & Butterworth, 2012) and WM subgroups (Fletcher et al., 2012).

We used LPA (Latent GOLD 4.5; Vermunt & Magidson, 2008) to identify algebraic subgroup profiles on the basis of performance on the algebraic tasks. Model selection is based on goodness of fit indexes, including the Bayesian information criterion (BIC), the Akaike information criterion (AIC), and an r^2 value of entropy. Based on preliminary analysis (described below), we selected a four-group solution that provided the best representation of data in relation to a prior prediction. Validation of classes involved comparing the final LPA model on performance on several tasks contributing the algebraic performance and/or ability. LPA was used to determine whether algebraic worry and WM subgroups could be identified (mean algebraic worry, mean WM problem accuracy, and proportion of terms correctly recalled). The BIC, AIC3 (AIC with a penalty factor of 3), and CAIC (bias-corrected AIC model) were used to estimate model fit (Collins & Lanza, 2010). The entropy measure was used to indicate how well the model classified individuals into groups (entropy values closer to 1 suggest good classification).

Results

Initial analyses

Descriptive statistics are reported in Tables 2–4. Algebraic problem solving performance was correlated with both the Calculations and Applied Problems subtests of the Woodcock–Johnson III, indicating that the task was related to, but distinct from, general math ability.

To determine whether judging the equivalence equation pairs affected worry ratings, a 2 (Difficulty: easy or hard) × 2 (Equivalence: equivalent or nonequivalent) analysis of variance (ANOVA) was conducted using students' worry ratings (see Table 4 for algebraic judgment accuracy, worry, and RT means and standard deviations). Worry was higher for hard judgments compared with easy judgments, $F(1, 75) = 33.71$, $p < .001$, partial $\eta^2 = .31$; no main effect of equivalence was found, $p = .227$. The interaction between problem difficulty and equivalency was significant, $F(1, 75) = 10.48$, $p = .002$, partial $\eta^2 = .12$. Worry for easy equivalent problems was judged lower than worry for easy nonequivalent problems, $p = .002$, and for hard equivalent problems, $p < .001$. Worry for hard nonequivalent problems was judged higher than worry for easy nonequivalent problems, $p = .01$, but did not differ from worry for hard equivalent problems, $p = .127$. These findings suggest that students' worry ratings vary between judging the equivalence of pairs of algebraic equations and are affected by difficulty.

Latent profile analyses of worry and working memory measures

We used Latent Gold (Vermunt & Magidson, 2008) to determine whether worry–WM subgroups could be identified. WM recall and problem accuracy and mean worry ratings for the four equivalent-type problems (easy–hard × equivalent–nonequivalent) were entered into the analysis. Data

Table 2
Means (and standard deviations) for working memory, algebraic judgment, and algebra problem solving performance and the control measures reaction time, Woodcock–Johnson III Calculations and Applied Problems subtests, and Raven's matrices tasks.

		N	Mean (*SD*)
Working memory	Accuracy	76	0.76 (0.16)
	Response time (s)	76	7.86 (2.34)
	Recall	76	0.58 (0.21)
Algebraic judgment	Accuracy	76	0.75 (0.18)
	Response time (s)	76	9.85 (2.32)
	Worry (0–5)	76	1.02 (1.02)
Algebraic problem solving	Easy	76	0.56 (0.33)
	Hard	76	0.33 (0.36)
	Total	76	0.45 (0.33)
Reaction time		75	351.3 (69.9)
Woodcock–Johnson III	Calculations	65[a]	117.8 (13.6)
	Applied Problems	76	105.7 (9.1)
Raven's matrices		66[a]	118.7 (12.8)

Note. Recall is the proportion of terms correctly recalled.
[a] $N < 76$ where students did not complete in-class testing.

Table 3
Zero-order correlations for algebra performance, working memory, and judgment tasks and the control measures reaction time, Woodcock–Johnson III subtests, and Raven's matrices.

	1	2	3	4	5	6	7	8	9	10	11
1. Algebra	–										
2. WM Acc	.75**	–									
3. WM RT	−.18	.10	–								
4. WM Rec	.45**	.32**	.01	–							
5. Jud Acc	.73**	.67**	−.03	.35**	–						
6. Jud RT	−.23*	−.16	.35**	−.05	.03	–					
7. Wor E	−.38**	−.47**	−.13	−.33**	−.58**	−.05	–				
8. Wor H	−.58**	−.60**	−.07	−.37**	−.63**	.14	.76**	–			
9. RT[a]	−.31**	−.31**	−.08	−.17	−.15	.15	.16	.30**	–		
10. Calc[b]	.62**	.53**	−.02	.60**	.65**	.02	−.58**	−.62**	−.22	–	
11. Ap Prob	.74**	.59**	−.05	.56**	.61**	−.09	−.48**	−.60**	−.13	.64**	–
12. Raven's[c]	.46**	.40**	.16	.46**	.53**	.05	−.52**	−.46**	−.14	.62**	.50**

Note. WM Acc, working memory problem accuracy; WM RT, working memory response time; WM Rec, working memory recall; Jud Acc, worry judgment accuracy; Jud RT, worry judgment response time; Wor E, worry for easy problems; Wor H, worry for hard problems; RT, reaction time; Calc, Woodcock–Johnson III Calculations subtest; Ap Prob, Woodcock–Johnson III Applied Problems subtest.
* $p < .05$ level.
** $p < .01$ level.
[a] $N = 75$.
[b] $N = 65$.
[c] $N = 66$.

Table 4
Means (and standard deviations) for algebraic judgment accuracy, worry ratings, and response times as a function of problem difficulty and equivalence.

		Accuracy		Response time		Worry	
		N	*M* (*SD*)	N	*M* (*SD*)	*N*	*M* (*SD*)
EQ	Easy	76	0.83 (0.22)	76	9.22 (2.72)	76	1.25 (1.24)
	Hard	76	0.56 (0.29)	69[a]	11.63 (3.29)	76	1.14 (1.10)
NE	Easy	76	0.88 (0.19)	76	9.55 (3.24)	76	0.73 (0.96)
	Hard	76	0.75 (0.27)	72[a]	9.60 (3.24)	76	0.97 (1.09)

Note. EQ, equivalent problems; NE, nonequivalent problems.
[a] $N < 76$ where all problems were incorrect.

were fitted to one to six latent profiles (see Table 5 for the fit statistics). The BIC and CAIC were smallest for the four-profile solution, indicating an optimal balance between model fit and parsimony (Collins & Lanza, 2010). The AIC3 statistics did not reach an optimal profile model. The entropy value for the four-model solution was high (.965), suggesting good precision of fit of individuals to groups.

Table 5
Fit statistics for latent profile analysis solutions.

Profile	LL	BIC	AIC3	CAIC	Npar	Entropy
1	−190.64	416.02	405.27	424.02	8	1.00
2	−132.34	321.16	303.69	334.16	13	.98
3	−94.49	267.16	242.97	285.16	18	.98
4	−79.00	257.91	227.00	280.91	23	.97
5	−68.25	258.12	220.50	286.12	28	.95
6	−51.74	246.82	202.48	279.82	33	.96

Note. LL, log likelihood; BIC, Bayesian information criterion; AIC3, Akaike's information criterion with a penalty factor of 3; CAIC, bias corrected AIC model; Npar, number of parameters.

Bootstrap procedures found that the difference between the three- and four-profile solutions was significant, $p < .001$, indicating improvement of model fit for the four-profile solution.

Fig. 4 shows the mean performance of the four subgroups as a function of working memory accuracy and recall as well as performance on easy/hard × equivalent/nonequivalent problems. One group ($n = 27$) displayed high performance for both the recall and problem accuracy components of the WM task and had low worry ratings across all problem types; this group was labeled the high working memory/low math worry (HM/LW) group. A second group ($n = 22$) had moderate recall and accuracy WM performance; this group's worry judgments were moderate for easy equivalent problems and increased for hard problems. This group was labeled the moderate working memory/high worry (MM/HW) group. A third group ($n = 23$) displayed poor recall performance but high accuracy in the WM task; worry judgments were low but showed a small increase for hard problems. This group was labeled the moderate working memory/low math worry (MM/LW) group. Finally, a fourth group ($n = 5$) displayed poor recall and accuracy and high worry judgments, particularly for hard problems. This group was labeled the low working memory/high math worry (LM/HW) group.

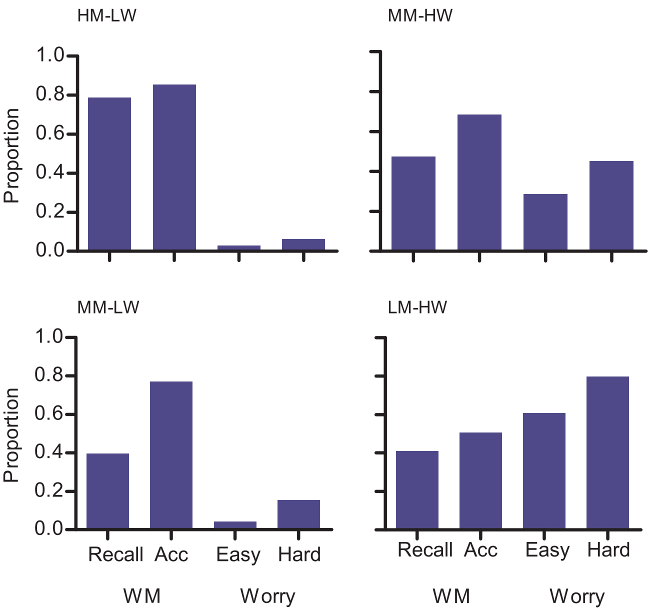

Fig. 4. Subgroup profiles: Means for working memory problem accuracy (Acc) and working memory recall (Recall) and worry ratings for easy equivalent (EE), easy nonequivalent (EN), hard equivalent (HE), and hard nonequivalent (HN) problems.

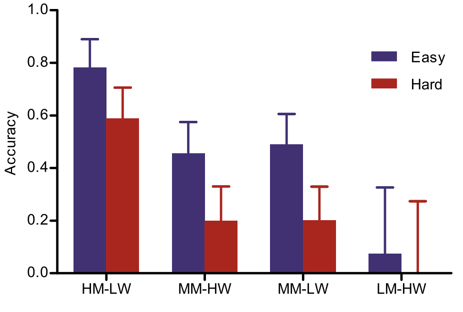

Fig. 5. Mean algebraic problem solving accuracy as a function of group membership (error bars = 2 standard errors).

Latent profile subgroups and problem solving

Initial analyses revealed no differences in the worry ratings for correct and incorrect judgments as a function of group; so worry ratings were collapsed. To investigate the relationship among worry, working memory, and algebra performance, a 4 (Subgroup) × 2 (Difficulty: easy or hard) mixed ANOVA examined the relationship between subgroup membership and algebraic problem solving accuracy (see Fig. 5). Accuracy was overall higher for easy questions, $F(1, 73) = 38.26$, $p < .001$, partial $\eta^2 = .34$. There was also a main effect of group membership, $F(3, 73) = 13.27$, $p < .001$, partial $\eta^2 = .35$. Bonferroni post hoc tests revealed that the HM/LW group had better algebra performance than each of the other groups, $p < .001$. There was no statistically significant difference among all of the other groups, MM/HW versus MM/LW, $p = 1.00$, MM/HW versus LM/HW, $p = .21$, and MM/LW versus LM/HW, $p = .15$. There was no significant interaction between subgroup membership and problem difficulty, $F(3, 73) = 1.55$, $p = .21$. The findings suggest that worry–WM subgroup membership may predict algebraic problem solving performance. Given that higher WM and lower MA were associated with better algebraic problem solving accuracy, these findings suggest that algebraic worry and/or WM capacity may contribute to algebraic problem solving performance.

We used multivariate linear regression to determine whether worry–WM subgroup membership contributed to algebraic performance over and above the contributions of nonverbal IQ and general math ability (an analysis of covariance [ANCOVA] was deemed as unsuitable due to the unequal group sizes). Latent profiles were coded as dummy variables with HM/LW, MM/LW, and LM/HW as the reference group for Models 1, 2, and 3, respectively. Results of these analyses are reported in Table 6. The multivariate linear regression analyses examined the worry–WM profiles, nonverbal IQ (Raven's matrices), Woodcock-Johnson III Calculations (general math ability), and basic RT on algebraic problem solving accuracy and were significant, $\chi^2(6) = 51.82$, $p < .001$. The regressions indicate that higher Calculations and lower RT (but not nonverbal IQ) were associated with better algebraic problem solving performance, and the worry–WM profiles contributed to variance in algebraic performance. Model 1 shows that after taking into account RT, nonverbal reasoning, and Calculations performance, the HM/LW and MM/HW groups had better algebraic problem solving performance than the LM/HW group. Model 2 shows that the MM/HW group performed worse than the HM/LW group but was not different from the MM/LW group. Model 3 shows that the HM/LW group had better algebraic problem solving than each of the other groups. The findings suggest that worry–WM profiles are distinct from nonverbal reasoning, RT, and math ability in their association with algebraic problem solving performance.

Discussion

Our study sought to identify algebraic worry–WM profiles in a sample of adolescent girls and to determine the relationship between these profiles and algebraic problem solving performance. Four

Table 6
Outcome of linear regressions.

	Model 1		Model 2		Model 3	
	β	*p*	*β*	*p*	*β*	*p*
HM/LW	.64 (.19)	.001	.32 (.12)	.007		
MM/LW	.18 (.16)	.269	−.12 (.10)	.229	−.43 (.11)	< .001
MM/HW	.313 (.20)	.026			−.31 (.29)	.008
LM/HW			−.18 (.09)	.051	−.36 (.11)	.001
Raven's	.07 (.11)	.505	.07 (.11)	.505	.07 (.11)	.505
Calculations	.26 (.13)	.038	.26 (.13)	.038	.26 (.13)	.038
Reaction time	−.19 (.09)	.028	−.19 (.09)	.028	−.19 (.09)	.028

$R^2 = .55^{**}$ (.08); LL = 5.57

Note. Dependent variable is algebraic problem solving accuracy. Beta weights (and standard errors), R^2, and log likelihood (LL) are presented. Blank indicates group for each model is the reference group. HM/LW, high WM–low worry; MM/LW, moderate WM–low worry; MM/HW, moderate WM–high worry; LM/HW, low WM–high worry. Raven's, nonverbal IQ; Calculations, general math ability; RT, basic reaction time.

subgroups were identified from LPA that differed in worry and WM. However, whereas the HM/LW and LM/HW groups were identified, the other two groups had moderate WM and differed only in terms of worry, namely, MM/LW and MM/HW. The profiles suggest that WM and worry levels covary. Consistent with previous MA and math cognition research, WM–worry profiles predicted algebraic problem solving performance. LM/HW was associated with poor algebraic problem solving, and HM/LW predicted good algebraic problem solving. Despite differences in worry levels but similar WM levels, there was no difference in algebraic performance between the MM/LW and MM/HW groups, suggesting that with moderate WM MA does not impair math performance. Finally, the WM–worry profiles predicted algebraic performance after controlling for general cognitive measures, math computation ability, and processing speed.

The current findings suggest that high algebraic worry and low WM are associated with low algebraic problem solving performance. This finding is consistent with arithmetic research finding that high MA and low WM are associated with arithmetic problem solving (Ashcraft & Kirk, 2001; Hoffman, 2010; Raghubar et al., 2010) and suggests that MA also affects advanced math problem solving. WM is thought to play an important role in mathematical problem solving, but this relationship depends on math type, problem solving strategies, and WM domain (Raghubar et al., 2010; Simmons, Willis, & Adams, 2012). To overcome the issue of domain-relevant WM, this study assessed the WM–algebraic problem solving relationship with a WM task containing algebraic stimuli.

Previous research has shown that high MA is associated with poor arithmetic problem solving even when accounting for WM (Hoffman, 2010; Miller & Bichsel, 2004). Our study demonstrated an association between worry and algebraic problem solving; however, contrary to previous MA research and more consistent with predictions of ACT, the relationship was not linear. We found that high worry with low WM was associated with poor algebra problem solving and that low worry with high WM was associated with high algebraic problem solving, but there appeared to be no impact of high worry with moderate WM (when compared with low worry with moderate WM). This pattern is similar to research by Owens and colleagues (2014), who examined anxiety, WM, and combined math and general cognitive performance. They found that effects of anxiety differed with WM capacity and that for moderate WM there was no difference in performance between low and high anxiety. The current findings, and those of Owens and colleagues (2014), support ACT, which proposes that, in addition to disrupting WM, worry can also facilitate performance. If cognitive resources are sufficient (i.e., WM is high and a task is demanding), the facilitative effect could override the negative effects of worry and may improve performance. Our findings show no difference in performance between high and low worry for profiles with moderate WM. Therefore, there appeared to be no impairment of worry for individuals with moderate working memory, which may indicate a balance between the two opposing consequences of worry (impaired WM and facilitative effect), as suggested by Eysenck and Derakshan (2011) and Owens and colleagues (2014).

The current study found that the worry–WM groups overlapped with high WM and low worry and vice versa. The worry–WM association may be due to worry/anxiety levels, as suggested in previous MA research that higher MA results in a larger decrease to available nonverbal WM capacity (e.g., Ashcraft & Kirk, 2001; Miller & Bichsel, 2004). Although this is one explanation for the worry–WM overlap, we were unable to examine the direction of influence—whether worry affects WM or vice versa. Rather, the findings indicate that a different approach is required to separate the effects of WM and worry.

Group membership was also associated with general math ability and basic processing speed. However, regression analyses showed that group membership contributed to algebraic problem solving after controlling for nonverbal reasoning, general math ability, and basic processing speed. The finding suggests that although general math ability and basic processing speed are associated with algebra performance, the WM–worry–algebra performance relationship still exists after controlling for these factors.

Review of methodology

The current study used novel tasks designed to specifically assess algebraic *online* worry and working memory. Traditional MA scales seem to be based on the assumption that MA is a domain-general trait that is constant over time and context. The possibility that MA varies as a function of context is rarely examined. The online worry assessment was used to investigate worry responses to task difficulty and is similar to measures of anxiety and worry in children. Faces worry scales have been used with children previously (see Krinzinger, Kaufmann, & Willmes, 2009; Punaro & Reeve, 2012), and children have been shown to be more responsive to the term *worry* than to the term *anxiety* (Punaro & Reeve, 2012). Worry has also been identified as the component of anxiety that affects working memory and performance (Eysenck & Calvo, 1992; Liebert & Morris, 1967; Wine, 1971). Interestingly, the outcome/results of the worry scale in the current study mirror the findings of MA questionnaires in previous studies (Ashcraft & Kirk, 2001; Devine et al., 2012; Hopko, Mahadevan, Bare, & Hunt, 2003). One key difference of the worry measure used in the current study is that the online worry task was responsive to problem difficulty—a property that may prove to be beneficial to assessing changes in worry in response to problem difficulty, domain, time pressures, and how worry changes throughout a math class or test.

Our study used an algebraic dual span task to assess working memory. The purpose of this procedure was to address issues about the WM–math relationship raised by Raghubar and colleagues (2010). For example, the relationship between math and WM changes with age, problem solving strategy use, problem type, and skill level. Algebraic stimuli were used in a standard WM task (i.e., dual span) to address these issues and to better assess the WM–algebraic problem solving relationship. The WM–algebra performance correlations were moderate, suggesting that the algebraic WM task was assessing WM rather than algebra skills. The argument may be made that performance on an algebraic WM task is too domain specific and ignores the traditional verbal–spatial divisions of WM. However, there is evidence of further specialization of WM; Caplan and Waters (1999) proposed a specialization of verbal WM after finding differences between sentence structure and sentence meaning tasks. There is also behavioral and neurological evidence of differences between language and number WM, suggesting that number is a unique WM domain (Knops et al., 2006; Libertus et al., 2009).

Limitations and future research directions

We did not examine response times in algebraic problem solving. Processing efficiency has been predicted to be affected by worry before accuracy is affected (Eysenck & Calvo, 1992), and response times may provide more insight into the MA–performance relationship. Indeed, previous research has shown relationships between MA levels and arithmetic problem response times (Ashcraft & Faust, 1994). However, we found no correlations between our measures and response times for the working memory and algebraic judgment tasks, and it is possible that response time in algebraic problem solving may show a similar pattern.

Algebraic worry ratings could be expected to be associated with confidence. If students are confident in their math abilities, they may have little reason to worry. In the current study, we used the term *worry* to introduce students to our rating task, stressing that they focus on the process of making a judgment rather than on the outcome of the judgment per se. We suggest that *confidence* is more likely to be associated with whether an answer is correct or not. Nevertheless, it may be difficult in practice to separate worry/anxiety from confidence. It should be noted we found that worry ratings differed as a function of subgroup and problem difficulty but that subgroup and difficulty did not interact with each other. It would seem evident that worry (and possibly confidence) is sensitive to situational contexts (as predicted by ACT).

Currently, little is known about whether MA generalizes across math domains (e.g., across arithmetic, algebra, and geometry) or whether MA is stimulus driven and occurs as a function of different math stimuli. It is evident that anxiety varies within individuals across academic domains (e.g., arithmetic vs. spelling; see Punaro & Reeve, 2012). It is possible that MA/worry may vary as a function of different kinds of math problems. Initial MA may accrue from arithmetic problem solving experiences but might not generalize to complex math domains (e.g., algebra). Although arithmetic abilities may be involved in algebraic reasoning, it should not be assumed that MA generalizes to all area labeled as "mathematical."

The size of the low WM and high worry group was smaller than the sizes of the other groups. Possibly the nonsignificance reflects the LM/HW small sample ($n = 5$) rather than an absence of effect. The finding that only a small number of participants were assigned to a particular predicted data pattern is interesting in its own right and may indeed reflect the relative prevalence of individuals with these characteristics in the general population.

Research into the moderating effects of MA has shown associations between high MA and reduced WM (Ashcraft & Kirk, 2001; Eysenck & Derakshan, 2011; Owens et al., 2014). In non-math research, investigation of emotion regulation has found that the greater the WM capacity, the better the ability to control intrusive thoughts (Brewin & Beaton, 2002; Brewin & Smart, 2005) and negative emotions (Hofmann, Schmeichel, & Baddeley, 2012; Schmeichel & Demaree, 2010; Schmeichel, Volokhov, & Demaree, 2008). On the basis of these associations, assumptions have been made about the direction of influence of anxiety on WM (ACT) and of WM on emotions (emotion regulation). Our findings suggest co-occurrence between worry and WM. It is unclear (a) whether WM influences MA and/or vice versa and (b) whether low WM, high MA, or a combination of the two contributes to impaired math performance. A more precise characterization of the MA–WM relationship is needed to understand their respective contributions to math performance. Our findings may have implications for individuals with low WM; the poor regulation of emotion may result in higher anxiety levels, which would limit already reduced WM capacity. In particular, good WM capacity may constrain high MA, but limited WM capacity may increase MA as math difficulty increases.

Conclusion

In this study, we examined algebraic worry and WM in female high school students. We identified four groups that differed in worry level–WM capacity relations that were differentially related to algebraic problem solving ability. More specifically, we found a nonlinear relationship between algebraic performances and differences in worry level and WM capacity, consistent with predictions derived from ACT. Nevertheless, we acknowledge that our research is based on a static model of the relationships between worry level and WM capacity. Although the four groups that emerged from latent class analysis were consistent with expectations (i.e., high/low worry/WM), it is likely that worry/anxiety levels and/or WM capacities interact and/or change over time and may differentially affect problem solving. Indeed, emotion and cognition likely interact dynamically in learning contexts (e.g., studying for a test). The question of whether cognition and/or emotion remain stable or change over time and whether individual differences in change characteristics can be identified is of practical and theoretical significance.

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