Schooling Duration Rather Than Chronological Age Predicts Working Memory Between 6 and 7 Years: Memory Maestros Study

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ABSTRACT: ***Objective:*** **Low working memory (WM) is strongly linked with poor academic outcomes. WM capacity increases across childhood but how exposure to school is associated with WM development is not known. We aimed to determine extent to which chronological age and schooling duration are associated with WM at the population level.** ***Methods:*** **In 2012, children in Grade 1 (the second year of formal schooling in Victoria, Australia) from 44 schools in metropolitan Melbourne were recruited. Assessments occurred over the entire school year, with schools quasi-randomly allocated to one of the 4 school terms. WM (primary outcome) was measured using 2 subtests from the computerized Automated Working Memory Assessment: Backwards Digit Recall (verbal) and Mister X (visuospatial). Linear regression was used to examine relationships of WM with time in school and age.** ***Results:*** **Of the 1765 who provided consent, 1727 children (97.9%) had WM assessed throughout the 2012 school year. WM scores became steadily higher over the course of the year. Thus, scores were .77 and .53 SDs higher in Term 4 than Term 1 for verbal and visuospatial WM, respectively (*p* values for trend for both scores <.001); conclusions were unchanged when adjusted for age and potential confounders. Conversely, age associations attenuated fully once adjusted for school duration.** ***Conclusions:*** **Our results demonstrate, for the first time, that the developmental increases in WM are strongly associated with time spent in the classroom, above and beyond chronological age.**

(*J Dev Behav Pediatr 36:*68–74, 2015) **Index terms:** memory, short-term, exposure to school, child development, population-based cohort, cross-sectional studies.

Working memory (WM) is a key cognitive system linked with learning during the early years in school.[1] This system supports temporary limited-capacity memory storage and manipulation[2] and in children, low WM abilities are typically accompanied by poor academic outcomes.[3] Interventions designed to promote WM development have rapidly gained traction during the early school years, although as yet there is only limited evidence that the associated WM benefits lead to improved classroom function.[4]

WM varies greatly between individuals and increases across childhood.[5,6] Although the essential building blocks of WM are present during the preschool period, there is a period of rapid growth of these skills in early childhood, with slower growth in middle childhood and young adulthood.[7] Cross-sectional studies of children at various ages have demonstrated increasing WM with increasing chronological age.[2] Therefore, the early years of school could represent an important period when identification and intervention might optimize WM development.

Children start school with a range of WM abilities.[8] Biological risk factors such as preterm birth are known to adversely influence WM.[9] The role of other environmental risk factors such as social adversity is less clear, although overall executive functioning does seem to be affected by adverse early childhood experiences.[10] The age of school commencement varies within schools and across jurisdictions, and this may be another reason for diversity in WM abilities. Caregivers and teachers may play a particularly important role in scaffolding WM development through the provision of consistent nurturing early childhood environments.[11]

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During the first years of school, when WM is developing rapidly, it is not known whether a structured classroom environment plays a role in supporting WM. Simply after a longitudinal cohort of young children and measuring their WM development over time would not be able to answer this question as once a child has started school, age would be perfectly correlated with the time spent in the classroom. A population-based cohort recruited in the early years of school, where groups of children have WM measured at effectively random points during the course of an entire school year, enables this question to be examined. If the time exposed to the structured classroom environment has an independent effect, over and above actual age, in predicting WM development in this narrow window, this finding will have important implications for (1) timing of screening for low WM in early childhood and (2) enrolling children in intensive intervention programs that potentially disrupt the classroom schedule. In other words, to provide value, intervention effects would need to exceed the natural growth of WM development over a year of formal structured education. However, the latter has not been documented.

In 2012, children in Grade 1 (the second year of formal schooling in Victoria, Australia) from 44 schools in metropolitan Melbourne participated in population-level WM screening to assess their eligibility to enter a randomized controlled trial of a computerized WM intervention program.[12] We recruited in the second year of primary school education because, at least in Australia, it provides a more structured educational experience than the largely play-based first year.[12] This baseline population-level data collection provides a unique opportunity to examine determinants of WM development at early school age. The aim of this cross-sectional study was to examine links between WM development and both children's age and duration of school exposure in a population-based cohort whose assessments for logistic reasons were randomly distributed throughout the Grade 1 school year. We hypothesized that, during Grade 1, WM (both verbal and visuospatial) would be independently related to the duration of exposure to a structured classroom environment, even after adjusting for chronological age.

METHODS

Study Design and Sample Recruitment

The Memory Maestros population-based randomized controlled trial (Australian New Zealand Clinical Trials Registry No: ACTRN 12610000486022) recruited a large population-based cohort of Grade 1 children. Ethics approval was obtained from the Human Research Ethics Committee at the Royal Children's Hospital in Melbourne, and the study was also approved by the Victorian Government's Department of Education and Early Childhood Development and the Victorian Catholic Education Office.

Recruitment occurred in 2 stages. First, the study statistician (F.M.) generated a randomly ordered list of schools from each of the 3 major sectors (State, Catholic, and Independent) within a 20-km radius of our research institution. Schools were approached in the order on the list until sufficient students from each of the sectors were recruited to meet sample size requirements for the trial.[12] We approached each school's principal through telephone to request their agreement to take part; approximately, 66% of schools that were approached agreed to participate. To manage the logistics of recruiting and screening more than 1700 students at 44 schools, participating schools were divided into 4 groups for recruitment, corresponding to the 4 school terms during the school year (February to December, 4 terms each of 9–11 wk). This corresponded to the order in which they were recruited, based on their original order on the randomly generated list of schools. The timing for each child's working memory (WM) screening assessment was therefore also essentially random dictated solely by the school they attended.

In the second stage of recruitment, parents of Grade 1 children were approached through the school to participate in the study. All children whose parents provided written consent underwent a 15-minute computer-based WM assessment. A trained research assistant assessed each child during school hours in a quiet area. Schools were visited, and assessments completed sequentially, conducted for more than 3 to 7 days in each school. Two research assistants attended each assessment day, and each assessed up to 22 children per day. A total of 9 research assistants were involved in the assessments throughout the year.

Measures

Working Memory (Primary Outcome)

WM (primary outcome) was measured using 2 subscales from the computerized Automated Working Memory Assessment[13] Verbal WM was measured using the Backwards 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. Visuospatial WM was measured by the Mister X subtest, where the child is required to remember and mentally manipulate progressively longer strings of visually presented information (a cartoon figure holding a ball in 1 of 8 compass points). The standard (mean 100, SD, 15) and child raw scores, corresponding to number of successful trials are presented, with higher scores representing better WM. These 2 WM subtests have been successfully used previously to identify children with low WM and are sufficiently sensitive to detect changes in WM postintervention.[14]

Duration of Schooling (Exposure)

Duration of schooling (exposure) was a proxy measure based on when in Grade 1 children were recruited for WM screening. Because all children commence school simultaneously at the beginning of the preparatory (first) school year, all children have experienced approximately 10 months of school by Term 1 of

Grade 1 but around 20 months by the end of Term 4. Recruitment in Term 1 was conducted in March 2012, Term 2 in June 2012, Term 3 in August 2012, and Term 4 in October 2012.

Child Age (Exposure)

Child age (exposure) at the WM screening assessment was determined by caregiver report on the enrollment survey. Child age was expressed as years (to 2 decimal places) between the date of birth and the WM assessment. The quartiles were "<6.58 years," "6.58 to 6.86 years," "6.86 to 7.14 years," and ">7.14 years."

Potential Confounders

Potential confounders were chosen a priori and were measured through the parent survey completed at enrollment before the assessment. Child confounders were grade repetition (yes/no) and gender (boy/girl). Parent confounders were social risk indicators: highest level of maternal education (did not complete high school/completed high school/completed tertiary education); 2 parent family (yes/no); and average weekly household income (<$650; $650—$999; $1000—$1399; $1400—$1999; >$2000 A$).

Statistical Analysis

Data analysis was carried out using Stata version 12. Child and family demographics are described using standard statistical summary scores. To determine the association between school term and WM, we conducted 3 linear regressions to determine mean differences in raw verbal (Backwards Digit Recall) and visuospatial (Mister X) WM scores between the 4 school term groups. All analyses were corrected for the clustered recruitment of children by school using robust regression methods.[15] In Model 1, we conducted an unadjusted linear regression analysis for each of time in school and age. In Model 2, we included both time in school and age, adjusted for each other. In Model 3, we also adjusted for the potential child and social risk confounders (as detailed above).

Effect sizes for the adjusted mean difference were calculated by dividing the adjusted mean difference by the pooled SD for the whole cohort.

RESULTS

Study Characteristics

A total of 2747 children from 44 primary schools across Melbourne were approached to participate in the study. Consent was received from 1765 families (64.2%), of which 1727 children (97.9%) had their working memory (WM) assessed. Children whose parents provided consent but were not screened were either absent during the screening period or had moved schools before screening commenced.

Table 1 shows the characteristics of the cohort. Overall, the children in each school term had similar child, parent, and household characteristics. These characteristics are similar to the general Australian population, with the exception that more parents had completed a university degree (66.8%) than the expected rate of 43% of Australian adults.[16]

Association Between WM and Child Schooling

Table 1 also shows the raw and standard WM scores for the overall sample and by each school term group. Both the raw scores and the age-based standard scores rise steadily between Terms 1 and 4, and these age-based standard scores are higher in this Victorian sample than the normative UK population.[13]

Table 2 shows the differences in verbal WM raw scores as the school year progresses and as child age increases. Regarding school exposure, raw scores were substantially higher in Term 4, compared with Term 1, corresponding to an effect size of 0.77 (p values for trend $\leq .001$). This relationship persisted even after adjustment for age and further adjustment for other potential confounders. In contrast, the association between child age and increasing verbal WM scores ($p < .001$) was eliminated when adjusted for school term in Model 2, such that age no longer predicted WM independently.

Table 3 shows the differences in visuospatial WM raw scores as the school year progresses and as child age increases. Raw scores were substantially higher in Term 4 compared with Term 1. This corresponds to an effect size of 0.53 (p values for trend $< .001$), and the relationship remained after adjusting for confounders. Child visual spatial WM was only associated with child age before adjusting for confounders. This pattern of findings corresponds with that observed for verbal WM.

As a sensitivity analysis, all analyses were repeated excluding children who had repeated a grade, and this did not change the results (data not shown). Additional analyses using age as a continuous variable did not change the strength or direction of associations (data not shown).

DISCUSSION

Our results demonstrate for the first time that the development of working memory (WM) is strongly associated with time children have spent in the classroom in the second structured year of schooling, above and beyond their chronological age. Adjustment for other potential confounders including social risk did not alter our results.

Schools in Australia adhere to the Australian Curriculum,[17] which "sets out, through content descriptions and achievement standards, what students should be taught and achieve, as they progress through school." However, specific classroom methodologies and structure vary greatly both between and within schools. We recruited in random order 44 schools from the 3 major schooling sectors, and the proportion of these 3 school types in our sample is reflective of the proportion in the greater Melbourne area. Therefore, we believe that this gives us sufficient heterogeneity in classroom approaches to be confident of tapping the structured educational experience of the second year of schooling in general rather than any particular instructional methodology.

Table 1. Sample Characteristics by School Term

Variable	Whole Cohort N = 1785	By School Term Term 1 N = 281	Term 2 N = 389	Term 3 N = 472	Term 4 N = 643
Child					
Age					
Mean	6.9	6.6	6.7	6.9	7.2
SD	0.4	0.3	0.4	0.3	0.3
Male gender	910 (50.2)	153 (54.4)	175 (45.0)	256 (54.2)	326 (50.7)
Repeated a grade	115 (6.4)	18 (6.4)	27 (6.9)	24 (5.1)	46 (7.2)
Extra learning assistance at school					
Extra learning help	230 (12.7)	34 (12.1)	51 (13.1)	59 (12.6)	86 (13.4)
Special education group/class	85 (4.7)	16 (5.7)	16 (4.1)	24 (5.1)	29 (4.5)
Integration aide	51 (2.8)	12 (4.3)	13 (3.4)	10 (2.1)	16 (2.5)
Speech therapy	126 (7.0)	31 (11.1)	25 (6.4)	35 (7.5)	35 (5.5)
Other	100 (5.5)	18 (6.7)	18 (4.9)	22 (5.1)	42 (6.8)
Diagnosed condition					
Inattention problem	111 (6.2)	22 (7.8)	29 (7.5)	24 (5.1)	36 (5.6)
Anxiety	91 (5.1)	16 (5.8)	17 (4.4)	14 (3.0)	44 (6.9)
Behavioral/conduct problem	62 (3.5)	11 (3.9)	14 (3.6)	12 (2.6)	25 (3.9)
Developmental delay	51 (2.9)	14 (5.0)	11 (2.8)	9 (1.9)	17 (2.7)
Autism	32 (1.8)	11 (3.9)	7 (1.8)	3 (0.6)	11 (1.7)
Intellectual disability	15 (0.8)	3 (1.1)	5 (1.3)	2 (0.4)	5 (0.8)
Backwards digit recall score					
Raw					
Mean	9.8	8.4	9.2	9.9	10.8
SD	3.4	3.2	3.4	3.0	3.4
Standard					
Mean	105.7	102.1	104.6	105.7	108.1
SD	14.7	15.0	15.5	13.6	14.5
Mister X score					
Raw					
Mean	8.0	7.0	7.8	7.9	8.8
SD	3.6	3.3	3.6	3.3	3.7
Standard					
Mean	109.1	105.8	108.3	108.4	111.5
SD	15.7	15.1	16.0	15.0	15.8
Primary Caregiver					
Biological parent	1755 (96.9)	278 (99.3)	382 (99.2)	457 (98.5)	637 (99.2)
Male Gender	223 (12.3)	26 (9.3)	42 (10.9)	74 (15.9)	81 (12.6)
Married/De facto	1573 (86.9)	258 (92.1)	325 (84.0)	416 (89.3)	573 (89.4)
Highest level of education					
Did not complete high school	187 (10.5)	30 (10.7)	42 (10.8)	63 (13.5)	52 (8.1)
Completed high school	380 (21.4)	70 (24.9)	102 (26.4)	98 (21.0)	110 (17.1)
Completed university degree	1209 (66.8)	181 (64.4)	242 (62.7)	305 (65.4)	480 (74.8)
Household					
Other non-English languages spoken	283 (15.6)	38 (13.5)	62 (16.2)	121 (26.1)	62 (9.7)

(*Table continues*)

Table 1. Continued

Variable	Whole Cohort N = 1785	By School Term Term 1 N = 281	Term 2 N = 389	Term 3 N = 472	Term 4 N = 643
Weekly household income, $A					
<$650					
Mean	155	17	33	46	59
SD	9.1	6.5	8.9	10.5	9.4
$650–$999					
Mean	147	20	39	54	34
SD	8.7	7.6	10.6	12.3	5.4
$1000–$1399					
Mean	187	33	45	59	50
SD	11.0	12.6	12.2	13.4	8.0
$1400–$1999					
Mean	310	49	76	78	107
SD	18.3	18.7	20.6	17.7	17.1
Above $2000					
Mean	899	143	176	203	377
SD	52.9	52.6	47.7	46.1	60.1

Results are presented as N (%), unless otherwise indicated.

The children recruited in each school term were similar in terms of the rates of developmental/behavioral diagnoses and extra supports in school. In Australia, unlike the United States, children with learning disabilities are not mandated to receive special education support. Therefore, any extra learning help for these children must come from the school's discretionary budget and varies greatly ranging from teachers who are able to highly individualize the child's learning plan to extra time with parent volunteers in the classroom. Specific strategies, such as providing a classroom aid or specific therapy, are highly restricted and only available to children with severe behavioral or developmental disorders (e.g., autism or intellectual disability). One exception to this is the provision of pull-out small group support such as Reading Recovery (a literacy enrichment program that may be available in Grade 1 for children with slow literacy-based learning progress).[18] The diagnosis of a specific learning disorder is not commonly made by schools and is very unlikely to be made as early as Grade 1.

Alloway et al have previously demonstrated growth in WM skills (both verbal and visuospatial) with age, in a cross-sectional study of 708 children aged 4 to 11 years, with about 120 children in each age group.[5] They showed an increase in verbal WM mean raw scores (Backwards Digit Recall) of about 1 point and an increase in visuospatial WM mean raw scores (Mister X) of about 1.5 to 2 points between ages 6.5 and 7.5 years, with no sex differences.[5] This sample of UK children were in either their second or third year of structured education at this point. In contrast, on the same scale, this study showed a much more rapid increase in verbal WM during a single school year. This was independent of age per se, consistent with the hypothesis that the time spent in a structured classroom environment contributes in part to the developmental increase in verbal WM capacity during Grade 1. The magnitude of age-related increases in visuospatial WM observed in this study were more modest but not dissimilar to the increases seen in the study by Alloway et al, although time spent in the classroom, once again, corresponded to the increase in WM capacity.

The association between WM and time spent in the classroom was largely independent of social risk as defined by parent education, marital status, and household income, although it is acknowledged that these measures are proxies and that residual confounding is still a possibility. More generally, the results suggest that a structured and consistent classroom environment may help to level the academic playing field for children from a wide variety of social environments. Engel et al[10] have previously explored the influence of socioeconomic status (SES) on WM and language abilities in Brazilian children aged 6 to 7 years and reported that although receptive and expressive vocabulary were significantly higher in the high SES compared with the low SES group, measures of WM were largely independent of SES. The authors hypothesized that WM reflects "fluid cognitive abilities" that are independent of previous experience and acquired knowledge.[10]

This study has several strengths. To our knowledge, this is the largest study examining population-level changes in WM in children of early school age. The large numbers of children in each school term recruited

Table 2. Unadjusted and Adjusted Associations for Child Verbal Working Memory Raw Scores

	Model 1: Individual Models for Time in School and Age		Model 2: Including Both Time in School and Age		Model 3: Model 2, Adjusted for Potential Confounders[a]	
Variable	Mean Difference (95% CI)	ES	Mean Difference (95% CI)	ES	Mean Difference (95% CI)	ES
School term						
Term 1	Reference					
Term 2	0.83 (0.33–1.34)	.26	0.82 (0.32 to 1.32)	.25	0.95 (0.42 to 1.47)	.29
Term 3	1.51 (1.02–2.00)	.48	1.50 (1.02 to 1.99)	.46	1.62 (1.09 to 2.16)	.50
Term 4	2.46 (2.00–2.93)	.77	2.48 (2.01 to 2.94)	.77	2.42 (1.88 to 2.97)	.75
p^b	<.001		<.001		<.001	
Child age						
Quartile 1	Reference					
Quartile 2	0.92 (0.47–1.38)	.28	0.43 (−0.03 to 0.89)	.13	0.32 (−0.16 to 0.79)	.10
Quartile 3	1.02 (0.57–1.48)	.31	0.19 (−0.29 to 0.67)	.06	0.16 (−0.33 to 0.66)	.05
Quartile 4	1.55 (1.11–1.99)	.47	0.35 (−0.15 to 0.86)	.11	0.30 (−0.21 to 0.81)	.09
p^b	<.001		.34		.39	

[a]Social risk defined by child repeated year, gender, parental marital status, household weekly income. [b]*p* value is a test for trend.

throughout a single school year allow us to account for important potential confounders, such as chronological age and SES, and the random order in which schools were selected avoided a further potential source of bias.

The limitations of the study also need to be acknowledged. As this was a population-level study, it was necessary to sacrifice depth of assessment in favor of brief screening tasks that allowed us to rapidly screen large numbers of children. Nonetheless, we used well-validated, reliable, and widely used tests that are sensitive in detecting change in WM stemming from environmental experience, as observed in intervention studies.[4,14] Like many standardized neurocognitive measures, these tasks may suffer from task impurity, such that they are tapping skills additional to short-term memory and WM. This is particularly the case for the Mister X subtest, which is also dependent on visual perceptual ability. We did not recruit children at the start of their schooling career (the first year) but chose instead the second year (Grade 1), which provides a more highly structured educational experience in most schools. Whether WM would show a similar experience-based development time course during the first year is an outstanding question of great interest. The time spent in formal education is treated as a homogenous variable, and we cannot differentiate the effects of teachers, classroom environment, school philosophy, or practice. The parents of our cohort of children were more highly educated compared with the general Australian population, so that these results may not necessarily generalize to higher-risk populations. We recruited our

Table 3. Unadjusted and Adjusted Associations for Child Visuospatial Working Memory Raw Scores

	Model 1: Individual Models for Time in School and Age		Model 2: Including Both Time in School and Age		Model 3: Including Time in School, Age, Child Characteristics and Social Risk[a]	
Variable	Mean Difference (95% CI)	ES	Mean Difference (95% CI)	ES	Mean Difference (95% CI)	ES
School term						
Term 1	Reference					
Term 2	0.77 (0.23 to 1.31)	.23	0.78 (0.24 to 1.32)	.24	0.80 (0.23 to 1.37)	.24
Term 3	0.88 (0.36 to 1.40)	.27	0.89 (0.36 to 1.41)	.27	0.87 (0.29 to 1.45)	.26
Term 4	1.77 (1.27 to 2.26)	.53	1.75 (1.26 to 2.25)	.53	1.60 (1.01 to 2.19)	.48
p^b	<.001		<.001		<.001	
Child age						
Quartile 1	Reference					
Quartile 2	0.03 (−0.46 to 0.51)	.01	−0.28 (−0.78 to 0.21)	−.08	−0.33 (−0.85 to 0.18)	−.1
Quartile 3	0.83 (0.35 to 1.31)	.25	0.31 (−0.21 to 0.83)	.09	0.21 (−0.33 to 0.75)	.06
Quartile 4	1.0 (0.57 to 1.50)	.30	0.29 (−0.25 to 0.83)	.09	0.16 (−0.39 to 0.72)	.05
p^b	<.001		.09		.23	

[a]Social risk defined by child repeated year, gender, parental marital status, household weekly income. [b]*p* value is a test for trend.

population-based cohort from 44 schools (2–6 classrooms per school) across the 3 major Australian school sectors (State, Catholic, and Independent), from a wide variety of socioeconomic backgrounds, and so we are confident that we have captured a wide variety of school environments and teaching practices.

In conclusion, this study showed that WM development was strongly associated with time spent in a structured classroom setting, and that this effect was independent of chronological age in 6- to 7-year old children. These findings provide support for the view that in addition to developmental changes in WM already established in studies across whole school years, WM can be enhanced through the environmental experience provided by school.[6] The study findings have important implications both for research and educational practice. The results of WM screening programs need to be interpreted cautiously, taking into account time spent in school, rather than only age at time of testing. WM screening may be more usefully reframed as longitudinal WM surveillance: a lack of expected progression in the setting of involvement in a structured classroom setting may be a marker for increased risk of adverse learning outcomes. This hypothesis will be explored in future longitudinal research with this cohort of children. Future research should also focus on those features of educational environments and teaching that most effectively enhance and support WM development.

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