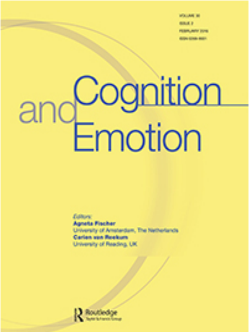

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Worry and working memory influence each other iteratively over time

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Little research has examined whether the relationship between working memory (WM) and anxiety/worry remains stable or changes over time; and, if changes occur, the factor(s) influencing change. Claims about influence are typically inferred from data collected at a single time point, and may misrepresent the nature of influence. To investigate the iterative influence of WM and Worry and/or vice versa, 133 fourteen-year-olds completed WM and Worry measures several times over the course of a single day as they prepared for a math test. We used a bivariate latent difference score model to analyse possible changes in WM–Worry relationships. The best fitting model indicated high Worry predicts decreases in WM, and low or decreased WM predicts increases in Worry; high WM with low Worry predicts accurate problem solving; low WM with high Worry predicts inaccurate problem solving. Findings show relationships between WM and Worry varies considerably over a single day, and initial disadvantages become worse over time.

Keywords: Working memory; Math anxiety/worry; Latent difference score model; Stability and change; Cognition–emotion interactions.

INTRODUCTION

Most research that has studied the impact of emotion on cognitive functions (or vice versa) has examined the relationship at a single time point; and little research has examined how these factors might affect each other over time. Consider studying for a math test. How do emotional states (anxiety/worry) and cognitive functions [working memory (WM)] change over a period of study? Do they remain stable, or do they affect each other iteratively over time? Practice may elicit anxiety/worry, which in turn may impair cognitive functions (e.g., WM); and impaired cognitive functions may in turn increase anxiety, further diminishing the effectiveness of cognitive functions. To investigate the impact of emotion (worry) on cognition functions (WM) (and vice versa), we investigate the ways in which math worry and WM affect each other iteratively over the course of single day as 14-year-olds study for a math test. We use a bivariate latent difference score model (BLDSM; Grimm, An, McArdle, Zonderman, & Resnick, 2012), which allows examination of the interplay between two constructs, to characterise the likely iterative impact of WM and math worry on each other.

Research has shown associations between math anxiety (MA), WM and math problem solving

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ability (Ashcraft & Kirk, 2001; Hoffman, 2010; Mattarella-Micke, Mateo, Kozak, Foster, & Beilock, 2011; Miller & Bichsel, 2004). However, the direction of influence between MA, WM and math ability is unclear. A commonly held view is that MA increases cognitive demands, which reduces WM capacity, which in turn, impairs problem solving ability (Ashcraft & Kirk, 2001; Derakshan & Eysenck, 2009; Faust, 1996; Miller & Bichsel, 2004). It is of course possible that deficits in math ability per se are responsible for poor math problem solving and, in turn, are linked to increases in MA (Ma & Xu, 2004; Maloney, Ansari, & Fugelsang, 2011; Maloney, Risko, Ansari, & Fugelsang, 2010).

Association between MA and WM has been established by comparing individuals' WM and self-reported MA (e.g., Ashcraft & Kirk, 2001; Hoffman, 2010; Maloney et al., 2010; Miller & Bichsel, 2004; Wu, Barth, Amin, Malcarne, Menon, 2012). On the basis of current findings, the direction of influence between MA and WM cannot be determined. Ashcraft and Kirk (2001), for example, found that, compared to students with low MA, students with high MA had reduced WM, were slower and less accurate solving mental addition problems, and also showed greater impairments solving difficult problems. Hoffman (2010) found that after controlling for self-efficacy and WM, MA was only related to accuracy solving difficult arithmetic problems; furthermore, after controlling for WM, MA was not related to enumeration ability. These findings suggest that both MA and WM are likely related to math problem solving, but the precise nature of the relationship is unclear. We suggest it may be possible to better characterise the MA/WM/problem solving relationship by examining changes in MA and/or WM over time.

Cognitive functions (e.g., attention and WM) may affect or be affected by MA. Findings from non-math research show that cognition (e.g., WM) may serve as a regulator or distracter moderating emotion (e.g., anxiety; Hofmann, Friese, Schmeichel, & Baddeley, 2011; Ochsner & Gross, 2005; Van Dillen, Heslenfeld, & Koole, 2009). For example, Van Dillen and Koole (2007) found self-reported mood was less negative when WM load was high compared to when it was low. Moreover, WM has also been associated with better emotion regulation ability: individuals with greater WM capacity are better able to control intrusive thoughts (Brewin & Beaton, 2002; Brewin & Smart, 2005) and negative emotions (Schmeichel & Demaree, 2010; Schmeichel, Volokhov, & Demaree, 2008). Cognitive regulation of emotion may have implications for individuals with low WM; poor regulation of emotion may reflect high MA levels, impairing WM even more and amplifying math problem solving disadvantage.

One difficulty interpreting the significance of MA–WM research findings is that the context and/or purpose of the research activity is rarely specified. Different outcomes tend to occur when individuals complete a task as an end in itself, compared to completing the task as part of a meaningful goal (e.g., studying for an exam; Brown, 1978, 1992). Moreover, since MA–WM relations are often examined at a single time point, it is difficult to distinguish between trait and state properties of MA. Test circumstance may interact with WM and MA (and vice versa) and influence outcomes. Indeed, there is evidence of short-term changes in WM–MA relationships. In an adolescent sample, Trezise and Reeve (2014a) found that students initially belonging to a high WM-low math Worry group remained in the same group over a single day. Conversely, students who initially belonged to a moderate WM or high Worry group were likely to move to a lower WM group. Trezise and Reeve demonstrated patterns of stability/change in WM–MA relationships, but they did not examine the change process. Consequently, the Trezise and Reeve study was unable to to characterise the effects between WM and Worry (i.e., the direction of influence between WM and Worry). It is possible that one factor (WM *or* MA) may affect the other (MA or WM), or there may be a mutual influence relationship between WM *and* MA over time.

By early adolescence, students have experienced solving arithmetic problems for many years, but are likely to have only recently encountered algebra.

Algebra is troublesome for many students (Knuth, Alibali, McNeil, Weinberg, & Stephens, 2005): compared to arithmetic, it requires abstract reasoning, and algebraic competence is claimed to require formal reasoning ability (Piaget & Inhelder, 1969; Tolar, Lederberg, & Fletcher, 2009). Surprisingly little is known about the significance of MA and WM in algebraic problem solving. We suggest a better understanding of WM–MA interactions will help characterise the associations between algebra/math and WM, and between algebra/math and MA.

The study

In the present study 14-year-olds completed several WM and MA tests over the course of a single day as they studied for an algebra test. The goal is to examine the ways in which WM and MA affect each other over the day, and how the change pattern of influence affect algebraic problem solving. A dual span task (Conway et al., 2005) comprised of alphanumeric symbols assessed WM. An algebraic judgement task assessed task-specific MA/worry. We focused on math Worry since it has been identified as the cognitive component of state anxiety (Eysenck, Derakshan, Santos, & Calvo, 2007; Liebert & Morris, 1967), and is thought to affect WM (Eysenck et al., 2007; Hayes, Hirsch, & Mathews, 2008; Owens, Stevenson, Hadwin, & Norgate, 2012; Trezise & Reeve, 2014b). According to attentional control theory (Eysenck et al., 2007), anxiety affects cognitive processing because *state anxiety* increases worry. Moreover, trait-worry is thought to be the component of anxiety that impairs the ability to filter threat-related information from WM (Stout, Shackman, Johnson, & Larson, 2014). Problem solving was assessed by mentally solving algebraic problems.

We used a BLDSM (dual change score modelling) to examine changes in WM–worry relationships. BLDSM is a form of structural equation modelling that allows a test of influence between two variables over time (Grimm et al., 2012; McArdle, 2009). BLDSM tests whether change (e.g., increase in Worry rating between two adjacent time points) is predicted by previous levels (e.g., Worry rating at baseline). Furthermore, comparison of models can be used to assess the nature of the relationship within and between variables. BLDSM is designed to model change parameters, controlling for prior performance and change, and in doing so we can examine changes in WM and/or worry, and whether previous performance/change predicts changes. Grimm et al. (2012) extended the model to enable examination whether change (e.g., increase in Worry rating between Time = 2 and Time = 3) is predicted by previous level (e.g., Worry rating at Time = 2) and previous changes (e.g., increase in Worry rating between Time = 1 and Time = 2).

Our interest is whether a unidirectional model (i.e., Worry influences WM, or vice versa, and does not change outcomes) or a bidirectional model best fits the data. Since previous research has not examined bidirectional influence over time, we cautiously suggest several outcomes. If the model is consistent with the claim that high Worry reduces WM capacity, then an immediately preceding Worry score, or change in Worry, would predict a change in subsequent WM (Hypothesis 1a). If greater WM capacity reduces Worry, then previous WM capacity, or change in WM capacity, would predict subsequent change in Worry (Hypothesis 1b). If both of the aforementioned relationships occur, it would suggest a bidirectional relationship between Worry and WM (Hypothesis 1c). Further, if changes (to WM or Worry) are predicted only by previous Worry score or WM capacity, it would suggest that change occurs, but the nature of the change relationship remains constant (Hypothesis 2a). In other words, if WM or Worry changes are predicted by previous changes, it would suggest that the nature of the WM–Worry relationship changes dynamically over time (Hypothesis 2b). Consistent with previous research, we expect that both large WM capacity and low Worry would predict good problem solving accuracy, and that both small WM capacity and high Worry would predict poor problem solving accuracy (Hypothesis 3; Ashcraft & Kirk, 2001; Raghubar, Barnes, & Hecht, 2010).

MATERIALS AND METHODS

Participants

One hundred forty-three 14-year-olds attending mixed gender independent high schools in an Australian city, participated in the study. Individuals who performed below chance, or showed random responding at Time 1 were excluded (n = 17), leaving a final sample of 133 participants (M = 14 years 4 months, SD = 4 months), comprising 97 boys and 40 girls. (The differences in gender numbers reflected enrolments at the schools in which the research was conducted.) Common to Australian urban high schools, the sample comprised students from diverse multicultural and socio-economic backgrounds. According to school personnel, none of the participating students had identified learning difficulties, and all had normal or corrected to normal vision. The research was approved by, and conducted in accordance with the requirement of, the authors' University's Human Research Ethics Committee. Approximately 95% of students invited to participate in the research did so.

Procedure

Students completed three algebraic tasks: (1) Algebraic WM, (2) Algebraic judgement/Worry (Worry) and (3) Algebraic Problem Solving. Tasks were completed in two sessions in a single day (see Figure 1 for test sequences). As WM is thought to directly impact math reasoning, we deemed it important to establish WM abilities at the beginning of each test session, and immediately prior to the problem solving task. In Session 1 the task order was: (1) WM, (2) Worry, (3) WM, (4) Worry and (5) WM. In Session 2 the order was: (1) WM, (2) Worry, (3) WM and (4) algebraic problem solving test. Students were informed they would complete a sequence of activities over two sessions, and there would be a test at the end of the day. Students completed the initial session first thing in morning, following which they attended normal (non-math) classes; in the afternoon they completed the second session. All tasks were completed on 13′′ laptop computers running Inquisit 3.0.6.0 software (2011). Each session lasted 40 minutes.

Materials

The *Algebraic WM* was based on Turner and Engle's (1989) operation span task, modified to use alphanumeric symbols and algebraic statements. The task was designed to assess the ability to process and remember alphanumeric symbols. WM has been conceptualised as general abilities (e.g., Lovett, Reder, & Lebiere, 1999) and as a set of domain-specific constructs (Engle, 2010; Miyake & Shah, 1999). Engle (among others), for example, argues that WM involves "as many domain-specific stores as there are different ways of thinking" (p. S17, 2010). Indeed, evidence suggests that math problem solving ability may comprise a specific domain for which domain-general measures may not capture ability differences (see LeFevre, DeStefano, Coleman, & Shanahan, 2005; Raghubar et al., 2010). In the present study we employed alphanumeric symbols to assess domain-relevant WM. The task required students to both appraise algebraic statements, and remember alphanumeric symbols (see Figure 2).

Each trial consisted of an algebraic statement appraisal, and the presentation of an algebraic symbol to remember. Algebraic statement appraisal

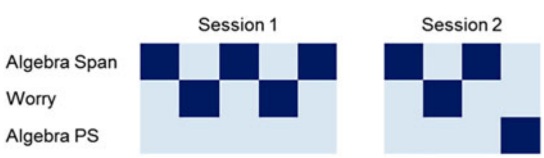

Figure 1. *Study design and task sequence for testing sessions one and two. Dark squares indicate task completed. Task sequence is left to right.*

required students to decide whether an algebraic statement correct or incorrect (e.g., 3y + 2 = 20; y = 2) by pressing a key on their computer (students were given 15 seconds to respond). An alphanumeric symbol then appeared on the screen (e.g., “4x”) for 1600ms. After *n*-trials, a 3 × 4 matrix consisting of 12 alphanumeric symbols appeared on-screen (see Figure 2).

Students received instructions and training for the appraisal and span components separately and then completed two practice sets, prior to Session 1. For the appraisal component, students were instructed to judge the accuracy of a possible answer to an algebraic equation, rather than solve an algebraic equation. For the span component, students were instructed to remember each alphanumeric symbol in the order they were presented. Their task was to select the symbols from the matrix that had appeared in the trials, in the order presented. Students were instructed to do their best on the appraisal and span components; they were not informed about the researchers’ interests.

Students completed two sequences of two-, three-, four-, and five-trial sets (i.e., 2 × 2, 3, 4 and 5 trial sets; see Figure 2). Order of presentation of set length was randomised. We were interested in the proportion of alphanumeric symbols correctly recognised. We used the partial scoring procedure suggested by Redick et al., (2012) and Conway et al. (2005), rather than ‘absolute’ maximum list span score typically used in developmental research. Psychometric properties (e.g., test–retest and internal consistency) favour partial scoring, rather than absolute scoring in complex span task (see Redick et al., 2012).

The *Algebraic Worry* task was used to assess worry students experienced while making algebraic judgements. Students were shown pairs of algebra equations of the form mx + c_1 = c_2 and judged whether the value of the variable (x) in the two equations had the same value (equivalent equations), or different values (non-equivalent equations; see Figure 2). The design of the judgement procedure was based on Canobi, Reeve, and Pattison’s (1998, 2003) arithmetic equation judgement task which examined children’s ability to “notice” the presence/absence of “commuted relationships” in two equations. Following each judgement, the Faces Anxiety Scale (Bieri, Reeve, Champion, Addicoat, & Ziegler, 1990) appeared on the screen and students rated their Worry experienced while making their judgement. The Faces Anxiety Scale comprised six faces depicting increasing Worry (neutral to extreme Worry) and has been used to assess academic-related worry in previous research (Punaro & Reeve, 2012; Trezise & Reeve, 2014a).

Students completed training and practice in both the judgement and worry components of the task. For algebraic judgements, students were

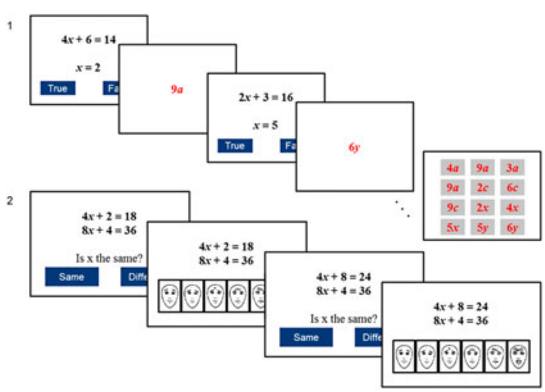

Figure 2. *Example stimuli for the (1) WM, and (2) Worry tasks. A two trial sequence on the algebraic WM task is depicted: two trials each containing a processing (correct/incorrect) and memory (alphanumeric symbol) phase, and alphanumeric symbols on a recognition matrix. Algebraic Worry task involves a judgement about the equivalence of two equations, followed by a worry rating.*

instructed the task was to compare two equations and indicate whether the value of x was the same, and they did not need to solve the equations. The judgement component required an ability to recognise commutative relationships. Students received training on how to use the worry scale: they were given non-math and math examples and practice problems. A variety of situations that may elicit different worry levels were described, and students discussed which worry face they would select to correspond with that worry level. Students were instructed to evaluate if they felt calm, a bit worried or extremely worried or anxious while making their judgement. They were explicitly instructed not to rate their confidence in their answer, but to evaluate their worry/affect while making their judgement. Students were not informed of their judgement accuracy. In Session 1, 16 equations pairs were rated each testing time point and in Session 2, 20 pairs were rated.

In the *Algebra problem solving* task students solved linear algebra equations. The task comprised eight easy and eight hard equations presented in random order. The aim of the problem solving task was to assess students' ability to solve algebraic equations. The structure of the equations was based on the format that students encounter in their math classes. Difficulty was varied using known properties of equivalence relationships (see Humberstone & Reeve 2008; Trezise & Reeve, 2014b). Students were not informed about the form of the algebraic problem solving test prior to attempting it. Easy equations comprised three-terms problems with a variable, a coefficient and a constant on the left side of the equivalence sign, and a constant on the right (e.g., $mx + c_1 = c_2$). Hard equations comprised three-term problems, with a constant on the left, and a variable, a coefficient and a constant on the right side of the equivalence sign (e.g., $c_1 = m_1x + c_2$) (see Alibali, Knuth, Hattikudur, McNeil, & Stephens, 2007; Humberstone & Reeve, 2008). Each hard equation also included negative integers. Solutions ranged between −9 and +12. Students were given up to 15 seconds to respond. Correctness was recorded.

Analytic approach

We investigated the relationship between WM and Worry using Grimm et al.' s (2012) BLDSM approach. BLDSM is based on the premise of identifying the difference between scores on the same measure over two adjacent time points. In BLDSM, scores at each time point are referred to as *levels* and differences between scores are referred to as *changes*. The models examined levels (the WM capacity or Worry latent score at a single testing time point), at each time point and change (Δ) in levels between adjacent time points. For example, a person who has a Worry value of 2 at Time 1, and a Worry value of 4 at Time 2, their $\Delta T_1 = +2$. By separating out the change from scores, we can examine predictors of change. In these analyses, we examine how changes in WM and Worry are predicted by previous levels and change.

There are two stages in the analysis: first, a number of models (of increasing complexity) testing different WM–Worry relationships over time were run, and the best fitting model of the data were then identified; second, the best-fitting model was examined. The aim of testing several models was to evaluate different combinations of relationships between WM and Worry, and to identify the model that best describes the interactions and influences between WM and Worry. The model that best fitted the data was assessed by comparing goodness of fit indices based on likelihood ratio tests (-2LL). Information criteria indices included the adjusted Bayesian Information Criteria (aBIC), a comparative estimation of best fit, that accounts for degree of parsimony in the model by penalising the number of parameters in the model; the standardised root mean square residual (SRMR), which estimates the average difference between the sample covariance and estimated population (model) covariance; and a chi-square test. For all indicators, a lower information criterion indicates better fit; a value less than .08 is considered a good fit for SRMR (Hu & Bentler, 1999). We used the aBIC and SRMR indices as Hu and Bentler (1999) recommend reporting a comparative fit index and the SRMR to evaluate the best fitting model. We also used the Satorra-Bentler scaled chi-square test to compare goodness-of-fit between nested models.

An illustration of the predicted model is presented in Figure 3. Proportion of algebraic terms remembered was used to indicate observed WM score, and mean algebraic Worry was used to indicate observed Worry. The model assumes true scores of WM and Worry at the first test occasion (baseline) are represented by latent intercept scores $M[0]$ and $W[0]$, respectively. Change is represented by a combination of constant univariate and bivariate scores (see Figure 3). The constant scores are: (a) constant latent slope score, estimate for both WM and Worry, and represent a consistent change over time (S_M, WM slope, and S_W, Worry slope), and (b) constant additive parameter (α), with assumed a value of one (Ghisletta & McArdle, 2012).[1] Univariate scores assess within factor affects (i.e., effects of WM on WM, and Worry on Worry), in particular (c) proportional change (β), in which change is predicted by level at the previous time point (e.g., ΔM_1 regressed on M_1), and (d) changes to changes (ϕ), where change is predicted by changes at the previous time point (e.g., ΔM_2 on ΔM_1). ϕ was not estimated for Worry, because there was only one change score regression, resulting in a perfect linear dependency between S_W and ϕ_W. Bivariate scores (termed as coupling scores; Grimm et al., 2012) estimate the effects of WM on Worry, and of Worry on WM, and include (e) coupling proportional changes (γ), where changes are predicted by the level of another variable (e.g., ΔW_1 on M_1), and (f) coupling changes to changes (ξ) where changes are proportional to changes of another variable (e.g., ΔW_1 on ΔM_1).

A latent math problem solving true score (PS_μ) was represented by observed mean accuracy for easy and hard algebraic problem solving (see Figure 3). The problem solving true score was regressed on final time point WM and Worry true scores (ω). This allowed us to examine how WM and Worry levels immediately before the problem solving test, predicted problem solving accuracy.

There have been two suggestions about the relationships between WM and (math) anxiety previously: that WM helps control anxiety, and that anxiety reduces WM (Eysenck et al., 2007; Hofmann et al., 2011). For these reasons, we examined models that examined no effect of WM on Worry, or Worry on WM (Model 1), the effect of Worry level on WM (Model 2), the effect of WM capacity on Worry (Model 3) and the effects of WM capacity on Worry, and Worry level on WM (Model 4). However, few studies have examined WM and Worry/anxiety relationships over time: it is possible that changes in WM/Worry predict subsequent change (e.g., changes in WM may affect an individual's ability to control emotional responses). Therefore, we also examined the effects of changes to WM/Worry on subsequent changes. In addition to the effects of level on change, we also examined models that examined only effects of WM change on WM, and Worry change on Worry (Model 5), the effect of changes to Worry on WM (Model 6), the effect of changes to WM capacity to Worry (Model 7) and the effects of WM changes on Worry and of Worry changes on WM (Model 8).

We examined latent difference models of increasing complexity using Mplus (Muthén & Muthén, 2012). The models were constructed iteratively and represented different WM–Worry interactions. Eight models of increasing complexity were tested. Figure 3 describes the models. The four simplest models included change on level regressions (β and γ), but no change on change (ϕ and ξ were not fitted). Model 1 was a baseline model with "no coupling", in which only within variable (β) relationships (depicted by grey lines in Figure 3) were tested; the model only examined the effect of WM level on subsequent WM change and Worry level on Worry change (i.e., the model that WM and Worry do not influence each other). Model 2 (WM change on Worry) assessed with within variable relationships in Model 1 and Worry level predicting WM change (γ_{MW}: solid orange lines); the model tests the effect of an individuals' Worry on their WM capacity

[1] The letters a to f in parentheses represent the aspects of the parameterisation of the models.

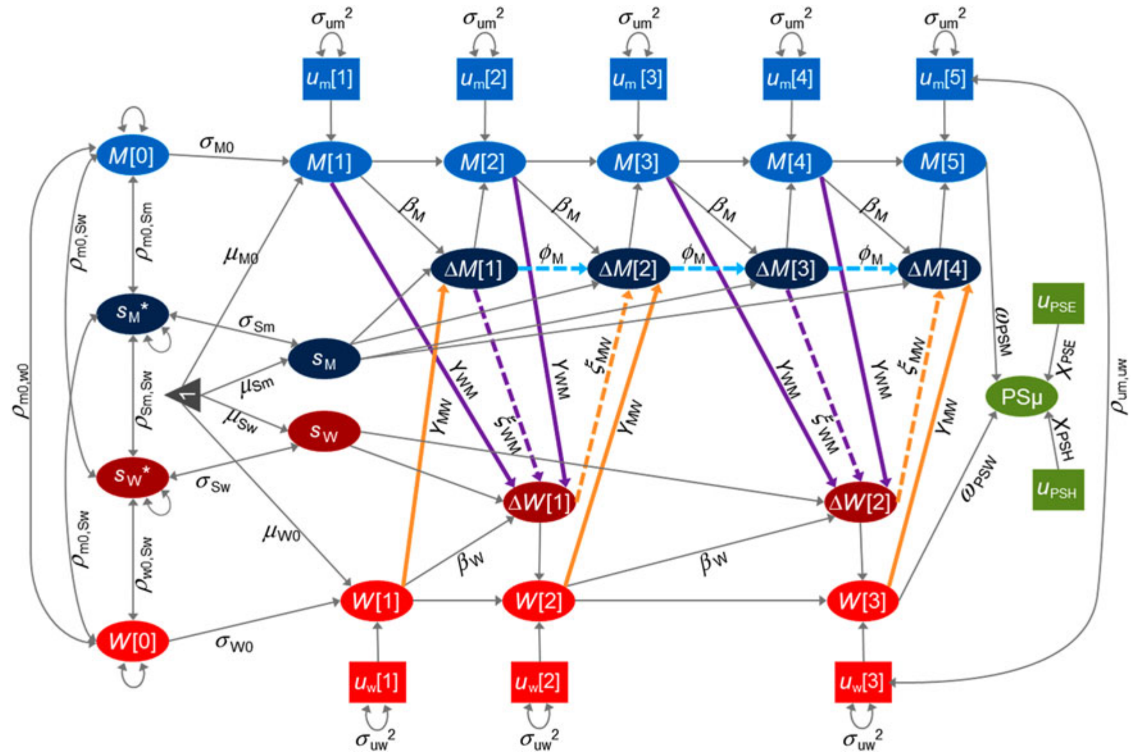

Figure 3. *Path diagram of a BLDSM with WM* (M)*, Worry* (W) *and problem solving (PSμ; with easy, E and hard, H). Final levels of WM and Worry are regressed on algebraic problem solving. There are five measurement occasions for WM, and three for Worry. Unlabeled paths are fixed equal to 1. Observed scores are represented by u; WM latent scores at time* t *by* M[t]*, Worry at time* t *by* W[t]. M*[0] and* W*[0] represent intercept (mean at* t = *0), and* S_M *and* S_W *represent slope, for WM and Worry, respectively. Grey lines represent the base model (Model 1), and are predicted in all models. Solid lines represent variations change on level (Models 2, 3 and 4), broken lines represent change on change (Models 5, 6, 7 and 8). Orange lines represent the effects of Worry predicting WM. Purple lines represent the effects of WM predicting Worry. Blue lines represent the effects of WM on WM.*

(e.g., whether high Worry reduces WM). Model 3 (Worry change on WM) assessed within variable relationships from Model 1 and WM level predicting Worry change (γ_{WM}: solid purple lines—the model examines the effect of an individuals' WM capacity on their Worry (e.g., whether low WM capacity leads to increases in Worry). Model 4 is a bivariate coupling model, which assessed within variable, WM change on Worry, and Worry change on WM change (all solid lines)—the model examined whether Worry levels predicts a change in WM, and whether WM capacity/level predicts a change in Worry.

The final four models examined both level (e.g., does WM capacity lead to a change in Worry?) and change (e.g., does a change to WM capacity lead to a change in Worry?) predicting change: they include all change on level relationships (β and γ) and all relationships depicted by solid lines in Figure 3. Model 5 is a "no change coupling" model; it includes the relationships models in Model 4 and within variable change (ϕ: broken blue lines) relationships (i.e., are changes in WM predicted by previous changes in WM, and are changes in Worry predicted by previous changes in Worry?). In other words, the no change coupling model assesses the effect of levels on change (as in Models 4), and the effect of within variable changes. Model 6 is a WM change on Worry change model, assessing within variable change (i.e., Model 5) and Worry change predicting WM change (ξ_{MW}: broken orange lines); it examines the effect of changes to Worry on WM (e.g., does a decrease in Worry lead to an increase in WM?). Model 7 is a Worry change on WM change model, assessing within variable change and WM change predicting Worry change (ξ_{WM}: broken purple lines); it examines the effects of changes to WM capacity on Worry (e.g., does an increase in WM lead to a decrease in Worry?). Finally, Model 8 is the full model, testing all within and bivariate level and change relationships (all solid and broken lines). This model examines within variable effects of both level and change, and all bivariate effects of both level and change (i.e., WM level predicting Worry change, Worry level predicting WM change, WM change predicting Worry change and Worry change predicting WM change).

RESULTS

Means and standard deviations for each task, at each time point are given in Table 1.

Table 2 shows the measures of fit for the various models. We refer to the models by the name and number presented in the method. The top row assesses fit of traditional bivariate models (Models 1–4), while the bottom row assesses goodness of fit for the extensions proposed by Grimm et al. (2012) (Models 5–8). We expected the best fitting model would support bivariate interactions (purple and orange lines in Figure 3). The aBIC indicates the WM change on Worry level (model 2), and the Worry change on WM change (Model 7) are the best fitting models

Table 1. *Means, standard deviations for WM, worry and algebraic problem solving*

	WM			Judgement/Worry		Problem solving	
	Span	Appraisal		Accuracy	Worry		
Time	*M* (SD)	*M* (SD)	Time	*M* (SD)	*M* (SD)	Diff	*M* (SD)
1	.55 (.20)	.80 (.16)	1	.69 (.20)	1.45 (1.15)	E	.53 (.38)
2	.47 (.24)	.68 (.26)	2	.67 (.20)	1.54 (1.30)	H	.20 (.26)
3	.45 (.24)	.56 (.34)	3	.66 (.20)	1.37 (1.14)		
4	.50 (.25)	.66 (.32)					
5	.44 (.30)	.57 (.36)					

Time, Testing Time Point; Diff, Difficulty; E, Easy; H, Hard.

Table 2. *Fit statisitics for traditional BLDSMs, and extensions of BLDSMs jointly fit to data*

Levels → Change				
	1	2	3	4
Model	No coupling	Worry → WM change	WM → Worry change	Bidirectional coupling
aBIC	−480.12	**−495.91**	−479.75	−495.29
χ^2	97.14	79.61	75.78	78.51
df	39	38	38	37
SRMR	0.11	0.10	0.12	0.09

Levels and change → Change (bivariate change coupling)				
	5	6	7	8
Model	No change coupling	Worry change → WM change	**WM change → Worry change**	Bidirectional change coupling
aBIC	−494.91	−493.96	**−495.92**	−495.57
χ^2	77.16	76.38	**74.42**	**74.04**
df	36	35	**35**	34
SRMR	0.09	0.09	**0.08**	0.09

Note: Bold text indicates information criteria best fit.
aBIC, adjusted Bayesian Information Criterion; χ^2 = chi-square, SRMR, standardised Root Mean Square Residual.

(aBIC = −496). Chi-square and SRMR values indicate the Worry change on WM change (Model 7), and full bidirectional change coupling (Model 8) models fit the data best (χ^2 = 75, SRMR = .08). The Worry change on WM change model (7) was deemed to be the model of best bit, as it was supported by all indicators. We also examined the full model (directional change coupling, Model 8); parameter estimates were very similar to that of the Worry change on WM change model (7), indicating that the full model did not add to the interpretation of the relationship between WM and Worry.

Table 3 presents the parameter estimates and standard error of the model. It shows an overall mean increase in Worry (mean slope). The model also shows that WM change is negatively predicted by Worry level (WM coupling change in Table 3): the higher the Worry level, the larger the decrease in WM; and Worry levels close to zero predict stability in WM. Changes to Worry were negatively predicted by WM level (Worry coupling change in Table 3) and WM change (Worry coupling change on change in Table 3). Thus the model predicts the lower the WM level, the larger the subsequent increase in Worry, whereas higher WM predicts stability in worry levels. Furthermore, if WM increases, then Worry will decrease; and if WM decreases, Worry will increase.

Problem solving was significantly affected by both WM and Worry (see Table 3). Algebraic problem solving was regressed on final scores of WM and Worry (refer to Figure 3). High algebraic problem solving accuracy was predicted by high final WM score, and by low final Worry score. The random effects, presented at the bottom half of Table 3, were not statistically significant, which indicates that random effects do not affect model interpretation.

The findings are different from previous research in two ways. First, the model shows that WM capacity change (and level), predict changes in Worry. Thus, if WM capacity is a value m at time t, the changes to Worry will differ depending on both m_t and how different m_t is from the previous time point, m_{t-1}. Second, these changes to WM and Worry are iterative over time. It is

Table 3. *Parameter estimates for model fit to WM, worry and problem solving data*

		WM		Worry	
		PE	SE	PE	SE
Fixed Effects					
Mean intercept	μ_{y0}	.53*	.02	.29*	.02
Mean slope	μ_s	.01	.10	.52*	.16
Proportional change	β	.06	.22	−.62	.51
Coupling change	γ	**−.30***	**.07**	**−.36***	**.14**
Change on change	ϕ	−.27	.24	–	–
Coupling change on change	ξ	–	–	**−.65***	**.26**
Final score on problem solving	ω	**.79***	**.14**	**−.45***	**.16**
		Easy		Hard	
Problem solving loadings	χ	1	0	.61*	.06
Random effects					
Univariate		PE	SE	PE	SE
Intercept variance	σ^2_{y0}	.03*	.04	.04*	.01
Slope variance	σ^2_s	.00*[a]	.00[a]	.04	.03
Covariant slope and level	$\sigma_{y0,s}$	−.00[a]	.01	.03	.02
Unique variance	σ^2_u	.02*	.00[a]	.01*	.00[a]
Bivariate			PE	SE	
WM intercept–Worry intercept variance	$\sigma_{y0,y0}$		−.01	.00[a]	
WM intercept–Worry slope variance	$\sigma_{y0,s}$		−.02	.01	
WM slope–Worry intercept variance	$\sigma_{s,y0}$		.01*	.00[a]	
WM slope–Worry slope variance	$\sigma_{s,s}$		.01	.01	
Observed WM–Worry score variance	$\sigma_{u,u}$		−.00[a]	.00[a]	

Note: Bold text indicates the statistically significant dynamic parameters that describe the interplay between WM and Worry, and problem solving.
PE, parameter estimate; SE, standard error of the parameter estimate.
[a]indicates value <.01.
*p < .05.

possible that changes lessen over time; however, our model suggests a multiplier effect between WM and Worry over time.

In summary, the model shows that for an individual with initial high WM and low Worry, it is likely WM capacity will be maintained, Worry be maintained/decrease, and algebraic problem solving accuracy will be high. For an individual with initial large WM and high Worry, WM will decrease, Worry will remain stable and algebraic problem solving accuracy will be moderately high. For an individual with initial small WM and low Worry, WM will decrease slightly, Worry increase and algebraic problem solving accuracy will be low to moderate. For an individual with small WM and high Worry, the equations shows a steep decline in WM, a positively accelerating increase in Worry and low algebraic problem solving accuracy.

DISCUSSION

The present study investigated the iterative influences of Worry and WM on each other over a single day, and their impact on algebraic problem solving. The research provides evidence, for the first time, of (1) the direction of influence between WM and Worry, and (2) the changing nature of influences in the WM–Worry relationship over time, and how these changes affect problem solving. We have shown high Worry scores predict decreases in

WM capacity, and small WM capacity, or decreases to WM capacity predict increases in Worry (supporting Hypothesis 1c). The findings demonstrate dynamic changes in WM and Worry over a short time period, supporting Hypothesis 2b. Consistent with previous research and Hypothesis 3, the findings also suggest math problem solving is positively associated with WM, and negatively associated with Worry scores.

The study shows that WM capacity and Worry may change within a short time frame (e.g., a math class or test). Our model suggests the effect of Worry on WM (and problem solving) differs depending on WM capacity; and the effect of WM on Worry (and problem solving) differs depending on Worry level. WM and Worry showed changes that varied across time, rather than decreasing/increasing linearly. Moreover, these changes to WM and Worry affected problem solving abilities. On the basis of the final model, a student with initial higher WM and lower Worry will likely maintain WM and Worry levels, and algebraic problem solving accuracy would remain high. Conversely, for a student with low WM and high Worry, WM is likely to decrease, Worry increase and problem solving would be impaired. Thus, the model suggests that what begins as relatively small differences between individuals in WM and Worry, through their mutual iterative influences, would lead to much larger differences. Moreover, it appears that individuals with low WM and/or high Worry may be more vulnerable to changes, so that their initial disadvantage may amplify.

The model fit indices suggest that high Worry predicts WM decreases, supporting MA and general anxiety-performance research (e.g., Ashcraft & Kirk, 2001; Brunyé et al., 2013; Eysenck & Derakshan, 2011) that anxiety increases cognitive demands, resulting in reduced processing capacity available for WM. The model also suggests that increases in Worry ratings are predicted by low or decreases to WM scores, and increased WM predicts subsequent Worry decreases. The relationship may be a direct influence, in which WM regulates Worry responses, supporting emotion regulation research (Hofmann et al., 2011). Alternatively, WM may affect Worry indirectly: WM may predict problem solving, and students' Worry may be affected by performance. This indirect effect may support the notion that deficits in cognitive abilities are responsible for poor math problem solving and associated with increases in MA/Worry (Jansen et al., 2013; Ma & Xu, 2004; Maloney et al., 2011).

The findings highlight the importance of accounting for the relationship between WM and worry/MA, in examining the effect of WM or MA on math problem solving. Not accounting for the reciprocal relationship between MA and WM reduces the interpretability of findings. Accounting for WM–MA relationships in more traditional single time point studies could be achieved by examining individual profiles of WM/MA relationships. As noted by Trezise and Reeve (2014b), in single time point studies analytical techniques that group individuals based on their response patterns for WM and MA (e.g., latent class analysis) will likely lead to a more complete characterisation of the impact of WM or MA on math performance. Our findings also highlight the importance of assessing emotion–cognition relationships over time to examine changes within MA/WM relationships over time. Assessing WM and/or MA at multiple time points and using analytic methods that allow a characterisation of the stability and/or change in the interaction among factors (e.g., WM and MA) in individuals may provide a more complete account of the dynamic relationship between cognition and emotion.

Our online worry assessment procedure shows that Worry changes within a test session. Most measures of MA are questionnaire based (for example, the Abbreviated Math Anxiety Scale; Hopko, Mahadevan, Bare, & Hunt, 2003), and scores tend to be related to math problem solving or WM. Questionnaire measures are not designed to assess within task movements. Assessing the worry/anxiety students exhibit over time allowed us to examine whether their worry/anxiety relationships remained stable or changed (i.e., and ipso facto whether MA has trait or state properties). The findings show MA may fluctuate over short time periods (e.g., a math class), consistent with a state interpretation of MA. Distinguishing between trait and state MA, and their respective effects on math problem solving is an important issue for further research. Understanding the temporary (or stable) nature of MA may provide useful information for those interested in the prevention and/or treatment of MA.

In our study, context remained constant throughout the study: all stimuli were algebraic, the level of difficulty for the WM and Worry tasks remained constant and students received no feedback. However, the WM–Worry relationship may change with age, or in response to context, such as feedback, pressure or domain. The extent of change in WM and/or Worry may be smaller in an adults compared to the adolescent sample used in our research (see Steinberg, 2005). Providing students with feedback while progressing (for example, about the correctness of their responses) may change Worry ratings: Worry has been shown to increase after negative feedback, and decrease after positive feedback (Daniels & Larson, 2001; Morris & Fulmer, 1976; Morris & Liebert, 1973). Pressure (e.g., test situations) may also affect the WM–worry relationship. We assessed algebraic problem solving at the end of the day. If students had also completed an initial algebraic problem solving test, it may have affected the initial WM/Worry scores. A change in context (e.g., a change in domain) may also weaken the WM–worry relationship. Research has shown that changing domains can alter cognitive/emotional states (Ilkowska & Engle, 2010; Punaro & Reeve, 2012). We therefore worried that changing domains between tasks (e.g., a language WM task and an algebraic worry task) might have affected the WM–Worry relationship. Even changes between math domains may affect WM–Worry relationships. Algebra is a relatively new math domain for early high school students and requires formal reasoning ability (Tolar et al., 2009). Conversely, arithmetic is a well-learned domain and involves more fact-retrieval which places less demand on WM (Imbo & Vandierendonck, 2007, Raghubar et al., 2010). Further research is required to better understand the WM–Worry interactions for variations in context.

We used a WM task with alphanumeric symbols in order to assess domain-specific WM, and its relationship with algebraic problem solving. Changes in algebraic WM span likely reflect changes in individual's ability to access and process (i.e., WM capacity) alphanumeric symbols, rather than fluctuations in algebraic expertise over a single day. WM span showed an overall decrease across time; however, there was a slight increase in WM span between Set 3 and Set 4. The change may reflect distributed practice effects: learning is enhanced when a time lag separates study episodes (spaced practice), compared to when items are learned in a single episode (massed practice; see Cepeda, Pashler, Vul, Wixted, & Rohrer, 2006). The changes may also be associated with performance decrements that have been observed in time-on-task fatigue effects research (see Hockey, 2013; Matthews, Davies, Westerman, & Stammers, 2000): whether individual differences in WM and Worry are similarly associated with fatigue onset is an issue for further research.

Bivariate latent difference modelling has advantages over other methods of addressing hypotheses about dynamic relationships among variables. The model found a large regression weight of WM change on Worry change, but also large variability. This finding suggests that there may be latent categorical individual differences the effects of WM on Worry, which were unable to be fitted in the model. Future research should examine possible categorical differences in WM-Worry influences.

Conclusions

In sum, the present study demonstrates that WM and Worry influence each other iteratively over time. Research examining these relationships has often focused on one direction of the influence and assumed stability. Our findings reveal more complex relationships: there is a bidirectional influence between students' WM and Worry, and levels of WM and Worry change considerably within one day. These changes ultimately affect math problem solving. Of significance, individuals with low WM and/or high Worry may be more vulnerable to changes: their initial disadvantage may become amplified over time. Moreover, the study has demonstrated considerable changes in both cognition and emotion. It is important to further characterise these changes by exploring how the cognition–emotion relationships vary in response to external factors, such as feedback or domain.

Disclosure statement

No potential conflict of interest was reported by the authors.

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