

Recall memory in children with Down syndrome and typically developing peers matched on developmental age

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Abstract

Background Whereas research has indicated that children with Down syndrome (DS) imitate demonstrated actions over short delays, it is presently unknown whether children with DS recall information over lengthy delays at levels comparable with typically developing (TD) children matched on developmental age.

Method In the present research, 10 children with DS and 10 TD children participated in a two-session study to examine basic processes associated with hippocampus-dependent recall memory. At the first session, the researcher demonstrated how to complete a three-step action sequence with novel stimuli; immediate imitation was permitted as an index of encoding. At the second session, recall memory was assessed for previously modelled sequences; children were also presented with two novel three-step control sequences.

Results The results indicated that group differences were not apparent in the encoding of the events or the forgetting of information over time. Group differences were also not observed when considering the recall of individual target actions at the 1-month delay, although TD children produced more target actions overall at the second session relative to children with DS. Group differences were found when

considering memory for temporal order information, such that TD children evidenced recall relative to novel control sequences, whereas children with DS did not.

Conclusions These findings suggest that children with DS may have difficulty with mnemonic processes associated with consolidation/storage and/or retrieval processes relative to TD children.

Keywords Down syndrome, recall memory

Children with developmental disabilities must be able to successfully encode and retain information over the long term in order to realise and maintain the benefits of imposed education and intervention programmes. Whereas research has indicated that children with Down syndrome (DS) imitated demonstrated actions over short delays (Rast & Meltzoff 1995; Cupples & Iacono 2002; Kennedy & Flynn 2003; Feeley *et al.* 2011; Roberts & Richmond 2015), it is presently unknown whether children with DS recall information over lengthy delays at levels comparable with those of typically developing (TD) children matched on developmental age (DA). The present study was conducted to examine whether children with DS differed from TD peers matched on DA when considering the encoding and retention of information over a 1-month delay.

Down syndrome is a chromosomal disorder characterised by extra chromosomal material on the 21st pair (Selikowitz 1997); approximately 6000 infants with DS are born per year in the USA (Parker

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• Recall memory and Down syndrome

et al. 2010). Although DS results from three different genotypes that result in phenotypic variation, one of the central features of DS is intellectual impairment (Selikowitz 1997). Children with DS experience numerous cognitive challenges relative to TD children, including reduced IQ and issues with receptive and expressive language (Abbeduto *et al.* 2001; Laws & Bishop 2003). These cognitive deficits are associated with structural and functional neuroanatomical abnormalities. For example, children and young adults with DS have reduced brain volume relative to age-matched and sex-matched controls (Pinter *et al.* 2001), with area-specific reductions found in the cerebellum as well as frontal and temporal regions (Jernigan *et al.* 1993). Pinter *et al.* (2001) suggest that these neuroanatomical differences likely result from atypical–developmental processes during fetal or early postnatal development. As evidence of this, previous research has revealed differences in hippocampal cell proliferation during gestation (Guidi *et al.* 2008) and in hippocampal volumes during childhood as indicated by functional magnetic resonance imaging (Pinter *et al.* 2001). These early differences in hippocampal morphology likely contribute to observable deficits in learning and memory in infancy and early childhood.

The present research was conducted to examine hippocampus-mediated recall memory performance at encoding and after a 1-month delay in children with DS relative to TD children matched on DA. We chose to assess recall memory performance using an elicited imitation paradigm that has been extensively employed to study the emergence and development of recall memory early in life. In the version of the procedure developed by Bauer (Bauer *et al.* 2007; Lukowski & Bauer 2014), children are presented with novel three-dimensional stimuli for a child-controlled baseline period. A researcher then demonstrates how to perform a sequence of actions with the materials. Children are permitted to imitate the actions immediately after the demonstration as an index of encoding and/or after delays ranging from minutes to months as an index of long-term recall. The data are reduced to determine whether the child performed the demonstrated target actions and whether the completed actions were produced in the correct temporal order (for additional information, see Bauer *et al.* 2007).

Extensive research has been conducted to establish that the elicited imitation procedure assesses hippocampus-dependent declarative or explicit memory (Mandler 1990; Meltzoff 1990; Bauer 1996; Bauer 2002; Bauer 2007). Three relevant arguments are provided here. First, children verbally describe events that they previously experienced in imitation procedures once they gain access to language (Bauer *et al.* 2002). Evidence of later verbal accessibility suggests that the type of memory under investigation is declarative or explicit, as non-declarative or implicit memories cannot be expressed verbally. Second, individuals who have temporal lobe damage show deficits on age-appropriate imitation tasks (McDonough *et al.* 1995; Adlam *et al.* 2005) relative to control participants and individuals with frontal lobe damage (McDonough *et al.* 1995). Impaired performance by individuals with damage to medial temporal lobe structures also indicates that the elicited imitation paradigm assesses declarative or explicit memory (Squire & Zola-Morgan 1991). Third, whereas the sequence materials may serve to cue memory for the demonstrated target actions, they do not cue the temporal order in which the actions should be reproduced (Mandler 1990). As such, temporal order information must be encoded during sequence demonstration and maintained over time. For these reasons, the elicited imitation procedure is commonly accepted as the gold standard for studying the development of hippocampus-dependent recall memory in infancy and early childhood.

Studies of the development of recall memory have revealed that the ability to remember information over the long term emerges around 6 months of age and continues to develop thereafter. For example, after multiple experiences to to-be-remembered information, 6-month-old infants remember one out of three demonstrated target actions after a 24-h delay (Barr *et al.* 1996; Collie & Hayne 1999), whereas 9-month-old infants remember the target actions of two-step event sequences for 1 month. Even when multiple exposures are permitted, however, 9-month-old infants experience difficulty retaining temporal order information: work conducted with three independent samples has revealed that only approximately 50% of infants reproduced at least one two-step event sequence in the correct temporal order after 1 month (Carver & Bauer 1999; Bauer *et al.* 2001; Carver & Bauer 2001). Memory becomes more

• Recall memory and Down syndrome

robust in the second year of life, such that 13-month-old infants remember target actions and order information for up to 6 months (Bauer *et al.* 2000; see also Meltzoff 1995). Twenty-month-old infants recall individual target actions and pairs of actions over delays up to 12 months after when permitted multiple exposures to multi-step event sequences (Bauer *et al.* 2000). Even when only one demonstration is allowed, however, 20-month-old infants remember individual target actions and their order for 1 month (Bauer & Leventon 2013). Bauer suggests that advances in the reliability and robustness of recall in TD children result from developments in the temporal–cortical network that supports the encoding, consolidation/storage and retrieval of information (see Bauer 2002; Bauer 2004; Bauer 2006; Bauer 2008 and the Discussion section of this report).

Although wealth of information has been amassed on memory development in TD infants and children, only two studies to our knowledge have used the elicited imitation paradigm to examine recall memory in children with DS (Rast & Meltzoff 1995; Roberts & Richmond 2015). In one, Rast and Meltzoff (1995) examined 5-min delayed recall memory in 20-month-old to 43-month-old children with DS. Before the imposition of the delay, children in the experimental group watched as a researcher modelled a one-step action with novel stimuli. Children in the activity control group watched as a researcher manipulated the sequence materials in a random fashion but did not demonstrate the target actions, and children in the baseline control group interacted with the sequence materials but did not observe any actions demonstrated by the researcher. Findings indicated that children in the experimental group produced more target actions post-demonstration relative to children in the control groups, thereby indicating that children with DS are capable of 5-min deferred imitation. Other work also suggests that children with DS are competent imitators: Roberts and Richmond (2015) reported that preschoolers with DS outperformed TD children matched on DA on a deferred imitation task after a 24-h delay.

Despite findings indicating that children with DS imitate actions and sounds over short delays, the literature on the development of recall memory has not yet examined whether children with DS recall information over lengthy delays at levels comparable with TD children matched on DA. This question is

practically important, as education and intervention programmes for children with DS require that children encode the presented information and remember what is taught over extended delays. In the present study, we assessed recall memory using an elicited imitation paradigm given that imitation and social learning abilities are strengths of children with DS (Rast & Meltzoff 1995; Libby *et al.* 1997; Dykens & Hodapp 2001; Wright *et al.* 2006; Roberts & Richmond 2015). Based on previous research, we predicted that children in both groups would evidence encoding of the presented material relative to baseline (Rast & Meltzoff 1995; Roberts & Richmond 2015). We also anticipated that children in both groups would demonstrate forgetting over the 1-month delay, as has been demonstrated previously with TD children tested over this duration of time (Bauer *et al.* 2000; Hayne & Herbert 2004; Klein & Meltzoff 2009; Bauer & Lukowski 2010). When considering performance after the 1-month delay, we hypothesised that children with DS would perform less well than TD children and that the group differences would be more pronounced on measures of memory for temporal order information relative to measures of memory for individual target actions. We made this prediction based on previous work conducted with TD children indicating that temporal order information is more difficult to retain over the long term relative to memory for individual target actions.

Method**Participants**

Ten children with DS (mean age = 33 months, 5 days; range from 22 months, 4 days to 49 months, 3 days) and 10 TD children (mean age = 21 months, 6 days; range from 12 months, 19 days to 28 months, 6 days) served as participants. Approximately 70% of the children with DS were diagnosed by their paediatricians, whereas the remaining 30% were diagnosed through prenatal testing. Children with DS were recruited from local early intervention centres, organisations that provided educational and support services to children with DS and their families and through snowball sampling. Families with TD children were initially contacted through a mass mailing about the possibility of participating in research studies on early memory development with their children.

• Recall memory and Down syndrome

Interested families in both groups provided the research team with their phone number and email addresses and were contacted with additional information about participating in the study.

Parents of TD children reported that their children were undergoing a normative developmental course, whereas parents of children with DS reported that their children were not experiencing any co-morbid developmental disorders. Of the 20 participants in the final sample, 75% were Caucasian, 15% were Asian, 5% were African American and 5% were of mixed race. Thirty per cent of the children were of Hispanic ethnicity. Eighty-five per cent of mothers had obtained at least a four-year college degree. All parents received \$30 in appreciation of their participation, and children received either a small toy or a junior scientist t-shirt.

Materials and measures

Questionnaires

Parents provided demographic information, including child race and ethnicity, parent education and family income, among other things. They also completed other questionnaires that are the subject of other reports that are in preparation for publication.

Bayley Scales of Infant Development-III

The mental dimension of the Bayley Scales of Infant Development-III (BSID-III; Bayley 2006) was administered to all children at the first session for the purposes of matching groups on DA as has been performed in previous research (Wright *et al.* 2006; Gilmore *et al.* 2009; Venuti *et al.* 2009; Reddy *et al.* 2010).

Elicited imitation

Six event sequences were used across the two study sessions. The included event sequences were constrained by enabling relations, as the steps had to be completed in the demonstrated temporal order for the sequence end-state or goal-state to be realised (see Fig. 1 for an example sequence; see the appendix of Lukowski *et al.* 2015 for a verbal description of each event used in this report). We chose to use sequences constrained by enabling relations so as to allow the children with DS the best opportunity for immediate imitation and long-term delayed recall, as TD children younger than 20 months of age perform at chance on sequences that are arbitrarily ordered (Wenner & Bauer 1999). The sequences were block randomised and counterbalanced across phases; the present report concerns two sequences that were modelled and for which immediate imitation was permitted at the first session as well as two novel sequences that were presented only at the second session. The order of the two sequences within each phase was randomised.

Procedure

The study design and procedure were approved by the relevant Institutional Review Boards. A waiver of written informed consent was granted for the questionnaire portion of the study; parents signed informed consent statements at the first session indicating their willingness to allow their child to participate in the behavioural portion of the study. All children were tested by the first author, and each session was video recorded to allow for protocol checks and offline data coding.



Figure 1 Example of the three-step event sequence Make a Shaker. The left panel shows the first step of putting the block into one of the nesting cups; the middle panel shows the second step of assembling the nesting cups; the right panel shows the third step of shaking the assembled apparatus. The figure and caption are reproduced from Lukowski *et al.* (2015); the figure was also previously featured in Phung *et al.* (2014) (reproduced with permission).

• Recall memory and Down syndrome*Questionnaires*

Parents received the questionnaires by mail along with waiver of signed informed consent. Most of the parents completed the questionnaires at home and returned them to the researcher at the first session. Those parents who did not have the questionnaires completed at that time were asked to return them to the research team at the second session.

Bayley Scales of Infant Development-III

When the family arrived at the laboratory, the child was seated across from the researcher at an adult-sized table. The researcher engaged the child in a warm-up procedure that has been used in previous research to familiarise the child with the turn-taking format of the elicited imitation procedure (Bauer & Dow 1994; Bauer & Wewerka 1995; Bauer *et al.* 1995; Bauer *et al.* 2000; Bauer & Lukowski 2010; Phung *et al.* 2014; Lukowski *et al.* 2015). Once the child appeared comfortable with the researcher, the researcher administered the mental portion of the BSID-III (Bayley 2006). When the assessment was complete, parents were given a pamphlet describing age-appropriate developmental milestones for children of the tested ages along with the recommendation that they talk with their paediatrician if they had any concerns about the development of their child.

Elicited imitation

Children were tested in the elicited imitation procedure immediately after completing the BSID-III (Bayley 2006). Children were presented with four novel three-step event sequences at the first session. Once the sequence materials were placed on the table, the children were provided with a general verbal prompt ('What can you do with this stuff?'). This baseline period was child controlled, such that this phase of testing ended when children engaged in repetitive or off-task behaviours such as repeatedly banging the props on the table or dropping them on the floor (Bauer & Hertsgaard 1993; Bauer *et al.* 2000; Bauer & Lukowski 2010; Phung *et al.* 2014; Lukowski *et al.* 2015). Once the baseline period expired, the researcher demonstrated each sequence of actions twice in succession with narration.

Immediate imitation was permitted for two of the sequences as an index of encoding (Bauer 2005; Bauer *et al.* 2011; Bauer *et al.* 2000; Bauer & Lukowski 2010; Hayne & Herbert 2004; Herbert & Hayne 2000; Lukowski & Milojevich 2013; Lukowski *et al.* 2005; Phung *et al.* 2014). Children were given the sequence materials along with the name of the event ('You can use this stuff to Make a Shaker. How do you Make a Shaker just like I did?'). The imitation period ended when children engaged in repetitive or off-task behaviours.

Children returned to the laboratory after approximately 1 month (mean delay = 29 days; range from 27 to 35 days) to participate in an assessment of delayed recall memory. Delayed recall was assessed by providing children with the same event sequences that were modelled at the first session. Children were also presented with two novel control sequences that were not previously demonstrated by the researcher. These novel control sequences were included because the participants were expected to have developed more mature motor skills and problem-solving abilities over the 1-month delay. For this reason, differences in performance between baseline at the first session and delayed recall at the second session may result from increased spontaneous production of the demonstrated target actions and may not be because of memory *per se*. As such, the most stringent test of memory over long delays occurs when performance on previously modelled familiar sequences is compared with novel sequences presented at the same session (Carver & Bauer 1999; Bauer *et al.* 2000; Carver & Bauer 2001; Lukowski *et al.* 2005). The order in which the familiar and novel sequences were presented at the second session was counterbalanced.

Performance on familiar and novel control sequences was assessed in the same manner at the second session. The researcher placed the sequence materials for each event on the table in turn and provided the child with the name of the event as a retrieval cue for familiar events and as a suggestion of activities that could be completed with the novel sequence materials ('You can use this stuff to Make a Shaker. How do you Make a Shaker with this stuff?'). The delayed recall period ended when children engaged in repetitive or off-task behaviours.

• Recall memory and Down syndrome

Data reduction

Bayley Scales of Infant Development-III

The data obtained from the BSID-III (Bayley 2006) were reduced as described in the administration manual. The first author matched the DAs of the children with DS to those who were TD within 3 months, as has been performed in previous research (MacTurk *et al.* 1985; Venuti *et al.* 2009; Vanvuchelen *et al.* 2011).

Elicited imitation

The data were coded by an undergraduate research assistant who was unaware of the hypotheses of the study. Target actions were coded when the child performed any of the three actions modelled by the researcher. Pairs of actions completed in the correct temporal order were coded by marking the order in which the target actions were produced. The first occurrence of each target action was coded so as to reduce the likelihood of awarding credit for actions produced by chance or through trial and error, thereby providing for a conservative measure of recall (Bauer & Dow 1994; Bauer *et al.* 2000; Lukowski *et al.* 2005; Lukowski & Milojevich 2013; Phung *et al.* 2014; Lukowski *et al.* 2015). The first author then independently recoded the data for 25% of the sample ($n = 5$). Mean per cent agreement on the production of target actions and their order was 98% (range from 89% to 100%). The average number of target actions (maximum = 3) and pairs of actions produced in the correct temporal order (maximum = 2) were reduced separately by group (DS or TD) for each phase of testing (baseline, immediate imitation and delayed recall for familiar sequences) and by condition at the second session (delayed recall for familiar sequences and novel control sequences).

Table 1 Demographic information by group

	Down syndrome	Typically developing	Statistic	p-value
Chronological age (months)	32.82 ± 9.40	21.69 ± 4.16	$F = 11.73$	0.003
Developmental age (months)	21.50 ± 4.55	23.20 ± 4.69	$F = 0.68$	0.42
Infant sex (% girls)	50%	30%	$\chi^2 = 0.83$	0.36
Infant ethnicity (% Hispanic)	50%	10%	$\chi^2 = 3.81$	0.05
Maternal education (% with ≥4-year college degree)	90%	80%	$\chi^2 = 0.39$	0.53

Results

Demographic information

Demographic information is presented by group in Table 1. Children with DS were chronologically older than TD children, and there were more Hispanic children in the DS group relative to the TD group. Given these group differences, we conducted correlations to examine whether chronological age or ethnicity was associated with performance on the elicited imitation assessment. All of the correlations were non-significant (results available from the second author upon request). As such, these demographic variables were not considered as covariates in subsequent analyses.

Elicited imitation

Data from the elicited imitation assessment are shown in Table 2. We conducted 2 (group: DS or TD) × 3 (phase: baseline, immediate imitation and delayed

Table 2 Elicited imitation performance by group (means ± standard deviations)

	Target actions	Pairs of actions
Down syndrome		
Baseline	0.70 ± 0.63	0.10 ± 0.21
Immediate imitation	1.80 ± 1.09	0.95 ± 0.86
1-month delay		
Familiar sequences	1.35 ± 0.91	0.50 ± 0.53
Novel control sequences	0.85 ± 0.75	0.35 ± 0.41
Typically developing		
Baseline	0.75 ± 0.49	0.10 ± 0.21
Immediate imitation	2.20 ± 0.75	1.20 ± 0.67
1-month delay		
Familiar sequences	2.10 ± 0.74	1.00 ± 0.71
Novel control sequences	1.30 ± 0.48	0.30 ± 0.35

• Recall memory and Down syndrome

recall) mixed analyses of variance to determine whether group differences in performance were found by phase for familiar sequences (events that were modelled and for which imitation was permitted at the first session). Main effects of phase were found on both dependent measures [target actions: $F_{2,36} = 25.73$, $p < 0.0001$, $\eta_p^2 = 0.59$; pairs of actions: $F_{2,36} = 21.68$, $p < 0.0001$, $\eta_p^2 = 0.54$]. Follow-up pairwise comparisons revealed that children produced more target actions and pairs of actions at immediate imitation and delayed recall relative to baseline ($ps < 0.0001$). Evidence of forgetting over the 1-month delay was only found for pairs of actions, such that performance at immediate imitation exceeded that at delayed recall ($p < 0.02$). Main effects of group were not found for either dependent variable [target actions: $F_{1,18} = 2.03$, $p = 0.17$, $\eta_p^2 = 0.10$; pairs of actions: $F_{1,18} = 1.62$, $p = 0.22$, $\eta_p^2 = 0.08$] nor were significant Group \times Phase interactions [target actions: $F_{2,36} = 1.75$, $p = 0.19$, $\eta_p^2 = 0.09$; pairs of actions: $F_{2,36} = 1.38$, $p = 0.27$, $\eta_p^2 = 0.07$].

We then conducted two 2 (group) \times 2 (condition: familiar sequences and novel control sequences) to determine whether there were group differences in long-term recall memory. A main effect of group was found for target actions: $F_{1,18} = 4.39$, $p = 0.05$, such

that TD children produced more target actions across conditions relative to children with DS; a main effect of group was not found for pairs of actions: $F_{1,18} = 1.29$, $p = 0.27$, $\eta_p^2 = 0.07$. A main effect of condition was also apparent for target actions: $F_{1,18} = 15.84$, $p < 0.001$, $\eta_p^2 = 0.20$, such that across groups, children produced more target actions on familiar sequences relative to novel control sequences. The main effect of condition found for pairs of actions: $F_{1,18} = 12.69$, $p < 0.002$ was further qualified by an interaction with group: $F_{1,18} = 5.31$, $p < 0.03$, $\eta_p^2 = 0.47$ (Fig. 2). Follow-up pairwise comparisons conducted by group revealed that TD children performed more pairs of actions on familiar sequences relative to novel control sequences ($p < 0.001$), whereas differential performance by condition was not found for children with DS.¹ Follow-up pairwise comparisons conducted by condition revealed no differences in performance by group. A comparable Group \times Condition interaction was not found for target actions: $F_{1,18} = 0.84$, $p = 0.37$, $\eta_p^2 = 0.05$.²

Discussion

The present research was conducted to examine whether there were differences in encoding and

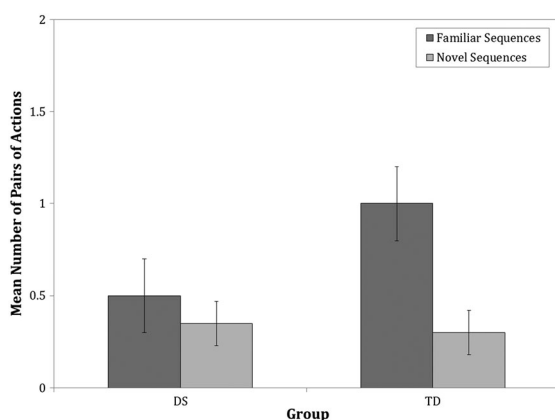


Figure 2 A Group \times Condition interaction was found for pairs of actions completed in the correct temporal order. Follow-up pairwise comparisons conducted by group revealed that typically developing children performed more pairs of actions on familiar sequences relative to novel control sequences; differences by condition were not found for children with Down syndrome. Follow-up pairwise comparisons conducted by condition revealed no differences in performance by group.

¹ We conducted a Bayesian analysis of null effects using the supplemental Excel file provided by Masson (2011) to test whether the alternative hypothesis was favoured over the null when examining memory for pairs of actions by TD children relative to novel control sequences at the second session. The findings revealed that the posterior probability value for accepting the alternative hypothesis was 0.94, indicating positive to strong evidence for accepting the alternative hypothesis based on the classification system proposed by Raftery (1995). A comparable analysis conducted on the data obtained from the children with DS revealed that the posterior probability value for accepting the alternative hypothesis was 0.46, a value so low that it is not listed in the classification system proposed by Raftery (1995).

² We conducted a statistical comparison of the effect sizes for the 2 (group) \times 2 (condition) interactions for target actions and pairs of actions completed in the correct temporal order. This analysis was conducted to determine whether the effect sizes of the two analyses were statistically significant despite the relatively small sample size. We first calculated the r effect sizes for both interactions ($r = 0.21$ for target actions and $r = 0.48$ for pairs of actions) and then compared them according to the procedure outlined in Meng *et al.* (1992). The z -test comparison for the two effect sizes was 2.0208 with a corresponding p -value of 0.04. As such, the effect sizes for the two tested interactions are significantly different.

• Recall memory and Down syndrome

1-month hippocampus-dependent recall memory in children with DS relative to TD controls matched on DA. The findings revealed that children in both groups were comparable in their encoding of target actions and their order and in their forgetting of information over the 1-month delay. Children in both groups showed comparable performance at immediate imitation and delayed recall on the production of individual target actions. Comparable performance across groups was maintained when considering memory for target actions after the 1-month delay, such that children produced more target actions across groups on familiar sequences at the second session relative to novel control sequences. Differential evidence of memory was only apparent when considering performance on pairs of actions completed in the correct temporal order. Whereas TD children performed more pairs of actions on familiar sequences relative to novel control sequences, children with DS did not. As such, TD children evidenced memory for temporal order over the 1-month delay, whereas the same was not true of children with DS.

As indicated earlier, we are aware of only two other studies that have examined recall memory in children with DS using an elicited imitation paradigm. One study indicated that children exposed to a single target action demonstrated retention after a 5-min delay relative to children in two control groups who did not witness the event demonstration (Rast & Meltzoff 1995). Whereas this finding is valuable in indicating that children with DS are capable of deferred imitation, it is limited in that comparisons were not made relative to TD children and a short delay was imposed between encoding and test. The imposition of a short delay between encoding and test is informative from a basic science perspective but has limited ecological validity as children with developmental disabilities are expected to remember learned information over much lengthier delays in the context of education and intervention programmes.

More recently, Roberts and Richmond (2015) examined 24-h deferred imitation in preschool-aged children with DS and TD children matched on DA. Their results revealed that children with DS performed 'better' on the tested event relative to TD children. These findings are inconsistent with our data and are somewhat surprising given what is

known about altered hippocampal morphology in infants and young children with DS (Pinter *et al.* 2001; Guidi *et al.* 2008). We suggest that one factor that may contribute to our divergent findings is that Roberts and Richmond (2015) did not determine whether children evidenced recall relative to baseline. The inclusion of a baseline comparison group is critical in determining (1) whether groups differ in their spontaneous production of target actions and their order before sequence demonstration and (2) in determining whether children evidence delayed recall. Without including a baseline comparison, it is unclear whether (1) the children in either group evidenced recall and (2) whether the obtained group difference resulted from variability in the spontaneous production of target actions or from memory for the presented actions and their order.

In contrast, our findings indicate that children with DS remember target actions over the 1-month delay but do not recall information pertaining to temporal order. One potential explanation for the observed findings may be that children with DS experience deficits in executive functioning (EF) that may contribute to sequencing problems or perseverative tendencies (e.g. focusing on only one target action or non-target action to the exclusion of the others; see Lanfranchi *et al.* 2010 and Rowe *et al.* 2006 for evidence of impairments, but also Roberts & Richmond 2015). This possibility is unlikely, as previous work with TD children has demonstrated that performance on immediate imitation is not significantly associated with performance on measures of EF (Wiebe *et al.* 2010). Moreover, if children with DS repeatedly performed either target or non-target actions, statistical analyses should have revealed that TD children completed more target actions at immediate imitation and delayed recall relative to children with DS. As reported earlier, children with DS did not experience performance deficits relative to TD children on familiar sequences at any phase of testing. As such, it is unlikely that group differences in EF account for the obtained results.

Another possibility may be that children with DS performed less well at the 1-month delayed recall assessment because of difficulty with receptive vocabulary, as the name of the event was provided as a retrieval cue at that time (Abbeduto *et al.* 2001; Laws & Bishop 2003). We attempted to account for

• Recall memory and Down syndrome

differences in this cognitive ability by group by matching children on DA using the BSID-III (Bayley 2006).³ Notably, however, the collected data suggest that differential receptive language ability was not likely associated with performance at either immediate imitation or delayed recall.

Whereas the sequence name may serve to cue the target actions that may be completed with the props, information about temporal order information is not apparent in the linguistic prompt. As such, problems with receptive language would be associated with reduced memory for target actions, not temporal order information.

A more probable explanation for reduced memory for temporal order information by children with DS relative to those who are TD may result from alterations in critical hippocampal and prefrontal morphology. In TD children, developments in the reliability and robustness of recall are critically associated with the maturation of the temporal-cortical network that supports encoding, consolidation/storage and retrieval processes (Markowitsch 2000; Zola & Squire 2000; Eichenbaum & Cohen 2001). Bauer (2002, 2004, 2006, 2008) has previously reviewed the development of this circuitry and its implications for advances in recall memory. Although an extensive discussion of the neural circuitry and its development is beyond the focus of this paper, Bauer indicates that one notable period of vulnerability in the formation and maintenance of new memories by TD children occurs during the extended process of consolidation/storage. This vulnerability may result from the protracted development of hippocampal regions (such as the dentate gyrus) and prefrontal areas associated with consolidation/storage. Bauer (2004) suggested that new synapses form (synaptogenesis) in the dentate gyrus and the prefrontal cortex; TD children show increasing proficiency in the recall of temporal order information (Bauer *et al.* 2006). Because children with DS experience decreased brain volume in these areas that are critical for memory consolidation/storage (Jernigan *et al.* 1993; Pinter

et al. 2001), they may experience more difficulty remembering challenging temporal order information relative to TD children while experiencing relatively intact memory for individual target actions. Structural imaging work is needed, however, to correlate aspects of temporal and prefrontal volumes to mnemonic performance at encoding and over the long term.

Additional experimental work should also be conducted using techniques that allow for the identification of whether variability in consolidation and storage and/or retrieval processes is responsible for the effects observed herein (Lukowski & Bauer 2014). For example, electrophysiological techniques such as event-related potentials have been used to examine whether variability in encoding and/or consolidation and storage was associated with measures of long-term behavioural recall in infants (Carver *et al.* 2000; Bauer *et al.* 2003), whereas behavioural manipulations have been used to determine whether children adequately store and/or retrieve information (Bauer 2005). Such experimental techniques could be easily employed with children with DS.

Future work should also be conducted to examine the parameters that best support long-term recall memory and related abilities in children with DS. In the present research, children were allowed the opportunity to imitate the event sequences immediately after their presentation, an encoding manipulation that has been shown to facilitate long-term recall memory in some TD samples (Bauer *et al.* 1995; Lukowski *et al.* 2005). Allowing TD infants' repeated exposures to to-be-remembered information also enhances recall in comparison with situations in which infants are allowed fewer exposures (Bauer *et al.* 2001). Future research should examine whether these and other encoding manipulations that effectively facilitate recall in TD samples also serve to benefit children with DS. If research reveals that these manipulations are effective at promoting encoding and recall in children with DS, they should be incorporated into education and intervention programmes for children with DS so as to maximise the learning and retention of presented information.

Although future work is necessary, the present research contributes significantly to our understanding of cognitive functioning in children with DS. The primary limitation of this study was our inclusion of a rather small sample of children in comparison with

³ Future research should include more stringent procedures for matching children on developmental age, as the emerging convention is to report group differences in developmental age that meet or exceed $p = 0.50$ (we thank an anonymous reviewer for providing this information).

• Recall memory and Down syndrome

developmental research conducted with TD children (the sample of children with DS was comparable with or larger than that of many previous studies of children with DS – Lemons & Fuchs 2010; Schoenbrodt *et al.* 2014; van Bysterveldt *et al.* 2010; Wright *et al.* 2013). Nevertheless, this research indicated that children with DS demonstrated levels of encoding and forgetting that were comparable with those of TD children matched on DA. After the 1-month delay, children with DS demonstrated recall of individual target actions but not order information, whereas TD children demonstrated recall of both dependent measures. These findings suggest that children with DS may experience difficulty with mnemonic processes associated with consolidation and storage and/or retrieval and have important implications for intervention efforts and future research.

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References

- Abbeduto L., Pavetto M., Kesin E., Weissmen M. D., Karadottir S., O'Brien A. *et al.* (2001) The linguistic and cognitive profile of Down syndrome: evidence from a comparison with Fragile X syndrome. *Down Syndrome: Research and Practice* 7, 9–15.
- Adlam A.-L. R., Vargha-Khadem F., Mishkin M. & de Haan M. (2005) Deferred imitation of action sequences in developmental amnesia. *Journal of Cognitive Neuroscience* 17, 240–8.
- Barr R., Dowden A. & Hayne H. (1996) Developmental changes in deferred imitation by 6- to 24-month-old infants. *Infant Behavior and Development* 19, 159–70.
- Bauer P. J. (2006) Constructing a past in infancy: a neuro-developmental account. *Trends in Cognitive Science* 10, 175–81.
- Bauer P. J. (2005) Developments in declarative memory. *Psychological Science* 16, 41–47.
- Bauer P. J., Wiebe S. A., Carver L. J., Waters J. M. & Nelson C. A. (2003) Developments in long-term explicit memory late in the first year of life: behavioral and electrophysiological indices. *Psychological Science* 14, 629–35.
- Bauer P. J., Wiebe S. A., Carver L. J., Lukowski A. F., Haight J. C., Waters J. M. *et al.* (2006) Electrophysiological indexes of encoding and behavioral indexes of recall: examining relations and developmental change late in the first year of life. *Developmental Neuropsychology* 29, 293–320.
- Bauer P. J., Güler O. E., Starr R. M. & Pathman T. (2011) Equal learning does not result in equal remembering: the importance of post-encoding processes. *Infancy* 16, 557–86.
- Bauer P. J. (2004) Getting explicit memory off the ground: steps toward construction of a neuro-developmental account of changes in the first two years of life. *Developmental Review* 24, 347–73.
- Bauer P. J. (2002) Long-term recall memory: behavioral and neuro-developmental changes in the first 2 years of life. *Current Directions in Psychological Science* 11, 137–41.
- Bauer P. J., Wenner J. A., Dropik P. L., Wewerka S. S. & Howe M. L. (2000) Parameters of remembering and forgetting in the transition from infancy to early childhood. *Monographs of the Society for Research in Child Development* 65, 1–204.
- Bauer P. J., Wiebe S. A., Waters J. M. & Bangston S. K. (2001) Reexposure breeds recall: effects of experience on 9-month-olds' ordered recall. *Journal of Experimental Child Psychology* 80, 174–200.
- Bauer P. J. (2007) *Remembering the times of our lives: memory in infancy and beyond*. Erlbaum, Mahwah, NJ.
- Bauer P. J. (2008) Toward a neuro-developmental account of the development of declarative memory. *Developmental Psychobiology* 50, 19–31.
- Bauer P. J. (1996) What do infants recall of their lives? Memory for specific events by one- to two-year-olds. *The American Psychologist* 51, 29–41.
- Bauer P. J., DeBoer T. & Lukowski A. F. (2007) In the language of multiple memory systems: defining and describing developments in long-term declarative memory. In: *Short- and Long-Term Memory in Infancy and Early Childhood: Taking the First Steps towards Remembering* (eds P. J. Bauer & L. M. Oakes), pp. 240–70. Oxford University Press, New York.
- Bauer P. J. & Dow G. A. (1994) Episodic memory in 16- and 20-month-old children: specifics are generalized but not forgotten. *Developmental Psychology* 30, 403–17.
- Bauer P. J. & Hertsgaard L. A. (1993) Increasing steps in recall of events: factors facilitating immediate and long-term memory in 13.5- and 16.5-month-old children. *Child Development* 64, 1204–23.

• Recall memory and Down syndrome

- Bauer P. J., Hertsgaard L. A. & Wewerka S. S. (1995) Effects of experience and reminding on long-term recall in infancy: remembering not to forget. *Journal of Experimental Child Psychology* **59**, 260–98.
- Bauer P. J. & Leventon J. S. (2013) Memory for one-time experiences the second year of life: implications for the status of episodic memory. *Infancy* **18**, 755–81.
- Bauer P. J. & Lukowski A. F. (2010) The memory is in the details: relations between memory for the specific features of events and long-term recall during infancy. *Journal of Experimental Child Psychology* **107**, 1–14.
- Bauer P. J., Wenner J. A. & Kroupina M. G. (2002) Making the past present: later verbal accessibility of early memories. *Journal of Cognition and Development* **3**, 37–41.
- Bauer P. J. & Wewerka S. S. (1995) One- to two-year-olds' recall of events: the more expressed, the more impressed. *Journal of Experimental Child Psychology* **59**, 475–96.
- Bayley N. (2006) *Bayley Scales of Infant and Toddler Development-III*. Harcourt Assessment, San Antonio, TX.
- Carver L. J. & Bauer P. J. (2001) The dawning of a past: the emergence of long-term explicit memory in infancy. *Journal of Experimental Psychology: General* **130**, 726–45.
- Carver L. J. & Bauer P. J. (1999) When the event is more than the sum of its parts: 9-month-olds' long-term ordered recall. *Memory* **7**, 147–74.
- Carver L. J., Bauer P. J. & Nelson C. A. (2000) Associations between infant brain activity and recall memory. *Developmental Science* **3**, 234–46.
- Collie R. & Hayne H. (1999) Deferred imitation by 6- and 9-month-old infants: more evidence for declarative memory. *Developmental Psychobiology* **35**, 83–90.
- Cupples L. & Iacono T. (2002) The efficacy of 'whole word' versus 'analytic' reading instruction for children with Down syndrome. *Reading and Writing* **15**, 549–74.
- Dykens E. M. & Hodapp R. M. (2001) Research in mental retardation: toward an etiologic approach. *Journal of Child Psychology and Psychiatry* **42**, 49–71.
- Eichenbaum H. & Cohen N. J. (2001) *From Conditioning to Conscious Recollection: Memory Systems of the Brain*. Oxford University Press, New York.
- Feeley K. M., Jones E. A., Blackburn C. & Bauer S. (2011) Advancing imitation and requesting skills in toddlers with Down syndrome. *Research in Developmental Disabilities* **32**, 2415–30.
- Gilmore L., Cuskelly M., Jobling A. & Hayes A. (2009) Maternal support for autonomy: relationships with persistence for children with Down syndrome and typically developing children. *Research in Developmental Disabilities* **30**, 1023–33.
- Guidi S., Bonasoni P., Ceccarelli C., Santini D., Gualtieri F., Ciani E. *et al.* (2008) Neurogenesis impairment and increased cell death reduce total neuron number in the hippocampal region of fetuses with Down syndrome. *Brain Pathology* **18**, 180–97.
- Hayne H. & Herbert J. (2004) Verbal cues facilitate memory retrieval during infancy. *Journal of Experimental Child Psychology* **89**, 127–39.
- Herbert J. & Hayne H. (2000) Memory retrieval by 18–30-month-olds: age-related changes in representational flexibility. *Developmental Psychology* **36**, 473–84.
- Jernigan T. L., Bellugi U., Sowell E., Doherty S. & Hesselink J. R. (1993) Cerebral morphologic distinctions between Williams and Down syndromes. *Archives of Neurology* **50**, 186–91.
- Kennedy E. J. & Flynn M. C. (2003) Training phonological awareness skills in children with Down syndrome. *Research in Developmental Disabilities* **24**, 44–57.
- Klein P. J. & Meltzoff A. N. (2009) Long-term memory, forgetting, and deferred imitation in 12-month-old infants. *Developmental Science* **2**, 102–13.
- Lanfranchi S., Jerman O., Dal Pont E., Alberti A. & Vianello R. (2010) Executive function in adolescents with Down syndrome. *Journal of Intellectual Disability Research* **54**, 308–19.
- Laws G. & Bishop D. V. M. (2003) The comparison of language abilities in adolescents with Down syndrome and children with specific language impairment. *Journal of Speech, Language, and Hearing Research* **46**, 1324–39.
- Lemons C. J. & Fuchs D. (2010) Modeling response to reading intervention in children with Down syndrome: an examination of predictors of differential growth. *Reading Research Quarterly* **45**, 134–68.
- Libby S., Powell S., Messer D. & Jordan R. (1997) Imitation of pretend play acts by children with autism and Down syndrome. *Journal of Autism and Developmental Disorders* **27**, 365–83.
- Lukowski A. F., Wiebe S. A., Haight J. C., DeBoer T., Nelson C. A. & Bauer P. J. (2005) Forming a stable memory representation in the first year of life: why imitation is more than child's play. *Developmental Science* **8**, 279–98.
- Lukowski A. F. & Bauer P. J. (2014) Long-term memory in infancy and early childhood. In: *The Wiley Handbook on the Development of Children's Memory* (eds P. J. Bauer & R. Fivush), pp. 230–54. West Sussex, UK, Wiley-Blackwell.
- Lukowski A. F. & Milojevich H. M. (2013) Sleeping like a baby: examining relations between habitual infant sleep, recall memory, and generalization across cues at 10 months. *Infant Behavior and Development* **36**, 369–76.
- Lukowski A. F., Phung J. N. & Milojevich H. M. (2015) Language facilitates event memory in early childhood: child comprehension, adult-provided linguistic support and delayed recall at 16 months. *Memory* **5–6**, 848–63.
- MacTurk R. H., Hunter F. T., McCarthy M. E., Vietze P. M. & McQuiston S. (1985) Social mastery motivation in Down syndrome and nondelayed infants. *Topics in Early Childhood Special Education* **4**, 93–109.
- Mandler J. M. (1990) Recall of events by preverbal children. In: *The Development and Neural Bases of Higher Cognitive*

• **Recall memory and Down syndrome**

- Functions* (ed. A. Diamond), pp. 485–516. New York Academy of Science, New York.
- Markowitsch H. J. (2000) Neuroanatomy of memory. In: *The Oxford Handbook of Memory* (eds E. Tulving & F. I. M. Craik), pp. 465–84. Oxford University Press, New York.
- Masson M. E. J. (2011) A tutorial on a practical Bayesian alternative to null-hypothesis significance testing. *Behavior Research Methods* **43**, 679–90.
- McDonough L., Mandler J. M., McKee R. D. & Squire L. R. (1995) The deferred imitation task as a nonverbal measure of declarative memory. *Proceedings of the National Academy of Sciences* **92**, 7580–84.
- Meltzoff A. N. (1990) The implications of cross-modal matching and imitation for the development of representation and memory in infancy. In: *The Development and Neural Bases of Higher Cognitive Functions* (ed. A. Diamond), pp. 1–31. New York Academy of Science, New York.
- Meltzoff A. N. (1995) What infant memory tells us about infantile amnesia: long-term recall and deferred imitation. *Journal of Experimental Child Psychology* **59**, 497–515.
- Meng X.-L., Rosenthal R. & Rubin D. B. (1992) Comparing correlated correlation coefficients. *Psychological Bulletin* **111**, 172–5.
- Parker S. E., Mai C. T., Canfield M. A., Rickard R., Wang Y., Meyer R. E. *et al.* (2010) Updated national birth prevalence estimates for selected birth defects in the United States, 2004–2006. *Birth Defects Research Part A* **88**, 1008–16.
- Phung J. N., Milojevich H. M. & Lukowski A. F. (2014) Adult language use and infant comprehension of English: associations with encoding and generalization across cues at 20 months. *Infant Behavior and Development* **37**, 465–79.
- Pinter J. D., Brown W. E., Eliez S., Schmitt J. E., Capone G. T. & Reiss A. L. (2001) Amygdala and hippocampal volumes in children with Down syndrome: a high-resolution MRI study. *Neurology* **56**, 972–4.
- Raftery A. E. (1995) Bayesian model selection in social research. *Sociological Methodology* **25**, 111–63.
- Rast M. & Meltzoff A. N. (1995) Memory and representation in young children with Down syndrome: exploring deferred imitation and object permanence. *Development and Psychopathology* **7**, 393–407.
- Reddy V., Williams E., Costantini C. & Lan B. (2010) Engaging with the self: mirror behaviour in autism, Down syndrome and typical development. *Autism* **14**, 531–46.
- Roberts L. V. & Richmond J. L. (2015) Preschoolers with Down syndrome do not yet show the learning and memory impairments seen in adults with Down syndrome. *Developmental Science* **18**, 404–19.
- Rowe J., Lavender A. & Turk V. (2006) Cognitive executive function in Down's syndrome. *The British Journal of Clinical Psychology* **45**, 5–17.
- Schoenbrodt L., Eliopoulos L. & Popomaronis E. (2014) Parent-training in narrative language intervention with children with Down syndrome. *Down Syndrome: Research and Practice* **12**, 241–7.
- Selikowitz M. (1997) *Down Syndrome: The Facts*, 2nd edn. Oxford University Press, New York.
- Squire L. R. & Zola-Morgan S. (1991) The medial temporal lobe memory system. *Science* **253**, 1380–6.
- Van Bysterveldt A. K., Gillon G. & Foster-Cohen S. (2010) Integrated speech and phonological awareness intervention for pre-school children with Down syndrome. *International Journal of Language and Communication Disorders* **45**, 320–35.
- Vanvuchelen M., Feys H. & De Weerd W. (2011) Is the good-imitator-poor-talker profile syndrome-specific in Down syndrome?: evidence from standardised imitation and language measures. *Research in Developmental Disabilities* **32**, 148–57.
- Venuti P., de Falco S., Esposito G. & Bornstein M. H. (2009) Mother-child play: children with Down syndrome and typical development. *American Journal on Intellectual Developmental Disabilities* **114**, 274–88.
- Wenner J. A. & Bauer P. J. (1999) Bringing order to the arbitrary: one- to two-year-olds' recall of event sequences. *Infant Behavior and Development* **22**, 585–90.
- Wiebe S. A., Lukowski A. F. & Bauer P. J. (2010) Sequence imitation and reaching measures of executive control: a longitudinal examination in the second year of life. *Developmental Neuropsychology* **35**, 522–38.
- Wright C. A., Kaiser A. P., Reikowsky D. I. & Roberts M. Y. (2013) Effects of a naturalistic sign intervention on expressive language of toddlers with Down syndrome. *Journal of Speech, Language, and Hearing Research* **56**, 994–1008.
- Wright I., Lewis V. & Collis G. M. (2006) Imitation and representational development in young children with Down syndrome. *British Journal of Developmental Psychology* **24**, 429–50.
- Zola S. M. & Squire L. R. (2000) The medial temporal lobe and the hippocampus. In: *The Oxford Handbook of Memory* (eds E. Tulving & F. I. M. Craik), pp. 485–500. Oxford University Press, New York.

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