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BRIEF REPORT

Brief Report: Longitudinal Trajectory of Working Memory in School-Aged Children on the Autism Spectrum: Period of High Plasticity and "Late Bloomers"

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Abstract

Purpose While working memory (WM) is a powerful predictor for children's school outcomes, autistic children are more likely to experience delays. This study compared autistic children and their neurotypical peers' WM development over their elementary school years, including relative growth and period of plasticity.

Methods Using a nationally-representative dataset, latent growth models were built to examine periods of high plasticity and the relationship between children's performance upon school entry and their relative growth.

Results While both groups made steeper gains during the early school years, autistic children's period of highest plasticity was prolonged by 1 year, which suggests a larger window for interventions. Further, autistic children who started kindergarten with poorer WM were more likely to make rapid growth during the last 3 years of elementary school, which is when their neurotypical peers' development started to plateau.

Conclusion Findings should prompt various stakeholders to examine interventions and instructions to maximize autistic children's growth in WM. Further, the continued support and monitoring by educators throughout autistic children's late childhood can be particularly beneficial for the "late-bloomers."

Keywords Autism spectrum disorder · Working memory · Developmental trajectory · Longitudinal relationship

Introduction

Executive functioning (EF) skills involve sustaining attention, resisting impulsive responses, mentally manipulating information, and changing course of action as needed (Diamond, 2016). These critical skills account for children's school success and are more powerful predictors of school outcomes than IQ, pre-literacy skills, or foundational math skills (Diamond, 2016). Executive functioning has been shown to be a unitary construct at an early age, but from around the time when children enter formal schooling, the following three subdomains of EF statistically load as dissociable factors: working memory, cognitive flexibility, and inhibition (Friedman & Miyake, 2017). Working memory (WM), an important component of EF, involves executing goal-directed behaviors and engaging in deliberate memory search for goal-related information (Barrett et al., 2004). Working memory can be auditory, which entails maintaining speech-based information, or visuospatial, which involves retaining visual or spatial features (Baddeley, 1986). Auditory WM is viewed as a verbal information-processing system, which is commonly measured with memory span tasks. Memory span tasks, such as forward and backward digit span (Roman et al., 2014), typically require ordered serial recall of a sequence, and the correctly recalled length of the sequence is used as a measure of auditory WM capacity.

In order to respect the preference of many autistic self-advocates, 'person-first language' and 'identity-first language' were used interchangeably throughout this paper.

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Working Memory and School Outcomes

As working memory is responsible for controlling one's attention, temporarily storing information, and retrieving information from long-term memory (Baddeley, 2000), WM plays a critical role in children's cognitive development and school success from an early age. For example, when a child is given verbal instructions by their teacher, they need to retain the information contained at the beginning of the spoken sentence until the end. Then they need to use that information while retrieving their prior knowledge relevant to the task, in order to complete the task. Without effective WM, the information would be lost before they are able to execute the task.

Consequently, WM is closely related to academic readiness (Swayze & Dexter, 2018), early mathematical skills (Bull et al., 2008; Harvey & Miller, 2017), language acquisition (Roman et al., 2014), Theory of Mind (Lecce et al., 2017), and positive classroom engagement (Fitzpatrick & Pagani, 2012). Working memory shows clear developmental changes during the first 5 years of life, which set the foundation for a more complex development (Garon et al., 2008). After this "sensitive period," (a period of relative plasticity with high susceptibility to environmental influences (Thompson & Steinbeis, 2020; Zelazo & Carlson, 2012)), WM continues to develop through elementary school years and early adolescence in more complex forms (Conklin et al., 2007; Gathercole et al., 2004; Luciana et al., 2005). However, despite extensive research on the development of WM during the preschool years, research on the continued progress of WM in school-aged children is limited (Best & Miller, 2010).

Working Memory in Autistic Children

Many children who qualify for special education exhibit a deficit in WM, and such delays are more frequently observed in children on the autism spectrum (Otero et al., 2014). Particularly for autistic students, WM deficits are associated with difficulties with critical school-readiness skills such as focusing, sustaining attention, and behavior regulation (Kercood et al., 2014). Moreover, autistic children's difficulties with auditory WM were linked to greater challenges in adaptive behaviors and heightened restrictive or repetitive behaviors (Kercood et al., 2014).

Several studies have examined cross-sectional profiles or longitudinal trajectories of auditory WM in school-aged students on the autism spectrum and their neurotypical (NT) peers. While autistic children make improvements in auditory WM over time (e.g., forward and backward digit span, recalling numbers and letters in ascending order when given different combinations), they show overall delays when compared to their neurotypical peers (Andersen et al., 2015; Chen et al., 2016). In addition, a recent longitudinal study (Vogan et al., 2018) demonstrated that autistic children and adolescents (ages 7–14) had impaired everyday WM as measured by parent reports (i.e., BRIEF; Gioia et al., 2000), and made no significant improvement across a 2-year time span. It is important to note that these studies had relatively small samples (n = 34 to 63 per subgroup[1]), and some conducted a cross-sectional analysis with two different age groups as opposed to following the same group of children. Furthermore, when studies were longitudinal the time frame was only 2 years, which may not have captured the entirety of autistic children's sensitive period for WM development. Therefore, a longitudinal analysis with a larger sample of autistic children during a longer time span examining their WM trajectory is indicated in order to better understand their developmental trajectory of WM. Ultimately, research is inconclusive on whether autistic children undergo their anticipated sensitive period and maturity point (a point in the development when susceptibility decreases and the growth stabilizes (Luna et al., 2007)) similarly to their NT peers.

Therefore, the current study examined WM trajectories including relative growth and period of plasticity using longitudinal data with seven data collection waves over the course of the entire elementary school years (i.e., 6 years). More specifically, we addressed the following research questions: (1) When do autistic children make the most rapid growth in WM during their elementary school years? (2) How does autistic children's WM performance upon entering kindergarten predict their rate of growth throughout their elementary school years? (3) How does autistic children's WM developmental trajectory differ from their NT peers?

Method

Dataset

This study used the restricted version of the Early Childhood Longitudinal Study, Kindergarten Class of 2010–2011 (ECLS-K:2011), a nationally representative dataset that follows the same cohort of children from kindergarten through fifth grade across 9 time points (Table 1). The ECLS-K:2011 dataset was sponsored by the National Center for Education Statistics (NCES) within the Institute of Education Sciences (IES) of the U.S. Department of Education. In total, approximately 18,170 children across about 1,310 schools and their parents, teachers, school administrators, and before- and

[1] See Appendix Table 6.

Table 1 Data collection schedule from T1 to T9

	Semester & grade	School year
T1	Fall of kindergarten	2010–11
T2	Spring of kindergarten	
T3	Fall of 1st grade	2011–12
T4	Spring of 1st grade	
T5	Fall of 2nd grade	2012–2013
T6	Spring of 2nd grade	
T7	Spring of 3rd grade	2014
T8	Spring of 4th grade	2015
T9	Spring of 5th grade	2016

SOURCE: U.S. Department of Education, National Center for Education Statistics (NCES), The Early Childhood Longitudinal Study, Kindergarten Class of 2010–2011 (ECLS-K:2011). Restricted-use data files

after-school care providers participated in the data collection. (Tourangeau et al., 2019).

Participants

Students were included in the autism sample in the present study if: (1) parents responded at least once during the six rounds of interview that their child had a diagnosis of autism or (2) the special education teacher responded at least once that the child was receiving special education services for a diagnosis of autism. Students were included in the NT sample in the study if: (1) parents reported *No* to the question “Did you obtain a diagnosis of a problem from a professional?” at each of the six rounds of survey. A case–control matching was attempted using the students’ math and reading scores in Kindergarten. However, approximately 1/3 of the autistic children did not have these scores. Autistic students who did not have reading and math scores had significantly lower WM than those who did throughout their elementary school years ($p > 0.05$). Excluding these children from the analysis would not provide a comprehensive picture of autistic children’s developmental trajectories. Therefore, a decision was made to retain the entire autism and NT sample. The final sample included approximately ($N \approx 310$) students in the autism group and approximately ($N \approx 3410$) in the NT group. All sample sizes are rounded to the nearest 10 per confidentiality agreement.

Measures

Demographic Characteristics

Demographic characteristics of the sample included: (1) race/ethnicity (White, Black, Hispanic, Asian-American/Pacific Islanders/Native Americans (AAPINA), other), (2) sex assigned at birth (male, female), (3) income range, and (4) parent’s educational level.

Table 2 Percentage of missingness in working memory at each time point

Time Point	% of Missingness	
	Autism Group (N = 310) %	NT Group (N = 3410) %
T1	30.19	11.33
T2	14.61	1.67
T3*	73.38	63.43
T4	21.43	1.82
T5*	73.70	64.75
T6	24.68	2.52
T7	29.22	3.38
T8	33.77	4.40
T9	38.64	5.37

N rounded to the nearest 10 per confidentiality agreement

SOURCE: U.S. Department of Education, National Center for Education Statistics (NCES), The Early Childhood Longitudinal Study, Kindergarten Class of 2010–2011 (ECLS-K:2011). Restricted-use data files

*Excluded from the analysis due to high percentage of missingness

Variable

Working Memory

Numbers Reversed subset of the Woodcock-Johnson III (WJ III) *Test of Cognitive Abilities* (Woodcock et al., 2001) was administered to measure WM from kindergarten through 5th grade, across 9 time points. Students were asked to repeat orally presented strings of numbers backward. The *W* score for the Number Reversed subtask was used as it is a standardized score that is particularly suited for longitudinal analyses, regression, and correlation (Tourangeau et al., 2019).

Analyses

Missing Data

Missingness in the WM scores is summarized in Table 2. In both Autism sample and the NT sample, high levels of missingness (> 60%) were observed in T3 and T5. Therefore, these 2 time points were excluded from further analyses. For the remaining time points, missing data were handled by Full Information Maximum Likelihood (FIML) as this method is shown to be robust with structural equation

Table 3 Fit indices for unconditional latent growth models

Working Memory	Subgroup	Model Type	X^2	df	p	CFI	RMSEA	SRMR
Model 1	Autism	Linear	134.779	23	0.000	0.896	0.132	0.114
Model 2	NT	Linear	2181.057	23	0.000	0.730	0.166	0.124
Model 3*	Autism	Piecewise; Knot at T6	36.618	19	0.009	0.984	0.058	0.040
Model 4	Autism	Piecewise; Knot at T7	54.652	19	0.000	0.967	0.082	0.065
Model 5*	NT	Piecewise; Knot at T4	268.236	19	0.000	0.969	0.062	0.033

SOURCE: U.S. Department of Education, National Center for Education Statistics (NCES), The Early Childhood Longitudinal Study, Kindergarten Class of 2010–2011 (ECLS-K:2011). Restricted-use data files

*Final models

models (SEMs) under the assumption of missing-at-random (MAR[2]) (Allison, 2003).

Latent Growth Modeling: Unconditional Model

Unconditional latent growth models were created using Lavaan package (Rosseel, 2012) in R statistical environment in order to estimate longitudinal trajectories while capturing individual variabilities in their growth (Flora, 2008). The starting point and rate of growth of WM developmental trajectory for each subgroup were modeled as latent variables.

Multivariate Normality

The WM scores from the seven time points did not meet the assumption of multivariate normality ($p<0.001$) based on Mardia's skewness and kurtosis test (Kres, 1983; Mardia, 1980). When the data violate the assumption of multivariate normality, a robust estimator can be used for a correction (Beaujean, 2014). As the "MLF" estimator (maximum likelihood estimation with standard errors based on the first-order derivatives) is shown to be useful for both complete and incomplete data (Beaujean, 2014), the MLF estimator was used when building the latent growth model for both subgroups.

Final Unconditional LGM

Fit indices for all unconditional Latent Growth Models built are summarized in Table 3. In order to determine the best fitting LGM for both subgroups, linear models as well as piecewise models were built. With piecewise models, a decision needs to be made for the transition point, or a "knot" representing a time point when the two linear slopes meet, as these models capture the nonlinear trajectories by adding another slope factor (Flora, 2008). For the autism group, the fit indices for a piecewise model with knot at T6 were $\chi^2 = 36.618$, df = 19, CFI = 0.984, RMSEA = 0.058, SRMR = 0.040 (Model 3). Because this model met the model evaluation criteria most closely (Hu & Bentler, 1999), it was chosen as the final model for the Autism group. The fixed factor loading matrix for the final model (Model 3 with knot at T6) is illustrated in Fig. 1.

$$\Lambda = \begin{bmatrix} 1 & 0 & 0 \\ 1 & 1 & 0 \\ 1 & 2 & 0 \\ 1 & 3 & 0 \\ 1 & 4 & 0 \\ \mathbf{1} & \mathbf{5} & \mathbf{0} \\ 1 & 5 & 2 \\ 1 & 5 & 4 \\ 1 & 5 & 6 \end{bmatrix}$$

Fall of kindergarten (T1)
Spring of kindergarten (T2)
Fall of 1st grade (T3)[4]
Spring of 1st grade (T4)
Fall of 2nd grade (T5)
Spring of 2nd grade (T6) - knot
Spring of 3rd grade (T7)
Spring of 4th grade (T8)
Spring of 5th grade (T9)

Fig. 1 Fixed factor loading matrix for the Autism group's final LGM model. SOURCE: U.S. Department of Education, National Center for Education Statistics (NCES), The Early Childhood Longitudinal Study, Kindergarten Class of 2010–2011 (ECLS-K:2011). Restricted-use data files. T3 and T5 are excluded from the analysis due to high missingness

For the NT group, the fit indices for a piecewise model with knot at T4 were $\chi^2 = 268.236$, df = 19, CFI = 0.969, RMSEA = 0.062, SRMR = 0.033 (Model 5). As this model met the model evaluation criteria most closely, it was chosen as the final model for the NT group. The fixed factor loading matrix for the final model (Model 5 with knot at T4) is illustrated in Fig. 2.

Results

Demographic Characteristics

Demographic characteristics of the autism sample and the NT sample are illustrated in Table 4. A majority of children was classified as White in both samples. Eighty-two percent of the children in the autism sample were male, while 46% were male in the NT group. Students' race and parents' educational levels did not differ significantly ($p>0.05$) among

[2] Both autism group and NT group passed Little's MCAR test with ^{2} =133.860 (p = 0.584) and ^{2}=140.767 (p = 0.106) respectively.

$$\Lambda = \begin{bmatrix} 1 & 0 & 0 \\ 1 & 1 & 0 \\ 1 & 2 & 0 \\ \mathbf{1} & \mathbf{3} & \mathbf{0} \\ 1 & 3 & 1 \\ 1 & 3 & 2 \\ 1 & 3 & 4 \\ 1 & 3 & 6 \\ 1 & 3 & 8 \end{bmatrix}$$

Fall of kindergarten (T1)
Spring of kindergarten (T2)
Fall of 1st grade (T3)[5]
Spring of 1st grade (T4) – knot
Fall of 2nd grade (T5)
Spring of 2nd grade (T6)
Spring of 3rd grade (T7)
Spring of 4th grade (T8)
Spring of 5th grade (T9)

Fig. 2 Fixed factor loading matrix for the NT group's final LGM. SOURCE: U.S. Department of Education, National Center for Education Statistics (NCES), The Early Childhood Longitudinal Study, Kindergarten Class of 2010–2011 (ECLS-K:2011). Restricted-use data files. T3 and T5 are excluded from the analysis due to high missingness

the autism and the NT group. The group difference was most pronounced in the students' sex assigned at birth ($p > 0.05$) as expected with the 4:1 ratio of male to female in autism diagnoses.

Parameter Estimates for Working Memory Development

Knot and Slopes

In the autism group, the first latent slope, or estimated rate of growth, was 7.806 ($p < 0.001$). It spanned from fall of kindergarten (T1) to spring of 2nd grade (T6). This implies that autistic children are expected to make 7.806 units of gain in WM per semester during this time. The "knot" was identified at T6, and the second latent slope was 4.131 ($p < 0.001$) which spanned from spring of 2nd grade (T6) to spring of 5th grade (T9). In the NT group, the first latent slope was 11.132 ($p < 0.001$), and it spanned from fall of kindergarten (T1) to spring of 1st grade (T4). The "knot" was identified at T4, and the second latent slope was 3.922 ($p < 0.001$) which spanned from spring of 1st grade (T4) to spring of 5th grade (T9). The knots and slope estimates are illustrated in Table 5 and Figs. 3, 4.

Table 4 Demographic characteristics of the Autism sample and the NT sample

Demographic characteristics	Autism (N = 310)	NT (N = 3410)	Pearson Chi-square	p
Race			2.1	0.717
White	170 (54%)	1930 (57%)		
Black/African-American	20 (8%)	220 (6%)		
Hispanic	70 (21%)	720(21%)		
Asian-American/Pacific Islanders/Native American	40 (11%)	380 (11%)		
Other	20 (7%)	170 (5%)		
Sex Assigned at Birth			147.221	< 0.001*
Female	60 (18%)	1840 (54%)		
Male	250 (82%)	1570 (46%)		
Income			23.774	< 0.001*
$20,000 or less	50 (19%)	430 (13%)		
$20,000 to $30,000	30 (13%)	310 (9%)		
$30,000 to $50,000	50 (20%)	510 (15%)		
$50,000 to $75,000	40 (14%)	610 (18%)		
$75,000 to $100,000	30 (13%)	570 (17%)		
$100,000 to $200,000	40 (16%)	770 (23%)		
$200,000 or more	20 (6%)	210 (6%)		
Parents' educational level			4.759	0.093
High School	50 (24%)	840 (25%)		
2–4 year College	140 (62%)	1870 (55%)		
Postgraduate Degree	30 (15%)	690 (20%)		

N rounded to the nearest 10 per confidentiality agreement

SOURCE: U.S. Department of Education, National Center for Education Statistics (NCES), The Early Childhood Longitudinal Study, Kindergarten Class of 2010–2011 (ECLS-K:2011)

Restricted-use data files

Table 5 Summary of parameter estimates for working memory development

	Autism (N = 310)	NT (N = 3,410)
Knot	Spring of 2nd Grade (T6)	Spring of 1st Grade (T4)
Latent Intercept (Initial Status)	420.077	444.854
Latent Slope 1	7.806	11.132
Latent Slope 2	4.131	3.922
Correlation between Initial Status and Slope 1	− 0.020 (p = 0.852)	− **0.786** (p < 0.001*)
Correlation between Initial Status and Slope 2	− **0.270** (p = 0.013*)	− **0.119** (p = 0.002*)
Correlation between Slope 1 and Slope 2	− 0.215 (p = 0.167)	− 0.022 (p = 0.693)

Bold values indicate statistically significant at p < 0.05

N rounded to the nearest 10 per confidentiality agreement

SOURCE: U.S. Department of Education, National Center for Education Statistics (NCES), The Early Childhood Longitudinal Study, Kindergarten Class of 2010–2011 (ECLS-K:2011)

Restricted-use data files

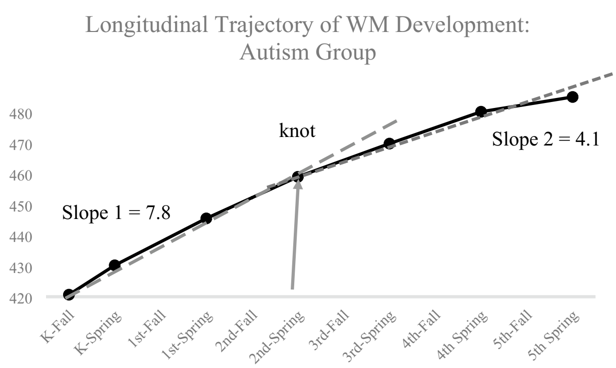

Fig. 3 Estimates of autistic children's working memory developmental trajectory, slopes, and the knot. SOURCE: U.S. Department of Education, National Center for Education Statistics (NCES), The Early Childhood Longitudinal Study, Kindergarten Class of 2010–2011 (ECLS-K:2011). Restricted-use data files

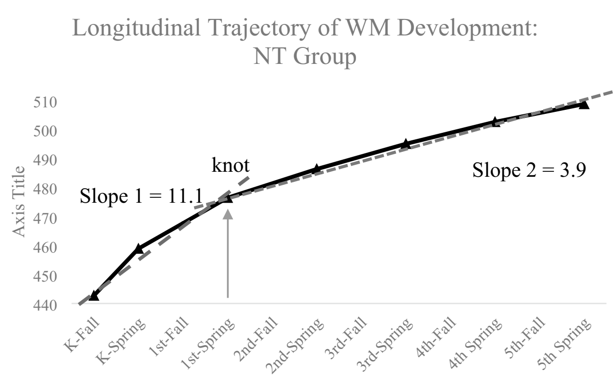

Fig. 4 Estimates of neurotypical children's working memory developmental trajectory, slopes, and the knot. SOURCE: U.S. Department of Education, National Center for Education Statistics (NCES), The Early Childhood Longitudinal Study, Kindergarten Class of 2010–2011 (ECLS-K:2011). Restricted-use data files

Relationship Between Latent Intercept and Slopes

In the autism group, the correlation between the intercept and the first slope was not statistically significant (p = 0.852). However, the correlation between the intercept and the second slope (T6-T9) was statistically significant (β = − 0.270, p = 0.013). Such a negative correlation implies that the lower the initial status upon school entry, the steeper the gains during T6 to T9. Moreover, the correlation between the first latent slope and the second latent slope was not statistically significant (p = 0.167). In the NT group, the correlation between the latent intercept and the first latent slope was statistically significant (β = − 0.786, p < 0.001), and the correlation between the latent intercept and the second latent slope was also statistically significant (β = − 0.119, p = 0.002). However, the correlation between the first and the second latent slopes was not statistically significant (p = 0.693). Parameter estimates for both groups' working development trajectories are summarized in Table 5.

Discussion

The current study explored longitudinal trajectories in auditory WM development among school-aged autistic children and their NT peers across a six-year time span. The results find that both groups made extensive gains in the earlier grades instead of following a linear trajectory, thus aligning with previous literature. However, unlike their NT peers whose WM performance demonstrates rapid gains during the first 2 years of their elementary school years (i.e., kindergarten to 1st grade), autistic children continued to make rapid gains for another year until the end of 2nd grade. Further, autistic children who exhibited poor WM upon school entry were more likely to make rapid growth *after* the "knot" (i.e., 3rd to 5th grade) but not *before* the "knot" (i.e., kindergarten to 2nd grade). In contrast, NT children who exhibited poor WM upon school entry were more likely to make rapid gains throughout their elementary school years, suggesting the presence of "late-bloomers" in WM development within the autistic population.

Rates of Growth and Locations of the "Knot."

The aforementioned findings suggest that autistic children continue to make relatively rapid growth beyond the *knot*, while the development in their NT peers substantially declines after the *knot*. Therefore, it is inferred that autistic children may potentially produce slower-but-steady gains in WM throughout their elementary school years, which allows for a longer window of opportunity for growth. Such findings are substantiated by a previous study that indicated the presence of a protracted window of EF plasticity in autistic children (O'Hearn et al., 2008). Consequently, this finding should influence various stakeholders to examine intervention approaches and instructional practices that maximize autistic students' growth during this "sensitive period."

There is emerging evidence that WM can be improved with targeted interventions. More importantly, some WM interventions demonstrated significant improvements in other untrained skills as well in children with or without disabilities. For example, auditory WM training produced a transfer effect in syntax and processing speed (Delage et al., 2022), and training in visuospatial WM skills generated improvements in reasoning (Jaeggi et al., 2010; Klingberg et al., 2005). Further, a combination of verbal and visuospatial WM training increased on-task behaviors (Green et al., 2012). However, other studies failed to replicate such far-transfers. Rather, they were effective in improving only the specific skills that they were trained on, without significant progress in other related skills that are important for school success (see Diamond & Ling, 2020 for a review). Therefore, a focused effort is necessary in developing WM interventions that reliably produce robust effects that can be maintained and generalized across other related skills, in order to maximize autistic children's school outcomes.

Relationship Between Initial Status and Rates of Growth

The findings indicated that autistic children who started at a low standing upon school entry made more rapid gains after 2nd grade, which was when the progress of both the NT group and the autism group as a whole began to plateau. Previous research noted that autistic children demonstrate persistent impairment in WM with little or no improvements regardless of age (e.g., Andersen et al., 2015; Chen et al., 2016; Vogan et al., 2018). However, these studies were limited either by their cross-sectional nature, or short term longitudinal examination (1–2 years). Some of these studies also included a sample with wide age ranges (e.g., 8 to adolescence), while significant gains are more often reported in younger age groups. While these studies provide us with important insights on autistic children's WM development, longitudinal analyses that span across 6 years as in the current study revealed that some autistic children, especially those who started kindergarten with poor WM, began to make rapid gains from 3rd grade and on. As some of the aforementioned studies included only a two-year window of development, the unique developmental trajectory of these "late-bloomers" may not have been adequately captured. As such, current findings suggest that there is a risk of making misleading conclusions about autistic children's WM trajectories when samples include a narrow range of age or when a brief window of time for longitudinal analyses is examined. Findings from this analysis further highlight the possibility that the "Matthew effect[3]" may not apply when describing autistic children's unique developmental trajectories. Taken together, without the understanding of such longitudinal relationship, educators or interventionists may miss out on the delayed window of high plasticity for these "late-bloomers" as their sensitive period remains unnoticed.

A recent meta-analysis revealed that student–teacher relationship is positively associated with children's WM development (Vandenbroucke et al., 2018). Therefore, teachers' continued support and close monitoring throughout autistic children's late childhood and adolescent years might be especially important for these "late-bloomers" WM development, a potential focus of future research.

Limitations

A few limitations are noted. First, the data collection starts in Fall of the kindergarten year, despite research indicating that the growth spurt in EF skills occurs between the ages of 3 and 5 (Garon et al., 2008). Therefore, findings from this study do not include analyses from an important early developmental period of WM. Secondly, while attempts to match the autistic sample to the NT sample on critical developmental areas (e.g., math and reading) were made, approximately 32% of the autistic students did not have reading or math scores. Therefore, we retained the entire autism and NT sample, which led to an NT comparison group that is distinctively larger than the autism group. Further, as the two subgroups were not matched on any cognitive measures, severity levels of autism symptoms, or oral language skills, any parallel comparisons between the autism and NT group on their WM performances at distinct time points should be interpreted

[3] Stanovich (1986) termed the Matthew Effect, which states that those who have more academic ability show a greater ratio of growth compared to those who are at a disadvantage in academic ability.

with caution. Instead, readers are encouraged to focus on the quality of developmental trajectories of the two groups, the relationships between their early performance and the rate of growth, and their periods of high plasticity. Moreover, the Numbers Reversed (Woodcock et al., 2001) tasks assess auditory WM only, and do not assess visuospatial WM. Although the Numbers Reversed task has a relatively lower language load when compared to other auditory WM tasks involving recalling words (e.g., sentence recall), autistic children's possible language or cognitive delays may have contributed to their performance. Such influence was not accounted for in the current analysis. Lastly, due to the nature of the dataset, the parent and teacher reports were used exclusively for students' diagnostic eligibility. Therefore, the children's formal autism diagnosis cannot be confirmed.

Regardless, this study is the first longitudinal study to our knowledge that examined autistic children's WM development over the entire elementary school years. As a result, it provides unique perspectives and a deeper understanding of the qualities of the developmental trajectories of WM for autistic children during this time. Further studies that examine the entire developmental trajectories from toddler years to adulthood would be especially beneficial to gain a better understanding of the EF developmental trajectories for the autistic population, as well as including the full spectrum of autistic children (a wider range of ability, SES, race and ethnicity) matched to NT children.

Implications & Future Directions

All the findings from the current study converge into an important implication that autistic children's WM may be more malleable at a younger age with a great diversity in their performances, and they may have a wider window for growth than their NT peers. While there is a robust evidence base that children's inherent characteristics such as having autism predict greater challenges with their WM performance, many researchers demonstrate that environmental factors can also play an important role (see Hughes, 2011 for a review). Therefore, it is critical that researchers examine possible explanatory factors that are both internal (e.g., disability status) as well as external (e.g., family or school environments) that contribute to maximizing autistic children's growth in WM during their "sensitive periods."

It is also noteworthy that autistic children show growth in accordance to their own unique developmental paths instead of following predictable growth paths exhibited by their NT peers. Therefore, drawing conclusions on autistic children's WM development based on the expected development of their NT peers may not be appropriate. Instead, facilitating educators', parents' and researchers' understanding of the heterogeneous and unique nature of autistic children's WM development is critical.

Appendix

See Table 6.

Table 6 Sample sizes of previous studies examining working memory of autistic children

Studies	Groups and ample sizes
Andersen et al., 2015	Autism (n = 34), ADHD (n = 72), NT (n = 45)
Chen et al., 2016	Younger group (ages 8–12): autism (n = 53); NT (n = 63) Older group (ages 13–18): autism (n = 58); NT (n = 51)
Vogan et al., 2018	Autism (n = 34), NT (n = 34)

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Author Contributions Sohyun An Kim devised the project and secured access to the dataset. Sohyun An Kim designed the study, performed the statistical analysis, and drafted the manuscript. Connie Kasari supervised the entire process from the inception of the study, provided critical feedback, and helped shape the manuscript.

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Declarations

Conflict of interest The authors declare no conflict of interest.

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