A comparison of simultaneous and sequential visuo-spatial memory in children born very preterm

Jenny Retzler, Samantha Johnson, Madeleine J. Groom & Lucy Cragg

View supplementary material ⧉

Published online: 31 Oct 2021.

Submit your article to this journal ⧉

Article views: 2076

View related articles ⧉

View Crossmark data ⧉

Citing articles: 2 View citing articles ⧉

Routledge
Taylor & Francis Group

OPEN ACCESS   Check for updates

A comparison of simultaneous and sequential visuo-spatial memory in children born very preterm

Jenny Retzler [a,b], Samantha Johnson [c], Madeleine J. Groom [d] and Lucy Cragg [b]

aDepartment of Psychology, School of Human and Health Sciences, University of Huddersfield, Huddersfield, UK; bSchool of Psychology, University of Nottingham, Nottingham, UK; cDepartment of Health Sciences, College of Life Sciences, University of Leicester, Leicester, UK; dDivision of Psychiatry & Applied Psychology, Institute of Mental Health, School of Medicine, University of Nottingham, Nottingham, UK

ABSTRACT

Research suggests that children born very preterm (≤32 weeks' gestation) are at greater risk of impairments in information processing (particularly when information is presented simultaneously rather than sequentially) and visuo-spatial short-term and working memory relative to children born at term. This study compared the performance of children born very preterm with their term-born peers to elucidate the nature of group differences in these areas. 113 children (65 very preterm; 48 term-born) aged 8-to-11 years completed four visuo-spatial recall tasks. Tasks varied by presentation type (simultaneous or sequential) and memory type (short-term or working memory). Both groups recalled more locations in simultaneous than sequential tasks, and in short-term than working memory tasks. In short-term memory tasks, children born at term recalled more locations than children born very preterm for the sequential task, but groups did not differ on the simultaneous task. The opposite pattern was observed in the working memory tasks, with no group differences on the sequential task, but better performance on the simultaneous task for children born at term. Our findings indicate that simultaneous processing may not be impaired in children born very preterm *per se*, with poorer performance observed only under high cognitive demand. This interaction suggests very preterm birth may affect the level of cognitive resources available during feature integration, the consequences of which become apparent when resources are already stretched. The impact of interactions with cognitive demand in this population should be an important consideration for educational support strategies, and for assessment in research and clinic.

As gestational age at birth decreases, the risk for cognitive, behavioral and educational problems increases, with impairments most commonly observed among children born very preterm (<32 weeks of gestation, Wolke et al., 2019). Converging evidence suggests that deficits in executive functions may be at the root of these sequelae (Taylor & Clark, 2016).

Executive functions, including working memory (WM), are cognitive processes required for performing goal-directed behaviors. WM, in particular, is poorer in children born preterm than at term (Houdt et al., 2019) and plays a crucial role in daily functioning. In contrast to short-term memory (STM), which reflects simple storage of items for a short period of time, WM reflects short-term storage of information whilst also carrying out another cognitive task (related or unrelated to the WM task). One dominant WM model (Baddeley & Hitch, 1974) posits the existence of STM stores supervised by a centralized executive system, which allocates resources to allow information processing to occur while items are retained in memory. These STM stores are considered domain-specific, leading researchers to distinguish between WM processes for verbal versus visuo-spatial information, although debate about domain-specificity is ongoing (see Morey et al., 2019; Logie, 2019; Morey, 2018; Morey et al., 2020).

Difficulty with attention and mathematics, which are common among children born very preterm, has been linked to difficulties in visuo-spatial working memory (VSWM) in both preterm and community samples (Allen et al., 2019; Lui & Tannock, 2007; Retzler et al., 2019; Simms et al., 2015) and those with ADHD (Martinussen et al., 2005). A detailed understanding of VSWM in children born very preterm may therefore inform support for children who are at-risk and may shed light on the nature of VSWM more generally.

Studies of clinical groups, including children with learning disabilities (Mammarella et al., 2018, 2006), patients with unilateral neglect (Wansard et al., 2015), and children with Williams Syndrome (Carretti et al., 2015) and Downs Syndrome (Lanfranchi et al., 2009), suggest that VSWM can be subdivided further on the basis of stimulus presentation (Cornoldi & Vecchi, 2004), whereby the to-be-remembered items are presented all at once (simultaneous) or one-by-one (sequential).

In typically developing populations recall on VSWM tasks tends to be better for simultaneous presentation compared with sequential tasks, with evidence for different developmental trajectories depending on task type (Pickering, 2001). Simultaneous presentation of location-based stimuli may encourage configural encoding, whereby participants bind items together into a single representation, either via conscious top-down processes or automatic gestalt principles. This is less likely in sequential presentations where the locations are not visible together (Bharti et al., 2020; although see De Lillo et al., 2016 for an analysis of factors that may facilitate the binding of sequential patterns into "paths"). Such feature binding may compress, or "chunk," the information to be held in memory, in effect, increasing memory capacity on simultaneous tasks.

This simultaneous/sequential distinction is of particular interest in preterm populations. Indeed, prior studies have reported greater difficulty with simultaneous than sequential processing in children born very preterm/very low birthweight (<1500 g; Hanke et al., 2003; Johnson et al., 2009; Larroque et al., 2008; Simms et al., 2013; Wolke & Meyer, 1999). Poorer performance on simultaneous tasks suggests that the ability to perceive, process and integrate information from multiple stimuli at once may be a core difficulty associated with very preterm birth. However, studies reporting greater difficulty in simultaneous versus sequential processing within preterm samples to date have all used composite scores drawn from the Kaufman Assessment Battery for Children (K-ABC; Kaufman, 2004). These aggregate performance from various visual and spatial tasks that differ in complexity. Poor scores may therefore be driven by greater

difficulty in specific tasks that are more cognitively demanding, or by poor performance across all tasks that involve simultaneous processing. Indeed, reanalysis of K-ABC data has shown that deficits in children born very preterm increase with cognitive workload demands (Jaekel et al., 2013), suggesting that the measurement of cognitive demand and simultaneous processing are conflated in this task battery.

The current study aimed to characterize the nature of differences in visuo-spatial memory and information processing in children born very preterm compared with children born at term, investigating performance on tasks that varied according to presentation type (simultaneous vs. sequential) and memory type (STM vs. WM). We hypothesized that children born very preterm would have poorer performance than children who were term-born on simultaneous than sequential tasks, at both levels of memory type. We also predicted a larger group difference on the simultaneous WM task than on the simultaneous STM task because the cognitive demand is higher for working memory.

Materials & methods

Ethics approvals

Ethics approval was granted by a UK NHS Research Ethics Committee (Coventry and Warwickshire; Ref: 13/WM/0203) and informed parental consent was obtained for all children, who also provided their assent.

Participants

Study recruitment is described in detail in Retzler et al. (2019) and a full description of the characteristics of those included in the current analysis is provided in the Supplementary Material.

In summary, all babies born ≤32 weeks' gestation and admitted for neonatal care in Nottingham University Hospitals NHS Trust between 01/01/2003 and 31/03/2006 were identified and traced to check their vital status. Of these, 65 children (29 female) aged 8–11 years (M = 10.10, SD = 0.86) were recruited to the study (16% of eligible births). The final very preterm sample were well matched on gestational age ($p = 0.89$), birthweight ($p = 0.59$), and sex ($p = 0.81$) to children born very preterm not recruited to the study (n = 406), but recruited children had higher socio-economic status (SES, as measured using the English Indices of Multiple Deprivation; $p = 0.006$).

A comparison group of 48 (22 female) children born at term (≥37 weeks' gestation) and aged 8–11 years (M = 9.51, SD = 1.01) from the same geographical area were recruited. In response to adverts placed in local schools, in the community and via the University of Nottingham volunteer database, children were screened for inattentive symptoms using the parent-rated Strengths and Weaknesses of ADHD and Normal-behavior scale (SWAN; see Measures). Children were selected to participate based on the SWAN scores to ensure that the seven points on the SWAN scoring scale were represented in the comparison group, reflecting a range of attentional abilities (far below average, below average, slightly below average, average, slightly above average, above average, far above average).

Children were excluded if the child or parent was non-fluent in English, if the child had disabilities that precluded testing, or if the child was on stimulant medication for ADHD and the child's parent or consultant did not to consent to a supervised withdrawal of the medication 48 hours in advance of the study. Medication withdrawal was not required as no children who participated in the study were on stimulant medication for ADHD at the time of participation. Parents of 20 children (6 term, 14 very preterm) reported neurodevelopmental conditions that had either been diagnosed (3 term, 10 very preterm) or were being investigated (3 term, 4 very preterm; see Supplementary Material).

Measures

Children completed measures of visuo-spatial memory as part of a larger test battery, and parents completed questionnaires measuring clinical symptoms.

Visuo-spatial memory

Simultaneous STM, sequential STM, simultaneous WM and sequential WM were tested using adapted versions of the same computerized task programmed using PsychoPy (Peirce et al., 2019). In this span-based "Treasure Hunt" location recall task, children were presented with a 4-by-4 grid of black squares, upon which coins were presented in specific locations. When prompted by a question mark on an empty grid, children were required to use the mouse to select the squares in which the coins had been presented (see Figure 1 for a graphic depicting an example trial for each task variant). In all versions, the task began with two locations to remember, and increased in one-location increments up to a maximum of 8 locations. To proceed to the next span level, two of the three trials in that span level had to be recalled correctly. There was a maximum of 21 trials in each task (3 trials per span level).

Manipulations of presentation type (simultaneous vs. sequential) affected the encoding phase. Simultaneous tasks presented all the coin locations at once, for a total time that equated to one second per location. Sequential tasks presented each coin location in sequence, for one second per location. This meant that the duration of the encoding stage for each span length was equal across tasks.

Manipulations of memory type (STM vs. WM) affected the maintenance stage of memory processing, where coin locations have been encoded and are stored (maintained) before retrieval. The STM tasks prompted recall immediately following presentation of all coin locations in the trial, with no retention interval, thereby taxing only immediate short-term memory processes. The WM tasks prompted recall after a 5-second retention interval, during which participants were required to complete a face-matching task while maintaining the coin locations in memory, in a dual-task design. The dual-task component of complex span tasks is thought to tax central executive resources, providing a measure of WM, rather than STM (Conway et al., 2005). The concurrent processing task used presented participants with a pair of faces taken from the Glasgow Face Matching Task stimulus set (Burton et al., 2010). Participants were required to verbally state whether the faces were the same or different. After each pair of faces the participant gave a verbal response which was recorded on the keyboard by the experimenter. To equalize concurrent processing demands while
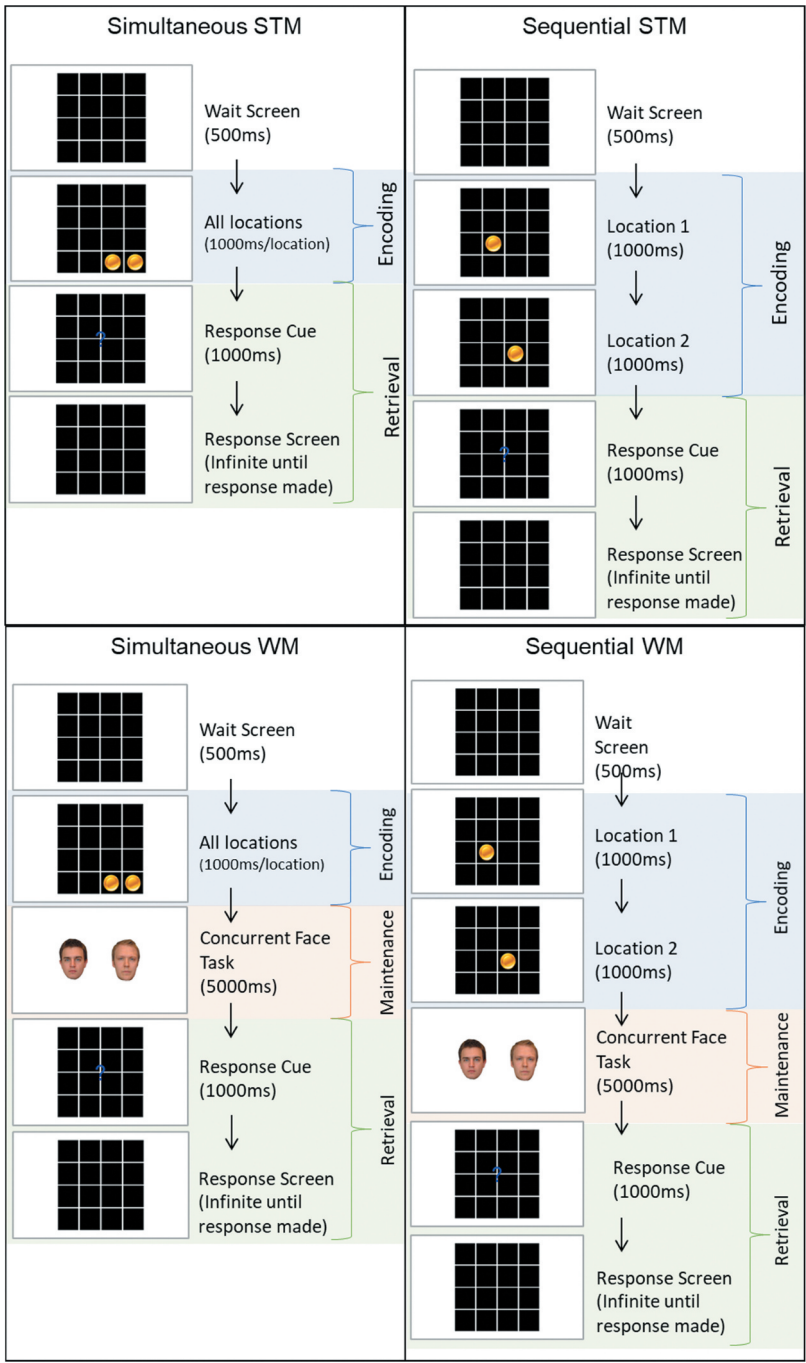
Figure 1. Graphic depicting example 2-span trial for all task variants.

accounting for individual differences in the speed of face processing, a new face pair was presented immediately following the keyboard press so that participants were engaged in face processing for the full retention interval.

Finally, retrieval instructions directed participants to recall the locations in which coins were presented. In sequential tasks they were asked to recall the locations in the same order they were presented, while this requirement was not (and could not be) made in the simultaneous versions. For a summary of task requirements at the encoding, maintenance and retrieval stages for each variant, see Table S1 in the Supplementary Material.

For all tasks, the score was calculated as the total number of correct locations recalled across completed trials, regardless of serial position (which was only applicable in sequential tasks), with higher scores reflecting better performance.

Participant characteristics and clinical symptoms

The vocabulary and matrices subtests from the Wechsler Abbreviated Scale for Intelligence – Second Edition (WASI-II; Wechsler et al., 2011) were used to provide an age-standardized estimate of full scale IQ (FSIQ-2). Inattentive and hyperactive-impulsive behavior were measured based on parent-report using the Strengths and Weaknesses of ADHD and Normal-behavior (SWAN; Polderman et al., 2007; Swanson et al., 2012). For characterizing the sample, measures of risk of ADHD, ASD and anxiety disorder were assessed using the Conners 3-P (Conners, 2008), Social Communication Questionnaire Lifetime version (SCQ; Rutter et al., 2003) and Multidimensional Anxiety Scale for Children-2 Parent (MASC-2P; March et al., 1997) completed by parents, respectively, with higher scores indicating greater symptoms. Children with scores above the pre-defined clinical cutoff were classified as "at risk" of diagnosis on these measures.

Analyses

Characteristics were compared between groups using chi-square analyses for categorical data and t-tests for continuous data (see *Supplementary Material*). Due to between-group differences in age and to adjust for variance caused by developmental effects, age was controlled in all subsequent analyses.

To assess group differences in task performance, a 2x2x2 mixed ANCOVA was conducted, with presentation type (simultaneous vs. sequential) as one within-subjects factor, memory type (STM vs. WM) as a second within-subjects factor, group (very preterm vs. term) as a between-subjects factor, and age as a covariate. Significant interactions were explored using pairwise comparisons controlling for age, with Sidak adjustments for multiple comparisons. Supplementary analyses with additional covariates or exclusions were conducted to assess the possibility any effects could be accounted for by inattention, IQ or suspected or confirmed diagnoses (see Supplementary Material).

Results

Overall, children born at term recalled significantly more locations (M = 43.85, SEM = 1.92) across the tasks than children born very preterm (M = 37.83, SEM = 1.62; $F(1,109) = 6.42$, $p = .013$, $\eta_p^2 = .056$), and there was a significant effect of age ($F(1,109) = 19.42$, $p < .001$, $\eta_p^2 = .151$) with recall increasing with age.

The main effects of presentation type and memory type were not significant ($p > 0.1$ for both). However, there was a significant 3-way interaction between presentation type, memory type and group $(F(1,109) = 7.86, p = .006, \eta_p^2 = .067;$ Figure 2), and a significant interaction between presentation type and age $(F(1,109) = 5.36, p = .022, \eta_p^2 = .047)$.

Table 1 presents mean number of locations recalled for each task variant, split by group, and results for between- and within-group pairwise comparisons.

First, between-group differences on each task were assessed. For the STM tasks, there were no differences in the number of locations recalled between children born at term and preterm gestations for simultaneous presentation (mean difference = 0.23 locations), but children born preterm recalled significantly fewer sequentially presented locations (mean difference = 7.81 locations). In contrast, for the WM tasks, children born very preterm recalled significantly fewer locations than children born at term for simultaneous presentation (mean difference = 13.00 locations), but there was no significant difference for sequential presentation (mean difference = 3.53 locations).

To further explore the interaction, we also examined within-group differences in presentation type and memory type. For both groups, and for both presentation types, recall on WM tasks was significantly lower than on STM tasks (all $p < .001$). Similarly, for both groups and for both memory types, simultaneous presentation resulted in significantly greater recall than sequential presentation ($p < .05$ in all cases).

The pattern of findings remained similar when controlling for inattention, for IQ, and with the exclusion of children with suspected or confirmed diagnosis of neurodevelopmental conditions.
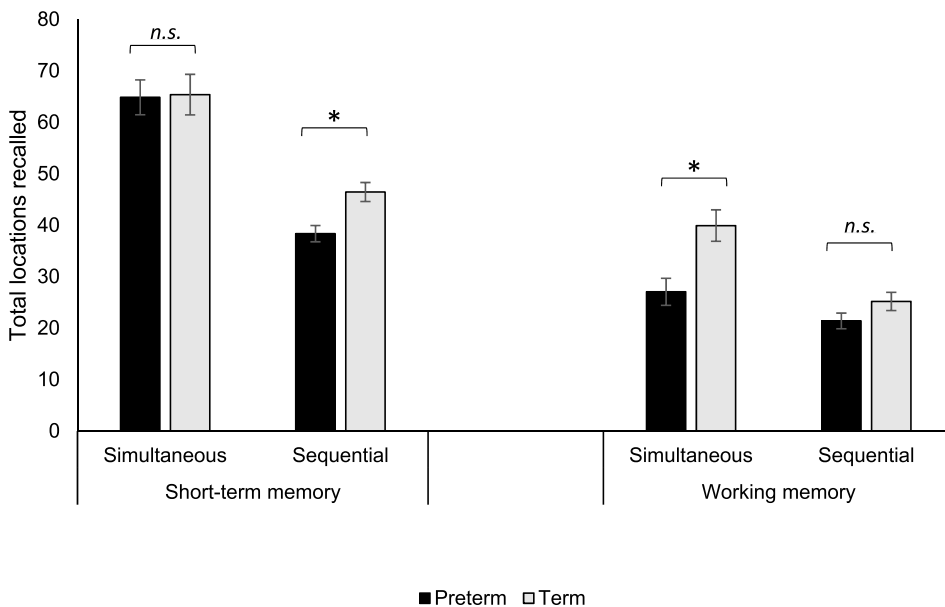

Figure 2. Marginal means for recall for term (gray bars) and preterm (black bars) children on each task variant. Error bars show standard error of the mean. Significance of between-group comparisons indicated.

Table 1. Mean performance scores by group and task type, and pairwise comparison statistics.

	Locations recalled M (SEM)		
Task	Very Preterm	Term	Between-group comparisons p (η_p^2)
Simultaneous STM	64.84 (3.39)	65.38 (3.94)	.967 (<.001)
Sequential STM	38.36 (1.59)	46.45 (1.85)	.002 (.083)
Simultaneous WM	27.07 (2.63)	39.93 (3.06)	.002 (.083)
Sequential WM	21.41 (1.52)	25.20 (1.77)	.151 (.019)
	Within-group comparisons p (η_p^2)		
Comparison	Very Preterm	Term	
Simultaneous vs. Sequential STM	<.001 (.396)	<.001 (.184)	
Simultaneous vs. Sequential WM	.021 (.049)	<.001 (.212)	
Simultaneous STM vs. Simultaneous WM	<.001 (.482)	<.001 (.218)	
Sequential STM vs. Sequential WM	<.001 (.434)	<.001 (.460)	

Note: Means reflect marginal means adjusted for age. SEM = Standard error of the mean.

Discussion

As hypothesized, children born at term recalled more locations in STM than WM tasks, and with simultaneous rather than sequential presentation. The same overall pattern was observed in the very preterm group, with recall highest in the simultaneous STM task, followed by the sequential STM task, then the simultaneous WM task, and lowest in the sequential WM task. The interactions with group aligned only partially with our hypotheses. On simultaneous tasks, we expected better recall in the term group for both STM and WM tasks, with a larger difference on the WM task. While the largest group difference was observed for the simultaneous WM task, performance on the simultaneous STM task did not differ between groups. Although we did not hypothesize group differences on sequentially presented tasks, children born at term recalled more locations than those born preterm in sequential STM tasks.

Understanding visuo-spatial memory

Our finding that simultaneously presented locations were recalled better than sequentially presented locations supports the concept that simultaneously presented location information encourages configural encoding, which likely reduces demands on memory capacity (Bharti et al., 2020; Pickering, 2001). This builds on findings from other clinical groups (Carretti et al., 2015; Lanfranchi et al., 2009; Mammarella et al., 2018, 2006; Wansard et al., 2015), providing further evidence for a dissociation between the way simultaneously and sequentially presented items are processed within the visuo-spatial memory system.

Understanding group differences in simultaneous visuo-spatial memory

Contrary to our predictions, we found no group difference in the recall of simultaneously presented locations on the STM task, on which both groups performed the best, suggesting that configural encoding occurred in both groups where cognitive demand was low. This finding highlights the limitations of drawing conclusions from composite scores such as those from the K-ABC.

In line with studies outlining the importance of cognitive workload for explaining impaired task performance in children born preterm (Jaekel et al., 2013), our prediction that the added cognitive demand of the WM task would increase group differences in simultaneous task performance was supported. Moreover, within the WM tasks, performance of children born very preterm was similar regardless of presentation type. Thus it would appear that under higher cognitive demand, children born very preterm were less likely to benefit from feature binding.

Although the literature suggests feature binding may be an automatic process that confers advantage in memory capacity, there is evidence of interactions between feature binding and cognitive demand at the neural level, even when behavioral performance is not affected. In typical adults, network activation patterns thought to reflect recruitment of additional cognitive resources (specifically, default mode network suppression) were observed during retrieval of bound features only when cognitive task demands were high, suggesting retrieval of bound features is automatic only where cognitive demand is low (Kochan et al., 2011). Moreover, in samples of adults (Daamen et al., 2015) and adolescents (Arthursson et al., 2017) born very preterm, studies of working memory have shown more task-related suppression in this same network relative to control groups. Again, the suppression was linked to those task variants highest in cognitive demand and but did not correspond to performance differences. The authors therefore concluded that the neural group differences likely reflected the greater cognitive effort required for those born at early gestations to maintain adequate task performance in the face of increasing demands.

We therefore propose that the interactions observed in our study may result from additional effort being required for feature binding in children born preterm that only manifests behaviorally when the effort required exceeds a threshold; that is, when there are higher levels of cognitive demand. For the very preterm group, it may be that even when cognitive demands are low the feature-binding requirements during retrieval on the STM task involved some additional effort rather than being automatic, although this cannot be determined from our study. The resources then required under the high demand WM task may have required such additional effort that the threshold beyond which the children were able to compensate was exceeded, impacting recall to a greater extent in children born very preterm than at term. Further research examining neural dynamics during such tasks would be needed to clarify the neural processes associated with this pattern of findings.

Understanding group differences in sequential visuo-spatial memory

The pattern of group differences observed on the sequential tasks was unexpected. Consistent with studies demonstrating poorer performance in visuo-spatial STM tasks in other preterm samples (Shum et al., 2008), there was a medium-sized group difference on the sequential task when recall was immediate (STM), with poorer recall in children born very preterm than at term.

Contrary to expectations however, there was no significant difference in sequential task performance for the WM task. Although this may reflect an area of relative strength in our preterm group, it is at odds with findings of larger group differences as task difficulty increases (Jaekel et al., 2013; Mulder et al., 2009). It could be that both groups experienced floor effects on the sequential WM task. However, 60% children born very preterm and 68% of children born at term proceeded beyond the 3-span level (equating to a minimum of 10 and maximum of 15 locations recalled), with ranges of 52 and 67 locations recalled for each group. Alternatively, it may reflect specific aspects of visuo-spatial memory with which children born preterm struggle. For example, if children born very preterm struggle with the encoding and/or retrieval of sequentially presented locations anyway, adding extra maintenance demand is unlikely to have as large an impact on recall as it may in children born at term, thus resulting in smaller group differences on the sequential WM than STM task. Indeed, although recall in the preterm group was significantly lower in the sequential WM task than the sequential STM task, the mean difference in locations recalled between the two tasks of 16.6, was lower than for the term group (21.2 locations). Further research would be needed to fully understand why there were no group differences observed in recall on the sequential WM task, yet it should be regarded positively that children born very preterm do not always perform more poorly than their term-born peers, even for some attentionally demanding tasks.

Implications

Taken together, our findings have several implications. On a theoretical basis, they provide further support for the distinction between the way simultaneously or sequentially presented items are processed in visuo-spatial memory (Cornoldi & Vecchi, 2004) and are consistent with the notion that feature-binding processes may be automatic under low cognitive demand, but resource-intensive where demands are higher (Kochan et al., 2011). Researchers and clinicians aiming to assess competencies in clinical populations or individuals should consider, (i) distinctions between memory and presentation types, (ii) that performance may reflect interactions between basic processing and cognitive demand, and (iii) that conclusions drawn from composite scores, such as the K-ABC measures, may be limited.

From an educational perspective, we know that decreasing gestational age at birth is associated with poorer educational performance and a higher prevalence of special educational needs (Alterman et al., 2021; MacKay et al., 2010), so it is interesting the very preterm group showed a similar overall pattern of performance to the term-born group. Visual integration of stimuli may be more resource intensive for children born preterm, but our findings suggest that they are still able to bind, store and retrieve items to increase memory capacity. Moreover, with low cognitive demands, the performance of children born very preterm was *better* for simultaneous than sequential presentation. This reframes the prior position that those born at earlier gestations find it easier to process information presented sequentially (Hanke et al., 2003; Johnson et al., 2009; Larroque et al., 2008; Simms et al., 2013; Wolke & Meyer, 1999). Targeted interventions and recommendations for educators should bear in mind that presenting visuo-spatial information sequentially may also present

challenges. Use of educational strategies that aim to minimize cognitive demand, such as memory aids or segmenting tasks for example, may be more beneficial, but further research with a focus on designing and evaluating such intervention strategies is required.

Strengths and limitations

To our knowledge, this is the first study to examine the interaction between cognitive demand and visuo-spatial memory in children born very preterm, and to assess group differences in simultaneous and sequential processing using a task other than the K-ABC. The paper is strengthened by the recruitment of a very preterm group representative of the eligible population in terms of birth weight, gestational age and sex, and the recruitment of a contemporaneous term-born comparison group. This paper is not without limitations however. Firstly, the group of children born very preterm recruited to the study were of higher socio-economic status than the wider eligible population and data on medical complications at birth were not available. Although the socio-economics bias is common in research, the very preterm sample were representative of the eligible population with respect to birth weight, gestational age and sex which are key predictors of neurodevelopmental outcomes. Secondly, although well matched on other variables, the very preterm group was significantly older than the comparison group. Age was covaried throughout our analyses to statistically adjust for this difference. Finally, it would have been interesting to investigate how neurological sequelae or perinatal characteristics aside from gestational age, may have affected visuo-spatial memory processing, but these details were not available.

Conclusions

This study examined the nature of deficits in visuo-spatial memory and simultaneous processing following very preterm birth. Children born very preterm had difficulty recalling simultaneously presented locations in a WM, but not STM task. Together with other evidence, our findings suggest that retrieval of bound representations may be resource-intensive for children born very preterm, who may therefore struggle more than their peers on tasks involving simultaneous visuo-spatial memory where cognitive resources are already stretched.

Disclosure statement

Funding

ORCID

Jenny Retzler http://orcid.org/0000-0002-0008-3104
Samantha Johnson http://orcid.org/0000-0001-8963-7881
Madeleine J. Groom http://orcid.org/0000-0002-5182-518X
Lucy Cragg http://orcid.org/0000-0001-7523-0204

References

Allen, K., Higgins, S., & Adams, J. (2019). The relationship between visuospatial working memory and mathematical performance in school-aged children: A systematic review. *Educational Psychology Review*, *31*(3), 509–531. https://doi.org/10.1007/s10648-019-09470-8

Alterman, N., Johnson, S., Carson, C., Petrou, S., Rivero-Arias, O., Kurinczuk, J. J., ... Quigley, M. A. (2021). Gestational age at birth and child special educational needs: A UK representative birth cohort study. *Archives of Disease in Childhood*, *106*(9), 842–848. https://doi.org/10.1136/archdischild-2020-320213

Arthursson, P.-M. S. H., Thompson, D. K., Spencer-Smith, M., Chen, J., Silk, T., Doyle, L. W., & Anderson, P. J. (2017). Atypical neuronal activation during a spatial working memory task in 13-year-old very preterm children. *Human Brain Mapping*, *38*(12), 6172–6184. https://doi.org/10.1002/hbm.23820

Baddeley, A. D., & Hitch, G. (1974). Working memory. In G. H. Bower (Ed.), *Psychology of learning and motivation* (Vol. 8, pp. 47–89). Academic Press. https://doi.org/10.1016/S0079-7421(08)60452-1

Bharti, A. K., Yadav, S. K., & Jaswal, S. (2020). Feature binding of sequentially presented stimuli in visual working memory. *Frontiers in Psychology*, *11*, 33. https://doi.org/10.3389/fpsyg.2020.00033

Burton, A. M., White, D., & McNeill, A. (2010). The Glasgow face matching test. *Behavior Research Methods*, *42*(1), 286–291. https://doi.org/10.3758/BRM.42.1.286

Carretti, B., Lanfranchi, S., De Mori, L., Mammarella, I. C., & Vianello, R. (2015). Exploring spatial working memory performance in individuals with Williams syndrome: The effect of presentation format and configuration. *Research in Developmental Disabilities*, *37*, 37–44. https://doi.org/10.1016/j.ridd.2014.10.031

Conners, C. K. (2008). *Conners 3-Parent Short Form*. MultiHealth Systems Inc.

Conway, A. R., Kane, M. J., Bunting, M. F., Hambrick, D. Z., Wilhelm, O., & Engle, R. W. (2005). Working memory span tasks: A methodological review and user's guide. *Psychonomic Bulletin & Review*, *12*(5), 769–786. https://doi.org/10.3758/bf03196772

Cornoldi, C., & Vecchi, T. (2004). *Visuo-spatial working memory and individual differences*. Psychology Press.

Daamen, M., Bäuml, J. G., Scheef, L., Sorg, C., Busch, B., Baumann, N., Bartmann, P., Wolke, D., Wohlschläger, A., & Boecker, H. (2015). Working memory in preterm-born adults: Load-dependent compensatory activity of the posterior default mode network. *Human Brain Mapping*, *36*(3), 1121–1137. https://doi.org/10.1002/hbm.22691

De Lillo, C., Kirby, M., & Poole, D. (2016). Spatio-temporal structure, path characteristics, and perceptual grouping in immediate serial spatial recall. *Frontiers in Psychology*, *7*, 1686. https://doi.org/10.3389/fpsyg.2016.01686

Hanke, C., Lohaus, A., Gawrilow, C., Hartke, I., Köhler, B., & Leonhardt, A. (2003). Preschool development of very low birth weight children born 1994–1995. *European Journal of Pediatrics*, *162*(3), 159–164. https://doi.org/10.1007/s00431-002-1127-1

Houdt, C. A., Van Oosterlaan, J., Wassenaer-Leemhuis, A. G., van, Kaam, A. H., & Aarnoudse-Moens, C. S. H. (2019). Executive function deficits in children born preterm or at low birth-weight: A meta-analysis. *Developmental Medicine and Child Neurology*, *61*(9), 1015–1024. https://doi.org/10.1111/dmcn.14213

Jaekel, J., Baumann, N., & Wolke, D. (2013). Effects of gestational age at birth on cognitive performance: A function of cognitive workload demands. *Plos One*, *8*(5), 7. https://doi.org/10.1371/journal.pone.0065219

Johnson, S., Hennessy, E., Smith, R., Trikic, R., Wolke, D., & Marlow, N. (2009). Academic attainment and special educational needs in extremely preterm children at 11 years of age: The EPICure study. *Archives of Disease in Childhood - Fetal and Neonatal Edition*, *94*(4), F283–F289. https://doi.org/10.1136/adc.2008.152793

Kaufman, A. S. (2004). *Manual for the Kaufman assessment battery for children*. AGS Publishing.

Kochan, N. A., Valenzuela, M., Slavin, M. J., McCraw, S., Sachdev, P. S., Breakspear, M., & Greenlee, M. W. (2011). Impact of load-related neural processes on feature binding in visuospatial working memory. *Plos One*, *6*(8), 8. https://doi.org/10.1371/journal.pone.0023960

Lanfranchi, S., Carretti, B., Spanò, G., & Cornoldi, C. (2009). A specific deficit in visuospatial simultaneous working memory in down syndrome. *Journal of Intellectual Disability Research*, *53*(5), 474–483. https://doi.org/10.1111/j.1365-2788.2009.01165.x

Larroque, B., Ancel, P.-Y., Marret, S., Marchand, L., André, M., Arnaud, C., Pierrat, V., Rozé, J.-C., Messer, J., Thiriez, G., Burguet, A., Picaud, J.-C., Bréart, G., & Kaminski, M. (2008). Neurodevelopmental disabilities and special care of 5-year-old children born before 33 weeks of gestation (the EPIPAGE study): A longitudinal cohort study. *The Lancet*, *371*(9615), 813–820. https://doi.org/10.1016/S0140-6736(08)60380-3

Logie, R. H. (2019). Converging sources of evidence and theory integration in working memory: A commentary on Morey, Rhodes, and Cowan (2019). *Cortex*, *112*, 162–171. https://doi.org/10.1016/j.cortex.2019.01.030

Lui, M., & Tannock, R. (2007). Working memory and inattentive behaviour in a community sample of children. *Behavioral and Brain Functions*, *3*(1), 12. https://doi.org/10.1186/1744-9081-3-12

MacKay, D. F., Smith, G. C. S., Dobbie, R., & Pell, J. P. (2010). Gestational age at delivery and special educational need: Retrospective cohort study of 407,503 schoolchildren. *PLoS Medicine*, *7*(6), e1000289. https://doi.org/10.1371/journal.pmed.1000289

Mammarella, I. C., Caviola, S., Giofrè, D., & Szűcs, D. (2018). The underlying structure of visuospatial working memory in children with mathematical learning disability. *British Journal of Developmental Psychology*, *36*(2), 220–235. https://doi.org/10.1111/bjdp.12202

Mammarella, I. C., Cornoldi, C., Pazzaglia, F., Toso, C., Grimoldi, M., & Vio, C. (2006). Evidence for a double dissociation between spatial-simultaneous and spatial-sequential working memory in visuospatial (nonverbal) learning disabled children. *Brain and Cognition*, *62*(1), 58–67. https://doi.org/10.1016/j.bandc.2006.03.007

March, J. S., Parker, J. D., Sullivan, K., Stallings, P., & Conners, C. K. (1997). The multidimensional anxiety scale for children (MASC): Factor structure, reliability, and validity. *Journal of the American Academy of Child and Adolescent Psychiatry*, *36*(4), 554–565. https://doi.org/10.1097/00004583-199704000-00019

Martinussen, R., Hayden, J., Hogg-johnson, S., & Tannock, R. (2005). A meta-analysis of working memory impairments in children with attention-deficit/hyperactivity disorder. *Journal of the American Academy of Child and Adolescent Psychiatry*, *44*(4), 377–384. https://doi.org/10.1097/01.chi.0000153228.72591.73

Morey, C. (2018). The case against specialized visual-spatial short-term memory. *Psychological Bulletin*, *144*(8), 849–883. https://doi.org/10.1037/bul0000155

Morey, C., Rhodes, S., & Cowan, N. (2020). Co-existing, contradictory working memory models are ready for progressive refinement: Reply to logie. *Cortex*, *123*, 200–202. https://doi.org/10.1016/j.cortex.2019.11.012

Morey, C. C., Rhodes, S., & Cowan, N. (2019). Sensory-motor integration and brain lesions: Progress toward explaining domain-specific phenomena within domain-general working memory. *Cortex*, *112*, 149–161. https://doi.org/10.1016/j.cortex.2018.11.030

Mulder, H., Pitchford, N., Hagger, M., & Marlow, N. (2009). Development of executive function and attention in preterm children: A systematic review. *Developmental Neuropsychology*, *34*(4), 393–421. https://doi.org/10.1080/87565640902964524

Peirce, J., Gray, J. R., Simpson, S., MacAskill, M., Höchenberger, R., Sogo, H., Kastman, E., & Lindeløv, J. K. (2019). PsychoPy2: Experiments in behavior made easy. *Behavior Research Methods*, *51*(1), 195–203. https://doi.org/10.3758/s13428-018-01193-y

Pickering, S. J. (2001). The development of visuo-spatial working memory. *Memory*, *9*(4–6), 423–432. https://doi.org/10.1080/09658210143000182

Polderman, T. J., Derks, E. M., Hudziak, J. J., Verhulst, F. C., Posthuma, D., & Boomsma, D. I. (2007). Across the continuum of attention skills: A twin study of the SWAN ADHD rating scale. *Journal of Child Psychology and Psychiatry*, *48*(11), 1080–1087. https://doi.org/10.1111/j.1469-7610.2007.01783.x

Retzler, J., Johnson, S., Groom, M., Hollis, C., Budge, H., & Cragg, L. (2019). Cognitive predictors of parent-rated inattention in very preterm children: The role of working memory and processing speed. *Child Neuropsychology*, *25*(5), 617–635. https://doi.org/10.1080/09297049.2018.1510908

Rutter, M., Bailey, A., & Lord, C. (2003). *The social communication questionnaire: Manual*. Western Psychological Services.

Shum, D., Neulinger, K., Ocallaghan, M., & Mohay, H. (2008). Attentional problems in children born very preterm or with extremely low birth weight at 7–9 years. *Archives of Clinical Neuropsychology*, *23*(1), 103–112. https://doi.org/10.1016/j.acn.2007.08.006

Simms, V., Gilmore, C., Cragg, L., Clayton, S., Marlow, N., & Johnson, S. (2015). Nature and origins of mathematics difficulties in very preterm children: A different etiology than developmental dyscalculia. *Pediatric Research*, *77*(2), 389–395. https://doi.org/10.1038/pr.2014.184

Simms, V., Gilmore, C., Cragg, L., Marlow, N., Wolke, D., & Johnson, S. (2013). Mathematics difficulties in extremely preterm children: Evidence of a specific deficit in basic mathematics processing. *Pediatric Research*, *73*(2), 236–244. https://doi.org/10.1038/pr.2012.157

Swanson, J. M., Schuck, S., Porter, M. M., Carlson, C., Hartman, C. A., Sergeant, J. A., Clevenger, W., Wasdell, M., McCleary, R., & Lakes, K. (2012). Categorical and dimensional definitions and evaluations of symptoms of ADHD: History of the SNAP and the SWAN rating scales. *The International Journal of Educational and Psychological Assessment*, *10*(1), 51. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4618695/

Taylor, H. G., & Clark, C. A. C. (2016). Executive function in children born preterm: Risk factors and implications for outcome. *Seminars in Perinatology*, *40*(8), 520–529. https://doi.org/10.1053/j.semperi.2016.09.004

Wansard, M., Bartolomeo, P., Bastin, C., Segovia, F., Gillet, S., Duret, C., & Meulemans, T. (2015). Support for distinct subcomponents of spatial working memory: A double dissociation between spatial–simultaneous and spatial–sequential performance in unilateral neglect. *Cognitive Neuropsychology*, *32*(1), 14–28. https://doi.org/10.1080/02643294.2014.995075

Wechsler, D., & Zhou, X., Psychological Corporation, & Assessment Library Materials (University of Lethbridge. Faculty of Education. Curriculum Laboratory). (2011). *WASI-II: Wechsler abbreviated scale of intelligence*.

Wolke, D., Johnson, S., & Mendonça, M. (2019). The life course consequences of very preterm birth. *Annual Review of Developmental Psychology*, *1*(1), 69–92. https://doi.org/10.1146/annurev-devpsych-121318-084804

Wolke, D., & Meyer, R. (1999). Cognitive status, language attainment, and prereading skills of 6-year-old very preterm children and their peers: The Bavarian longitudinal study. *Developmental Medicine and Child Neurology*, *41*(2), 94–109. https://doi.org/10.1111/j.1469-8749.1999.tb00561.x