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Changes in verbal and visuospatial working memory from Grade 1 to Grade 3 of primary school: Population longitudinal study

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ABSTRACT

Background: Adaptive working memory training is being implemented without an adequate understanding of developmental trajectories of working memory. We aimed to quantify from Grade 1 to Grade 3 of primary school (1) changes in verbal and visuo-spatial working memory, and (2) whether low verbal and visuo-spatial working memory in Grade 1 predicts low working memory in Grade 3.

Method: Design: Population-based longitudinal study of 1802 children (66% uptake from all 2747 Grade 1 students) at forty-four randomly-selected primary schools in Melbourne, Australia. Measures, Grades 1 and 3 (ages 6-7, 8-9 years): Backwards Digit Recall (verbal working memory) and Mister X (visuo-spatial working memory) screening measures from the Automated Working Memory Assessment (Mean 100; Standard deviation 15). Low working memory was defined as ≥1 standard deviation below the standard score mean. Descriptive statistics addressed Aim 1, and predictive parameters addressed Aim 2.

Results: 1070 (59%) of 2747 Grade 1 participants were reassessed in Grade 3. As expected for typically developing children, group mean standard scores were similar in Grades 1 and 3 for verbal, visuo-spatial and overall working memory, but group mean raw scores increased markedly. Compared to 'not low' children, those classified as having low working memory in Grade 1 showed much larger increases in both standard and raw scores across verbal, visuo-spatial and overall working memory. Sensitivity was very low (<0.13) for Grade 1 low working memory predicting Grade 3 low classifications.

Conclusion: While mean changes in working memory standard scores between Grade 1 and 3 was minimal, we found individual development varied widely, with marked natural resolution by Grade 3 in children who initially had low working memory. This may render brain-training interventions ineffective in the early school year ages, particularly if (as population-based programs usually mandate) selection occurs within a screening paradigm.

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BACKGROUND

Children's working memory has a pivotal role in health and education outcomes (Gathercole and Pickering 2000, Alloway 2009, Gathercole *et al.* 2008). This cognitive function enables individuals to temporarily store, process and manipulate verbal and visuo-spatial information (Baddeley 2000). During childhood, working memory is closely associated with a range of abilities including language development (Montgomery *et al.* 2010), formation of long-term memory (Lum *et al.* 2015), and mathematics and literacy (Gathercole and Pickering 2000, Alloway *et al.* 2009, Alloway and Alloway 2010, Gathercole *et al.* 2004, Monette *et al.* 2011). Despite this, little is known as to how working memory develops during the early years of primary school.

The suggestion that working memory may be malleable within individuals (Alloway *et al.* 2009) has influenced the development of computerised adaptive training programs in different settings that aim to activate and improve working memory abilities (Melby-Lervåg and Hulme 2013). Adaptive programs may be implemented with young children in a variety of settings when low working memory is identified following screening, surveillance or clinical presentation. The translational effectiveness of such programs has not been proven (Jacob and Parkinson 2015) for children with low working memory. This approach requires that programs target children whose low working memory would not otherwise recover – which in turn requires a sound knowledge of its developmental trajectory across the early school years. At present, little is known about the stability of working memory over this period.

Working memory components mature across childhood (Alloway and Alloway 2013, Alloway *et al.* 2006, Gathercole *et al.* 2004, Roberts *et al.* 2015, McAuley and White 2011, Michalczyk *et al.* 2013, Egami *et al.*). For instance, Gathercole et al.(Gathercole *et al.* 2004) found a significant positive linear association between age and performance for verbal and visuo-spatial storage and verbal manipulation in 736 children aged 4 to 15 years. These age-related differences are likely to reflect brain maturation processes such as an increase in storage capacity and improved processing efficiency (Cowan *et al.* 2011, Riggs *et al.* 2006,

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Alloway *et al.* 2006, Pentland *et al.* 2003). Formal education could also play a role; we recently reported that increases in working memory in Grade 1 children were strongly associated with time spent in school, even after accounting for chronological age (Roberts *et al.* 2015).

However, knowledge of these age-related increases is based almost entirely on cross-sectional data. Little is known about the longitudinal growth and stability of working memory over time *within* children, either in the general population or for those with low working memory abilities. Ideally, working memory remediation interventions would only be administered to those whose low working memory would otherwise persist, and not to those whose low working memory would resolve spontaneously. This requires sensitive, specific predictive tools capable of identifying this subgroup. If such programs are to be considered at the school level, these tools would need to be short and easily administered.

We sought to address these research gaps in a longitudinal school-based population study of Grade 1 children (aged 6-7 year old) followed up two years later with repeated measures of verbal and visuo-spatial working memory. Using short screening measures suited to the school setting, our aims were to:

1. Quantify the mean change in raw and standard working memory screening scores over a two year period from Grade 1 to Grade 3, for (a) the total sample and (b) children with and without low working memory screening scores at Grade 1; and
2. Estimate the predictive parameters of low working memory scores (ie. Sensitivity and specificity) in Grade 1 for later low working memory in Grade 3.

METHODS

Study Design

Data were drawn from the population-based cohort which formed the screening sample for the Memory Maestros trial (Roberts *et al.* 2016), based in metropolitan Melbourne, Victoria, Australia. Ethical approval was obtained from the Human Research Ethics

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Committee at the Royal Children's Hospital, with school research approval from the Victorian Department of Education and Training and the Catholic Education Commission of Victoria.

Participant Recruitment

Children were recruited in 2012 from 44 primary schools within a 20-kilometre radius of the Royal Children's Hospital, Melbourne. Eligible schools were approached in a random order using a random number list generated by an independent statistician. Recruitment continued until the required sample size for the trial was achieved, with a proportional number of schools from each of the government, Catholic and independent sectors.

Parents of all Grade 1 students (mean age 6.9 years, SD = 0.4) were approached to participate via a recruitment pack sent home by the classroom teacher. Grade 1 is the second year of primary school in the state of Victoria. Children participated in the study if parents returned a completed written consent form. A similar approach was used in 2014 to obtain consent for follow-up assessments when children were in Grade 3 (mean age 8.1 years, SD = 0.4).

Exclusion Criteria

Children were excluded if their parent reported on the enrolment survey an intellectual or physical problem likely to prevent them from completing the assessments (e.g. hearing or visual impairments). A developmental paediatrician (GR) telephoned these parents to discuss the condition before exclusion. Intervention children were also excluded from the current study (n=226) as the intervention aimed to improve working memory.

Data Collection

When children were in Grade 1 and 3, a trained researcher completed an individual working memory assessment with each child during school hours. Researchers were blinded

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to the child's initial assessment scores, whether they were in the trial subsample, and if so, their intervention status.

Measures

Working memory was assessed at both time points using the same two subtests from the validated Automated Working Memory Assessment (AWMA) (Alloway 2007), which took 15 minutes per child. Both subtests have successfully been used previously to identify children with low working memory(Holmes *et al.* 2009). Verbal working memory was assessed using the Backward Digit Recall subtest, in which progressively longer spoken strings of digits are presented and the child is required to recall these in the reverse sequence. Visuo-spatial working memory was assessed using the Mister X subtest. The child is presented with two cartoon figures, and has to judge whether the pair are holding a ball in the same hand or not. The figure on the right is rotated and presented in one of six possible rotated locations, and the child has to keep in mind the location of this ball. The child is then presented with another pair of figures and has to judge whether the pair are holding a ball in the same hand or not, and again the figure on the right is rotated and the child has to keep in mind the location of the ball. At the end of the sequence, the child is presented with a circle made of six dots and are required to point to the location of the ball held by the figure on the right in the first pair and in the second pair. This reflects a span of two, and the span increases progressively. This task requires the children to visually identify, manipulate and recall information as the stimuli sequence progressively gets longer. The 1 month test-retest reliability coefficient for Backward Digit Recall is 0.86 and for Mister X is 0.84. We used continuous raw scores and standard scores *(M*=100; *SD*=15) to examine working memory change over time. The raw scores correspond to the number of trials correctly answered on each subtest; higher raw and standard scores indicate better working memory. In addition, we created an overall working memory score using the mean of the standard and raw scores for the two subscales at each time point. Overall correlations are shown in Supplementary Table 1. Change in scores from Grade 1 to 3 were calculated separately for verbal, visuo-spatial and overall working memory.

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Varied criteria have previously been used to identify children with low working memory (Alloway *et al.* 2009, Gathercole and Alloway 2006). Based on a review by Gathercole and Alloway (Gathercole and Alloway 2006) of approaches used to diagnose working memory impairment, we defined at both time points a child as having "low" screening verbal or visuo-spatial working memory if their standard score was more than one standard deviation below the normative mean.

Statistical Analysis

All analyses were completed in Stata 15.0 (Statacorp, 2017). Descriptive statistics were used for sample demographic variables, and for verbal and visuo-spatial working memory scores in Grade 1 and 3.

For overall growth in children's verbal and visuo-spatial working memory scores, we present change scores from Grade 1 to 3 for (a) the total sample and (b) the children with and without initially low scores on each of the two subtests. Unadjusted and adjusted linear regressions were conducted to determine whether changes in working memory scores differed between children who were classified as having low scores in Grade 1, compared to those who did not. Adjusted regressions included *a priori* confounders of child sex, parent education level (did not complete high school, completed high school, completed college degree) and English as main language at home. All regressions included robust regression techniques, accounting for clustering of children within schools in which the variance estimates are adjusted to account for similarity between children within schools.

To determine how well low Grade 1 working memory scores predicted low scores at Grade 3 (Aim 2), we calculated the sensitivity, specificity, and positive and negative predictive values for children defined as low/not low for each subtest at Grade 1 versus these same parameters at Grade 3. In addition, we conducted Receiver Operating Characteristic (ROC) analyses (Zweig and Campbell 1993) to determine if there were any optimal cut-points in standard Grade 1 scores that would accurately predict low Grade 3 working memory in each domain. Optimal cut-points were determined using Youden's Index (Fluss *et al.*

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2005), which estimates the value on the predictor measure with greatest sensitivity and specificity to detect a given at-risk group.

For our sensitivity analyses, we repeated all the above analyses with the intervention children included in the sample, ie combining all 'low' children irrespective of intervention status (See Supplementary Table 1-2, and Supplementary Figure 1). Control children's findings alone are presented in this manuscript to avoid potential modification from the natural history of working memory by the intervention. However, findings were virtually identical for analyses with and without the intervention children included in the sample.

RESULTS

Participant and Family Characteristics

A total of 1802 (66%) of those approached had parental consent to participate and completed a working memory screening in Grade 1, when aged 6 to 7 years. Two years later in Grade 3, 1070 of these children (59% of the recruited Grade 1 cohort) again completed assessments, providing the analysed sample for this paper (see Figure 1). The characteristics of children in Grade 1 who did and did not participate in working memory testing at Grade 3 were similar on all variables (Table 1).

Change in Working Memory Scores from Grade 1 to Grade 3

Table 2 presents the change in working memory scores on the two subtests separately and combined from Years 1 to 3 for the total sample, as well as for those classified as low/not low. Mean raw scores increased for every measure in every group (whole sample, low and not low), in keeping with age-related cognitive development.

Mean standard scores for the whole sample were close to 110 on all three measures at baseline, indicating that our sample out-performed the normative population. These scores were relatively stable two years later, on average falling slightly by around 2 to 4 points by Grade 3. Findings were similar for the 'not low' group, though with a slightly larger fall of around 3 to 5 standard points. In contrast, mean standard scores rose markedly for those in

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the low working memory groups: 19.0 (95% CI 14.9 to 23.0) points for verbal, 20.5 (95% CI 16.8 to 24.1) points for visuo-spatial, and 15.0 (95% CI 10.6 to 19.5) points for overall working memory respectively. This very marked improvement for the low working memory groups brought their verbal and visuospatial working memory scores to within half a standard deviation below the whole sample mean, and their overall mean scores to within one standard deviation. Table 2 reports the highly significant differences in change scores for each measure between the low and not low groups, and Figure 2 illustrates these differing trajectories graphically.

Stability of Low Working Memory

Table 3 presents the proportions of children in the low and not low working memory groups at Grade 1 and Grade 3. Specificities for normal scores in Grade 1 predicting a normal score at Grade 3 were very high, at 0.95 (95% CI, 0.93 to 0.96) for verbal working memory and 0.95 (95% CI, 0.93 to 0.96) for visuo-spatial working memory. Conversely, the sensitivities of a low Grade 1 working memory score in identifying children with a low working memory score two years later were extremely low at 0.12 (95% CI, 0.07 to 0.20) and 0.10 (95% CI, 0.04 to 0.22) for verbal and visuo-spatial working memory, respectively. Thus, most (85% and 90%) children were not low at either time point for verbal and visuo-spatial working memory, respectively, while very few were categorised with low working memory at both time points (less than 2% and less than 1% for verbal and visuo-spatial working memory respectively). Of those classified as low in Grade 1, 79% and 90% respectively had normal scores in Grade 3, while the majority of children classified as low in Grade 3 were not previously categorised as having low working memory in Grade 1 (see Table 3).

Findings for overall working memory were similar, with specificity 0.98 (95% CI 0.97 to 0.99) and sensitivity 0.25 (95% CI 0.11 to 0.47). Therefore, 0.56% of children were classified as low at both time points, with 75% of children classified as low in Grade 1 no longer meeting the criteria for low working memory in Grade 3. Only 1.7% of children not classified as low at both time points.

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Determination of optimal cut-points using Receiver Operating Characteristic curves (Figure 3)

ROC analyses did not reveal any optimal threshold in Grade 1 scores that could predict low working memory in Grade 3 as all thresholds were within the expected normal range (i.e. standard score between 85 – 115) of working memory ability in Grade 1.". For verbal working memory, the area under the curve (AUC) was 0.65 (95% CI 0.60 to 0.69). Youden's Index indicates the optimal cut-point to be a standard score of 105 in Grade 1, which has a sensitivity of 0.66 and specificity of 0.55 for low verbal working memory in Grade 3. For visuo-spatial working memory, the AUC was 0.63 (95% CI 0.56 to 0.69) and optimal cut-point for Grade 3 low verbal working memory was a standard score of 106 (sensitivity = 0.66, specificity=0.53) in Grade 1. For overall working memory, the AUC was 0.75 (95% CI 0.66 to 0.85) and optimal cut-point was a standard score of 105 (sensitivity = 0.71, specificity=0.57). Even these "optimal" cutpoints would identify around half of all Grade 1 children as likely to be low in Grade 3, while still having unacceptably low sensitivity.

DISCUSSION

Our findings demonstrate marked instability in both raw and standardized working memory screening scores in the early school years at the individual child level, even though mean standard scores for all three measures appeared stable across this two year period. As a group, children classified as having low working memory in Grade 1 had scores very close to normative values by Grade 3. Therefore, low working memory in Grade 1, defined by a short screening measure, had very low sensitivity in predicting children with low working memory in Grade 3, with <2% of children classified as low at both time points. ROC analyses did not reveal any adequate optimal threshold in Grade 1 scores that could adequately predict low working memory in Grade 3. Taken together, these findings could explain not only why working memory training enjoys great popularity (working memory will inevitably improve

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post-training), but also why its effectiveness has not been borne out in rigorous randomized trials (Roberts *et al.* 2016), the inevitable improvement is largely unrelated to the training.

Our longitudinal finding that mean standard working memory scores remained relatively stable between Years 1 and 3 of primary school is consistent with past cross-sectional studies (Alloway and Alloway 2013, Alloway *et al.* 2006, Gathercole *et al.* 2004), as are the observed marked increases in raw scores. These latter findings align with current theories suggesting that average storage capacity and/or efficiency in speed of executing processes increase as the brain matures with age (Cowan *et al.* 2011, Alloway *et al.* 2006, Bayliss *et al.* 2003). However, there was marked inter-individual variability, with the largest increases in performance in children with low working memory scores in Grade 1.

These results suggest that working memory development varies between Grade 1 and 3 of primary school. As for other growth and developmental characteristics, individual children do not necessarily longitudinally follow cross-sectional population centiles. For example, a population study examining the related construct of IQ across the ages 7, 9, 11 and 13 years reported that "in a nontrivial minority of children, naturalistic IQ change is marked and real, but this change is variable in its timing, idiosyncratic in its source and transient in its course (Page 444)" (Moffitt *et al.* 1993). Neuroimaging studies in adolescents also suggest that the development of executive functions, including working memory, may include developmental spurts, deceleration and dip aligning with biological development (Vijayakumar *et al.* 2014). These change patterns in working memory development could manifest in other areas such as decreased school engagement, increased conduct difficulties and risk taking behaviour. However, both natural variation and its manifestations across the full age span of the school years remain conjectural in the absence of longitudinal studies that repeatedly measure working memory over this period.

To our knowledge, this is the first study to primarily examine working memory stability in children with low working memory using a longitudinal design. Therefore, no previous studies are available for comparison. Our findings suggest caution is required in current approaches to identifying children as potential candidates for working memory

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remediation, as well as how changes in intervention scores are interpreted when control groups are not available. Our findings also provide a platform for future research that investigates how working memory develops within individuals over time. This could explore whether certain patterns of development exist across the life course, how these patterns may influence functional outcomes such as academic achievement and behavior, and what factors may influence whether children with low working memory do or do not catch up to their peers.

Some limitations should be considered. We relied on the AWMA UK normative data, for which it is expected that 16% of children demonstrate working memory more than one standard deviation below the mean. In our study, only 5.7% and 5.5% of children were low on the verbal and visuo-spatial working memory subtests, respectively. This may be due to the intervention children being excluded from the primary analyses, as the intervention may have modified the natural history of working memory, despite the trial not demonstrating any differences in working memory between the intervention and control arms. However, even with the intervention children included, these figures were 10.8% and 8.1%, respectively. The higher figure may be more representative of the population-level prevalence, but it is difficult to determine given the intervention arm. This could mean that the AWMA UK normative data underestimate low working memory for Australian children, or that our relatively advantaged sample had better scores than those not recruited. Unfortunately, there are currently no validated working memory assessments that provide Australian norms. To examine the effect that this may have had on our findings, we conducted post-hoc sensitivity analyses using internally standardised scores derived from the AWMA raw scores for each child. Findings were similar in these analyses, suggesting that our findings were not influenced by the lack of Australian norms for this measure. Also, considering working memory as a continuous variable, short-term test retest reliability is high but longer-term stability is uncertain. This could be addressed by more accurate personalised predictive information, but this is not yet a reality.

A further limitation is that, although validated and widely used, our two-subtest working memory screens might simply have lacked the depth and/or breadth to identify

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children who will experience persistently low working memory: ie, children's working memory development could in fact be steady and stable if measured adequately. However, the trade-off is that longer, more divergent assessments would be difficult if not impossible to implement systematically within the school setting. Our study's tools were necessarily selected to accommodate population coverage. Furthermore, it is not clear whether the observed increases in the low working memory group in this study extend to other facets of working memory. Future research could focus on more comprehensive assessments of working memory, in order to enable evaluation of different components of verbal and visuo-spatial working memory.

In conclusion, standard working memory scores were not stable for individual children over a two year period, despite relatively stable group mean standard scores in working memory performance, especially those with low working memory. Using these measures, it would be hard to justify remediation, given that virtually all children with low verbal and visuo-spatial scores in Grade 1 had resolved spontaneously by Grade 3. Further longitudinal research could investigate how working memory develops in individual children over time, and whether there are developmental periods where intervention following screening for working memory may yield greater benefit.

KEY MESSAGES

- There was expected working memory development changes between Grade 1 and 3
- However, individual development varied greatly, with children identified as low in Grade 1 having the greatest increase in verbal, visuo-spatial and overall working memory
- Screening for low working memory in Grade 1, using a brief screener, had low sensitivity in predicting low working memory in Grade 3
- Further longitudinal research is required to understand how working memory develops over time in individual children to inform whether there are optimal intervention periods

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Table 1. Memory Maestros baseline characteristics; all values except age are n (%)

Baseline characteristic	Recruited Cohort (N=1802)	Retained	
		Yes (n=1070)	No (n=732)
Child			
Age, mean ± SD	6.9 ± 0.4	6.9 ± 0.4	6.9 ± 0.4
Male	918 (51)	543 (51)	375 (51)
Extra Assistance at School			
Extra learning support (e.g. reading recovery)	228 (13)	115 (11)	113 (15)
Special education group/class	85 (5)	45 (4)	40 (5)
Integration aide	51 (3)	21 (2)	30 (4)
Speech therapy	124 (7)	70 (7)	54 (7)
Other help	99 (5)	46 (4)	53 (7)
Automated Working Memory Assessment, mean ± SD			
Backwards Digit Recall			
Raw	10.2 ± 3.2	10.1 ± 3.2	10.4 ± 3.1
Standard Scores	107.5 ± 13.7	107.1 ± 13.9	108.7 ± 13.2
Mister X			
Raw	8.5 ± 3.4	8.3 ± 3.4	8.9 ± 3.2
Standard Scores	110.9 ± 14.8	110.0 ± 15.0	113.2 ± 14.0
Primary Caregiver			
Biological Parent	1747 (97)	1054 (99)	693 (95)
Male	223 (12)	122 (11)	101 (14)
Married / De Facto	1566 (87)	960 (99)	606 (83)
Highest Education Level			
Did not complete high school	186 (10)	105 (10)	81 (11)
Completed high school only	114 (6)	64 (6)	50 (7)
Completed further education	1204 (67)	761 (71)	443 (61)
Household			
English main language at home	1484 (82)	924 (86)	560 (77)
Government Support Card	292 (16)	146 (14)	146 (20)
Income in AU$ before tax			
<$650 per week	154 (9)	74 (7)	80 (11)
$650 - $999 per week	145 (8)	73 (7)	72 (10)
$1000 - $1399 per week	187 (10)	111 (10)	76 (10)

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$1400 - $1999 per week	307 (17)	190 (18)	117 (16)
>$2000 per week	897 (50)	581 (54)	316 (43)

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Table 2. Changes in standard and raw scores for (a) verbal and (b) visuo-spatial and (c) overall working memory

Variable	N	Mean (SD)		Between Grade 1 & 3 Mean Diff (95% CI)	Mean Diff (95% CI) between low and not low			
		Grade 1	Grade 3		Unadjusted	p-value	Adjusted[a]	p-value
Verbal								
Standard Scores								
Whole population	1068	107.5 (13.7)	105.1 (15.5)	-1.9 (-2.9 to -0.9)				
Low	110	78.2 (7.9)	97.8 (15.0)	19.0 (14.9 to 23.0)	22.1 (17.7 to 26.5)	<0.001	23.2 (17.9 to 28.5)	<0.001
Not Low	958	108.9 (12.3)	105.6 (15.1)	-3.2 (-4.1 to -2.2)	Ref		Ref	
Raw Scores								
Whole population	1068	10.2 (3.2)	13.2 (4.4)	3.0 (2.8 to 3.3)				
Low	110	3.8 (2.2)	11.5 (4.9)	7.5 (6.2 to 8.8)	4.7 (3.5 to 5.9)	<0.001	5.1 (3.6 to 6.6)	<0.001
Not Low	958	10.5 (2.9)	13.3 (4.3)	2.8 (2.5 to 3.0)				
Visuo-spatial								
Standard Scores								
Whole population	1070	111.0 (14.8)	106.3 (13.9)	-3.6 (-4.6 to -2.6)				
Low	58	79.7 (4.4)	100.4 (13.8)	20.5 (16.8 to 24.1)	25.5 (22.5 to 28.6)	<0.001	26.1 (22.5 to 29.6)	<0.001
Not Low	1012	112.4 (13.5)	106.7 (13.9)	-5.0 (-6.0 to -4.1)	Ref		Ref	
Raw Scores								
Whole population	1070	8.5 (3.4)	11.8 (4.4)	3.6 (3.3 to 3.8)				
Low	58	1.5 (1.0)	10.5 (6.2)	8.9 (7.4 to 10.5)	5.7 (4.3 to 7.1)	<0.001	5.3 (4.2 to 6.3)	<0.001
Not Low	1012	8.8 (3.1)	11.9 (4.2)	3.3 (3.0 to 3.5)	Ref		Ref	
Overall								
Standard Scores								
Whole population	1068	109.3 (11.5)	105.7 (11.8)	-3.6 (-4.6 to -2.6)				

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Low	24	79.2 (5.6)	94.6 (13.9)	15.0 (10.6 to 19.5)	18.2 (13.4 to 23.0)	<0.001	16.5 (11.6 to 21.4)	<0.001
Not Low	1044	109.8 (10.8)	106.0 (11.5)	-3.2 (-3.9 to -2.4)	Ref		Ref	
Raw Scores								
Whole population	1070	9.3 (2.6)	12.5 (3.5)	3.3 (3.1 to 3.5)				
Low	24	2.7 (1.3)	10.3 (6.2)	7.5 (5.3 to 9.8)	4.3 (1.7 to 7.0)	0.002	3.4 (1.4 to 5.4)	0.002
Not Low	1044	9.5 (2.5)	12.5 (3.4)	3.2 (3.0 to 3.4)	Ref		Ref	

a Adjusted regressions included *a priori* confounders of child sex, parent education level (did not complete high school, completed high school, completed college degree) and English as main language at home

Table 3. Percentage of children classified with low and not low (a) verbal and (b) visuo-spatial working memory at both Grade 1 and 3

(a) Verbal	Grade 3		
Grade 1	Low n (%)	Not low n (%)	Total
Low working memory	13 (1.2)	48 (4.5)	61
Not low working memory	97 (9.1)	910 (85.2)	1007
Total	110	958	1068

(b) Visuo-spatial	Grade 3		
Grade 1	Low n (%)	Not low n (%)	Total
Low working memory	6 (0.6)	53 (5.0)	59
Not low working memory	52 (4.9)	959 (89.6)	1011
Total	58	1012	1070

% value is out of overall total, 2 children did not have verbal working memory scores at both time points but did have visuo-spatial scores.

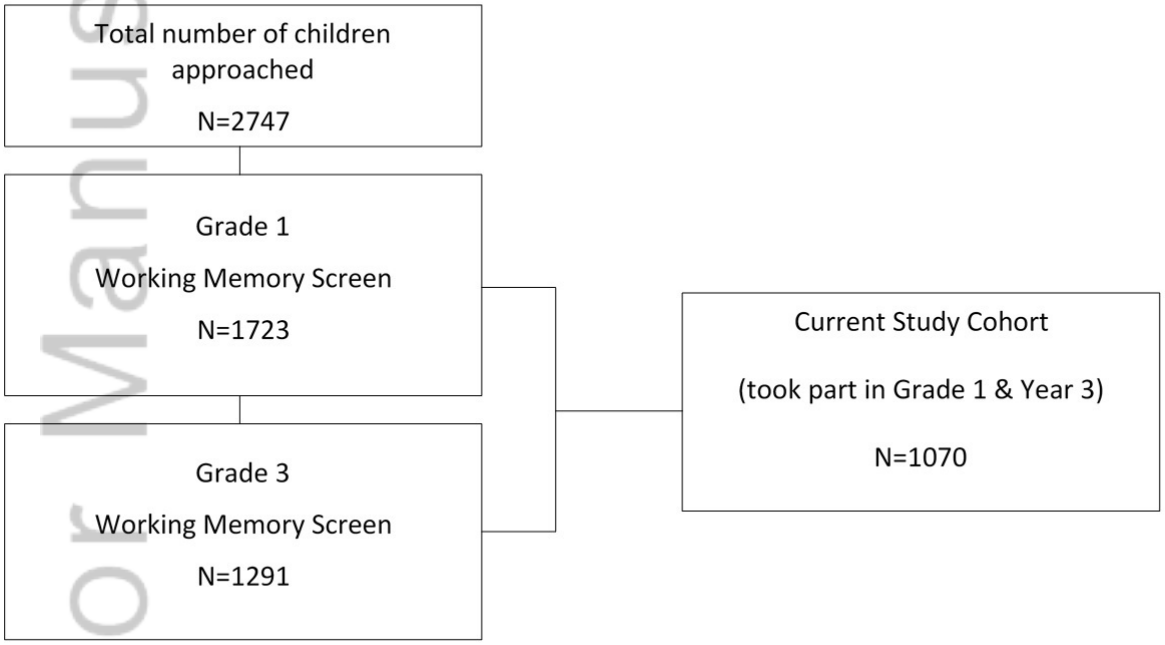
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