Brief Report: Immediate Memory for Movement Sequences in Children with and without Language Impairment

Rapport sommaire : mémoire immédiate des séquences de mouvement chez les enfants ayant ou non un trouble du langage

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Abstract

This study investigated the immediate recall and reproduction of visually presented movements by children with and without language impairments (LI). Ten children with LI ranging in age from 6:0 to 8:9 (years:months) and 10 age-matched peers with typically-developing language completed tasks requiring them to reproduce sequences of nonsymbolic arm movements that were presented at eight different rates of speed ranging from .5 s per movement to 4 s per movement. The children with LI performed significantly poorer than the control group in recalling arm movements across the presentation rates. Both groups of children tended to recall and reproduce arm movements presented at very slow intervals (4 s per movement) better than they recalled and reproduced arm movements presented at very fast intervals (.5 s per movement). These results suggest that children with LI have immediate visuospatial memory deficits for serial position and that children both with and without LI benefit from having visual information presented at a slow rate.

Abrégé

La présente étude porte sur la mémorisation et la reproduction de mouvements présentés visuellement à des enfants ayant ou non un trouble du langage. Dix enfants atteints d'un trouble du langage âgés de 6,0 à 8,9 ans (ans,mois) et dix enfants du même âge ayant un langage au développement caractéristique ont accompli une tâche leur demandant de reproduire des séquences de mouvements non symboliques des bras présentées à huit rythmes différents, allant de 0,5 s par mouvement à 4 s par mouvement. Les enfants ayant un trouble du langage ont nettement moins bien réussi que ceux du groupe contrôle, peu importe le rythme de présentation. Les deux groupes d'enfants se rappelaient généralement mieux des mouvements de bras et les reproduisaient mieux quand ils étaient présentés à un rythme très lent (4 s par mouvement) que quand ils étaient présentés à un rythme très rapide (0,5 s par mouvement). Ces résultats suggèrent que les enfants ayant un trouble du langage ont une déficience de la mémoire immédiate visuo-spatiale pour la position sérielle et que les enfants des deux groupes bénéficient que l'information visuelle soit présentée à un rythme lent.

Key words: immediate memory, language impairments, arm movements, rate of processing

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Children with language impairments (LI) exhibit difficulties with expressive and/or receptive language that impede their ability to communicate with those around them. Many of these children do not present with an organic etiology for their language impairments or exhibit significant deficits in other developmental areas (Leonard, 1998). Despite this general level of specificity, research has revealed that these children tend to demonstrate difficulties on a variety of nonverbal tasks (Bishop, 1992; Johnston, 1999). Based on these findings, it has been proposed that a general underlying psychological mechanism or a variety of psychological mechanisms may give rise to these children's difficulties with language development (Gillam, Cowan, & Marler, 1998; Miller, Kail, Leonard, & Tomblin, 2001; Tallal, Stark, Kallman, & Mellits, 1981). This study focused on memory as a psychological mechanism that may affect language development.

A leading theoretical explanation of language impairment suggests that difficulties with the cognitive abilities related to working memory processes have a negative impact on language development (Ellis Weismer & Hesketh, 1996; Gathercole & Baddeley, 1990; Montgomery, 1993). Much of the current research on memory is based upon the Baddeley and Hitch (1974) model of working memory, hereafter referred to as the Baddeley WM model. According to the Baddeley WM model, working memory consists of four components: a phonological loop, a visuospatial sketchpad, a central executive, and an episodic buffer (Baddeley, 2003). Verbal information is processed by the phonological loop, while visual and spatial information is processed by the visuospatial sketchpad. A central executive monitors the flow of information through the phonological loop and the visuospatial sketchpad. An episodic buffer provides additional storage for information from all sensory modalities and creates a unified code using this information.

This study concerns memory for visually-presented serial information. Serial memory plays an integral role in language processing by maintaining linguistic and phonological information in order while individuals process the meanings of words. According to the Baddeley WM model, phonological and visual information must be rehearsed or it will decay. Phonological information is maintained in the phonological store and rehearsed through the articulatory loop (Baddeley, 2003). Visuospatial information is similarly maintained through the visual cache and rehearsed through the inner scribe of this model (Logie, 1995). The central executive of the Baddeley WM model is significantly involved in the recall of visually presented information as well by allocating mental resources to simultaneous attention, coding, rehearsal, and recall processes (Romine & Reynolds, 2004; Rudkin, Pearson, & Logie, 2007).

A number of researchers have hypothesized that children with LI have deficits in encoding and recalling serial position of phonological stimuli (Fazio, 1998; Gillam, Cowan, & Day, 1995; Gillam et al., 1998). Less research has examined the recall of visually-presented serial information in children with LI. Research in this area has so far provided equivocal results. Bavin, Wilson, Maruff, and Sleeman (2005) found that children with LI performed significantly poorer than their age-matched peers with typically developing language on a serial memory task that required them to recall on a computer sequences of boxes that changed color. However, Archibald and Gathercole (2006) found that children with LI performed similarly to age-matched children with typically developing language on a serial memory task that required them to recall sequences of dots presented on a computer grid.

If children with LI do have problems with recalling some visually-presented serial information, it is not clear whether their difficulties are due to visuospatial or phonological memory difficulties alone or in combination with executive processing limitations. Executive processing has been defined as the ability to plan actions, maintain these plans in working memory prior to execution, and hinder irrelevant information and actions from occurring (Pennington & Ozonoff, 1996). Executive processing functions correspond closely with the actions of the central executive of the Baddeley WM model (Baddeley, 2003).

Hoffman and Gillam (2004) investigated the role of the central executive in children with LI while examining their recall of serial visuospatial stimuli and visually and auditorily presented serial phonological stimuli within a dual-processing experiment. They found that children with LI recalled both serial visuospatial and phonological stimuli with significantly less accuracy than their peers and that a large group difference occurred when children were required to disperse information processing demands across both phonological and visuospatial domains. These results were interpreted as indicating that children with LI may have smaller storage capacities in both phonological and visuospatial domains and executive functioning difficulties related to coordinating multiple processing resources effectively.

The current study further addressed whether children with LI do or do not have memory deficits for visually-presented serial information. We studied memory for nonsymbolic arm movements because these movements were less likely to lend themselves as directly to phonological encoding than other types of visually-presented stimuli such as common objects and numbers. It was thought that use of nonsymbolic movements may lead the children to exert extra mental coordinating effort to process multiple mental steps and to rely more heavily on visual encoding than on phonological encoding as a memory strategy. The present study does not allow us to be certain to what extent the phonological loop or the visuospatial sketchpad were used to encode the nonsymbolic movements. Previous research on typically-developing children, however, has shown us that children in the primary grades do not rely primarily on verbally-based strategies to encode and recall movement sequences, although they have exhibited emerging use of these strategies (Bouffard & Dunn, 1993; Ille & Cadopi, 1999; David, 1985).

Rate of information processing is another potential variable that may influence serial memory in children with LI. Children with LI may be sensitive to the rate at which information is presented due to inefficient use of executive coordinating functions (Hoffman & Gillam, 2004). It is also possible that children with LI may be slower to encode information into working memory and/or have faster memory decay due to deficits in encoding, storage, and rehearsal components of the phonological loop and/or visuospatial sketchpad (Fazio, 1998). The literature in this area has also proved to be inconclusive. For example, Fazio (1998) found that children with LI performed poorer than their peers with typically-developing language at recalling sequences of common objects, scribble drawings, and unfamiliar faces presented at a fast rate of 1.5 s per item with a 400 ms interstimulus interval (ISI). However, the two groups performed similarly when recalling sequences presented at a slow rate of 3.5 s per item with a 400 ms ISI. The present study further examines rate of information presentation as a variable in the serial memory of children with LI and attempts to assist in defining the critical window for processing speed by testing children with and without LI across a continuum of presentation rates.

Clinically, the results of this study may have implications for how speech-language pathologists plan assessment and intervention for children with LI. If the children with LI do demonstrate difficulties with the study's serial memory task, it may lead us to believe that some children with LI may benefit from having intervention assisting with executive functioning embedded into language therapy activities. Further, poor performance on a task that may require children to integrate visual and phonological information may lead us to take caution in teaching children with LI to primarily use visual self-cueing strategies to recall linguistic information. It may be more beneficial to use dynamic assessment to reveal what the most effective cueing strategies are for a child when recalling linguistic information. The results for the effect of rate on the children's recall and reproduction of the movements will give us insight into whether children with LI will remember visually-presented information best in language therapy and in the classroom if it is presented at a slow rate, a medium rate, or a fast rate.

The overall purpose of this study was to determine whether children with LI recall and reproduce sequences of nonsymbolic arm movements as accurately as their age-matched peers with typically-developing language and whether the rate of presentation influences performance in either group. The specific research questions were 1) Do children with LI recall and reproduce sequences of nonsymbolic arm movements as well as their age-matched peers with typically-developing language and 2) What is the effect of presentation rate on children with LI's recall and reproduction of sequences of nonsymbolic arm movements in comparison to their age-matched peers with typically-developing language?

Methods

Participants

Twenty children participated in two groups in this study. The group of children with LI consisted of 10 children, and the control group (CON) consisted of 10 chronologically age-matched peers with typically-developing language. Each group comprised 8 males and 2 females. The mean ages for the groups were: LI, 7 years, 5 months (*SD* = .75, range = 6:0-8:8), CON, 7 years, 4 months (*SD* = .87, range = 6:0-8:9). All of the children were monolingual English speakers. Both groups had none of the following as indicated by a checklist completed by their parent(s)/guardian(s): mental retardation, severe emotional disturbances, visual deficits other than corrected to normal, Autism Spectrum Disorders, hearing loss, and/or motor disorders (medically-diagnosed or neurogenically-based). The mean scaled score for the groups on the Grammatical Completion and Sentence Imitation Subtests of the Test of Language Development: Primary – 3rd Edition (TOLD: P3) [norming *M*=10, *SD*=3] were: LI, 5.1 (*SD* = 2.73) and CON, 11.2 (*SD* = 1.94). The children in the LI group all had diagnoses of language impairment from speech-language pathologists and were receiving language intervention services in school and/or private clinic settings.

Stimuli

The stimuli for the experimental task consisted of 16 sequences of nonsymbolic arm movements presented at rates ranging from .5 s per movement to 4 s per movement. There were five movements in each sequence, and two sequences were created at each of the following presentation rates: .5 s per movement, 1 s per movement, 1.5 s per movement, 2 s per movement, 2.5 s per movement, 3 s per movement, 3.5 s per movement, and 4 s per movement (i.e., 2 sequences x 8 presentation rates = 16 sequences). Each movement was included in each sequence. The movements included in the sequences were (1) both arms extended horizontally from the body, (2) both arms extended in front of the body with palms facing out, (3) both arms bent towards the face with index fingers pointing at the face, (4) one hand placed on top of the head with the palm facing down and the other arm extended horizontally, and (5) both arms extended in a 45-degree angle opposing one another as to create a diagonal line.

The sequences of movements were videotaped as they were performed by an adult. The rate calculations were averages based on the total time it took the individual to make all five movements in a sequence. These total times were within +/-.3 s of the exact times that would have been created by performing the movements at the exact rates. The rate calculations were made using the iMovie film-editing program.

Two videotapes were created to counterbalance the order in which the presentation rates of the sixteen movement sequences occurred. The sequences were placed in order from most rapid to least rapid in rate on the first videotape and were placed in the opposite order, from least rapid to most rapid in rate, on the second videotape. The order in which these sequences were presented was edited using the iMovie film-editing program. Possible order effects were analyzed by comparing the mean number correct at each rate for the children within each group who received the first videotape to those that received the second videotape. Order effects revealed were none to minimal as indicated by nonsignificant interactions at all presentation rates (Table 1 and 2).

Table 1
Order effects for LI group

Rate of presentation	Video 1 Mean	Video 1 SD	Video 2 Mean	Video 2 SD	*t*	*p*
4.0/s	2.50	3.00	1.60	1.14	0.57	.601
3.5/s	1.25	1.25	1.40	2.19	-0.13	.901
3.0/s	2.25	0.96	1.20	1.30	1.39	.207
2.5/s	1.75	2.22	1.60	0.89	0.13	.261
2.0/s	0.75	0.50	1.20	1.30	-0.71	.508
1.5/s	1.50	1.29	1.40	0.55	0.15	.892
1.0/s	1.75	1.50	1.60	1.52	0.15	.887
.5/s	1.0	1.0	0.82	0.70	0.00	1.000

Table 2
Order effects for CON group

Rate of presentation	Video 1 Mean	Video 1 SD	Video 2 Mean	Video 2 SD	*t*	*p*
4.0/s	3.00	2.00	5.20	2.68	-1.47	.183
3.5/s	2.00	1.58	3.20	1.30	-1.31	.228
3.0/s	3.20	1.30	1.40	1.14	2.32	.049
2.5/s	3.80	1.79	2.20	1.92	1.36	.210
2.0/s	3.60	2.88	2.40	1.14	0.87	.424
1.5/s	3.20	1.48	2.20	2.17	0.85	.423
1.0/s	3.60	1.82	3.80	0.45	-0.24	.822
.5/s	2.20	0.84	1.60	1.82	0.67	.529

Children also completed the Sentence Imitation and the Grammatic Completion Subtests of the TOLD:P3 (Newcomer & Hammill, 1997). The Sentence Imitation Subtest required a child to recall sentences immediately after the examiner produced them. The Grammatic Completion Subtest required a child to orally complete sentences produced by the examiner. The Nonword Repetition Subtest of the Comprehensive Test of Phonological Processing (CTOPP) (Wagner, Torgeson, & Rashotte, 1999) was administered to assess phonological working memory. The Nonword Repetition Subtest required a child to repeat phonetic sequences that were not words immediately after they were presented through an audiocassette player.

Procedures

The examiner initially requested that each child directly imitate each of the five movements individually in order to train the movements of the experimental task. After all five movements were imitated individually, each child was asked to recall and demonstrate all five movements together in any order before any data were collected. The examiner continued to train the movements until each child had accurately reproduced all five movements together or had participated in six training trials. The purpose of these training trials was to minimize learning (i.e., learning the movements) as a potential variable. All children participating in the study successfully imitated all five movements. Eight of the ten children in the LI group and all children in the control group recalled the five movements in any order during the training trials.

After participating in the training trials, each child participated in two practice trials in which sequences of two of the five movements were presented on a television monitor and data were not collected. One of the practice trials was presented at a 1 s per movement rate, and the other practice trial was presented at a 4 s per movement rate. Each practice trial was repeated until the child being tested accurately responded or had viewed the practice trial stimuli three times. Each child was expected to immediately recall and reproduce each sequence. As in training the movements, the purpose of the practice trials was to minimize learning (i.e., learning the task) as a potential variable. All children accurately responded to the practice trial stimuli before moving on to the trials from which data were collected.

The 16 trials of sequences of the five movements were presented on a television monitor. Children were required to recall and reproduce each sequence immediately after it was presented. Data were collected on the children's ability to recall and reproduce these sequences. All of the children produced a response for each sequence by producing movements immediately after each sequence and completed the task. In total, the children viewed and attempted to recall and reproduce 80 movements. The two orders of movements were counterbalanced across the two groups.

All the participants were videotaped while they performed the experimental task. Responses were also recorded and scored online by the examiner. These responses were later rescored by the examiner using the videotaped recordings of the participants.

The scoring system rewarded a point for each movement recalled in exact serial position of a sequence. This scoring system was used because previous serial memory research demonstrated that children with LI were poorer at recalling exact serial positions than recalling correct order without exact serial positions (Gillam et al., 1995). The quality of the production of the movements was not a criterion for correct production. There were 80 possible correct points for each administration of the 16 sequences.

Reliability

Interater reliability was assessed by having an independent rater examine and rescore the videotapes for a randomly selected sample of 20% of the participant pool. The resulting scored responses from the examiner and the independent rater were compared to determine point-by-point reliability. There was 98% agreement between the examiner's scoring and that of the independent rater.

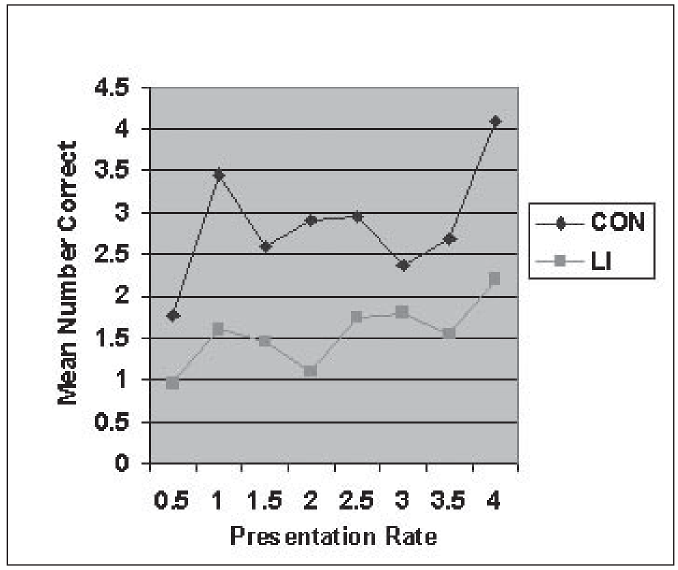

Figure 1. Mean number of items recalled in accurate serial position per sequence by the children with language impairment (LI) and the control group (CON) for each presentation rate.

Results

Data were analyzed using Poisson regression supported by the SAS statistical package. Poisson regression is a generalized linear statistical model that is most appropriate for analyzing results that include count variables and a Poisson distribution, which is typically skewed to the right. The data for both groups were slightly skewed to the right but were within +/- 2 SD of error. Reported probability levels of the Poisson regression analyses reflected generalized estimating equation adjustments for potential clustering effects within each child due to repeated measurements.

The main effects model included the group (LI versus CON) and the rate effect (rates .5, 1, 1.5, 2, 2.5, 3, 3.5 compared to rate 4). The generalized estimating equation of the Poisson regression analyses revealed that across the task presentation rates, the children in the LI group recalled significantly fewer movement items than the children in the CON group [LI $M = 11.67$, $SD = 3.77$; CON M = 23.2, $SD = 6.66$] [$Z = -5.62$, $p < .0001$] [Figure 1]. There was also a main effect for presentation rate. Across groups, children tended to recall arm movements presented at 4 s intervals better than they recalled arm movements presented at .5 s intervals ($p < .007$, adjusted p level due to multiple tests for p) (Table 3). Performance across groups at the 1.5 s, 3.0 s, and 3.5 s rate also approached significance. The interaction for group x rate was non-significant (2 = 3.95, $p = .79$), demonstrating that the overall rate effect did not differ across groups (Table 4).

Table 3
Mean, SD, difference, Z, and p values for each presentation rate

Rate of presentation	Mean	SD	Difference	Z	*P*
4.0/s	3.05	2.42	0.00	-	-
3.5/s	1.98	1.71	-.44	-1.87	.062
3.0/s	2.00	1.34	-.41	-1.94	.053
2.5/s	2.26	1.81	-.27	-1.12	.261
2.0/s	2.00	1.87	-.39	-1.57	.117
1.5/s	2.07	1.49	-.34	-1.97	.048
1.0/s	2.52	1.72	-.13	-.58	.563
.5/s	1.40	1.14	-.71	-2.98	.003

Table 4
Difference, Z, and p values for the interaction effect between group and rate

Rate of presentation	Difference	Z	*P*
4.0/s	0.00	n/a	-
3.5/s	0.05	.08	.940
3.0/s	.46	1.07	.284
2.5/s	.13	.23	.819
2.0/s	-.28	-.59	.553
1.5/s	.24	.66	.510
1.0/s	-.08	-.15	.885
.5/s	.18	.35	.728

Further data analyses revealed that when the phonological STM task (NWR Subtest) was factored in as a covariate, the main effect for the experimental task was no longer significant ($Z = -1.19$, $p = .23$), and the phonological memory task was significant as a covariate ($Z = 2.79$, $p < .01$) (Table 5). The children's performance on the Grammatic Completion Subtest language measure also reduced the effect of the group difference on the experimental task when added as a covariate. The main effect for group on the experimental task stayed marginally significant ($Z = -1.93$, $p = .053$) when the Grammatic Completion Subtest results were added, and this measure did not have a significant value as a covariate using this model ($Z = 1.37$, $p = .17$). Performance on the Sentence Imitation Subtest had less of an effect as a covariate of the experimental task than performance on the phonological STM task or the Grammatic Completion Subtest. The main effect for group on the experimental task maintained significance ($Z = -2.57$, $p = .01$) when performance on the Sentence Imitation Subtest was added, and performance on the Sentence Imitation Subtest did not approach significance as a covariate using this model ($Z = 1.24$, $p = .22$).

Table 5
Difference, Z, and p values for main effect model with nonword repetition added as a covariant

Parameter	Difference	Z	P
Experimental Task - LI	-.25	-1.19	.234
Experimental Task - CON	0.00	n/a	n/a
.5/s Rate	-.71	-2.98	.003
1.0/s Rate	-.13	-.58	.562
1.5/s Rate	-.34	-1.97	.048
2.0/s Rate	-.39	-1.57	.117
2.5/s Rate	-.27	-1.12	.261
3.0/s Rate	-.41	-1.94	.053
3.5/s Rate	-.44	-1.87	.062
4.0/s Rate	0.00	n/a	n/a
Nonword Repetition Task	.08	2.79	.005

Discussion

This study was designed to investigate memory for serial position in children with and without LI on a task involving the recall and reproduction of sequences of visually-presented nonsymbolic arm movements that were presented at a variety of rates. The first research question concerned whether children with LI recalled and reproduced sequences of visually presented nonsymbolic arm movements as well as their peers with typically developing language. The children with LI recalled and reproduced significantly fewer movements in correct serial position than their age-matched peers with typically developing language. The results of this study support the findings by Fazio (1998), Gillam and colleagues (Gillam et al., 1995; Gillam et al., 1998), Bavin et al. (2005), and Hoffman and Gillam (2004) showing that children with LI have difficulties recalling sequences of visually-presented information. The findings in this study are inconsistent with the results from a study by Archibald and Gathercole (2006) showing that children with LI do not perform more poorly than their age-matched peers when demonstrating their memory span for sequences of visually presented dot matrixes.

A possible reason for the difference in findings between this study and the study by Archibald and Gathercole (2006) may be that the ages of the participants differed. The age range of the participants in this study was 6;0 to 8;9 years, whereas the children in the Archibald and Gathercole (2006) study were generally older (7;0 to 12;5 years). Prior research on children with typical development has demonstrated that children use more effective memory strategies and integrate use of more memory strategies to recall information as they become older (Bouffard & Dunn, 1993; Imbo & Vandierendonck, in press; Kee, 1994). It may be possible that children with LI are delayed in their use of memory strategies during the primary grades and as they mature their strategy use begins to become more similar to their peers with typically developing language.

It is likely that this study concerned multiple components of the Baddeley WM model. Rudkin and colleagues (2007) argued that most information processing tasks involve more than one component of this model and that a pure measure of one component may not exist. Since a dual-task methodology was not used to examine whether any relationships between primary functions of the components of the model and the experimental task existed, we cannot identify the relative contributions of the components of the model with certainty. We did, however, complete an examination of covariance between the experimental task and a phonological memory task that gave some insight into involvement of both the visuospatial sketchpad and the phonological loop.

Efficiency in the functioning of the central executive may also have potential for explaining the difference between the performance by the groups of children on the experimental task. Prior research has established that the central executive plays a major role in recalling serial information and in performing the mental imagery necessary to plan and execute movement (Romine & Reynold, 2004; Rudkin et al., 2007; Salway & Logie, 1995). It has been hypothesized that sequentially presented information is more difficult to encode in a gestalt pattern than simultaneously presented information and that there may be an increased need for effective strategy use by the central executive to recall this information (Rudkin et al., 2007; Vogel, Woodman, & Luck, 2001). Perhaps children with LI have less mature strategy use for recalling information than children with typically developing language due to central executive functioning deficits. Findings by Akshoomof, Stiles, and Wulfeck (2006) that children with LI use less mature strategies for recalling and reproducing drawings than their peers with typically developing language support this hypothesis. Further, the children with LI in the present study may have had difficulty coordinating the transfer of information across the visuospatial sketchpad and the phonological loop, which may have overtaxed their central executive systems.

Possible central executive deficits in using mental imagery to recall and reproduce movements may also be related to the children with LI's poorer performance on the experimental task. This hypothesis is consistent with findings by Johnston and Ellis Weismer (1983) that revealed that children with LI performed more poorly than children with typically developing language on a mental rotation task due to deficits in mental imagery.

The second research question examined the effect of presentation rate on recall and reproduction of sequences of visually presented nonsymbolic arm movements in children with LI in comparison to their peers with typically developing language. The results of this study revealed that children in both groups recalled serial position information from visually presented sequences of nonsymbolic arm movements at the slowest presentation rate (4 s interval) significantly better than at the fastest presentation rate (.5 s interval).

These results are inconsistent with the findings by Fazio (1998) and Gillam and colleagues (1998) that showed a significant group effect for rate. Fazio (1998) found that there was a main effect for rate when comparing children with LI's recall of visually-presented serial information at 1.5 s intervals and 3.5 s intervals, whereas the results in this study indicate that significant differences in performance are only observed with a wider difference in rates by comparing performance at .5 s intervals to 4.0 s intervals. These results, however, are consistent with the findings of Hoffman and Gillam (2004) that children with LI and children with typically developing language do not differ significantly in recall based on the variable of rate. The findings in the study by Hoffman and Gillam (2004) that a main effect occurred for rate at a more narrow difference of 1.25 s with a 1.25 ISI and 2.25 s with a 2.25 ISI rates varied from the wider difference between .5 s and 4.0 s rates needed for a significant difference in performance in this study.

These inconsistencies in the amount of difference needed in rate to produce a significant effect across groups may have been related to the lack of power for analyses due to the small participant group sizes in this study. It is possible that the critical window for rate was also not captured because of the use of steady rate increases. Perhaps using very fast rates and very slow rates rather than steady increments of increased rate will identify a more robust effect for rate and give us more insight into the critical window for rate in future studies.

Clinically, the findings of this study have many implications for how speech-language pathologists plan assessment and intervention for children with LI. Since the children with LI performed poorly on a task that may have heavily relied upon the central executive resources of the Baddeley WM model, it is likely that some children with LI may benefit from intervention targeting central executive functions. For example, children with LI may need assistance in learning and using strategies for word finding and recalling linguistic information. Research has shown that children can learn to use strategies for learning and recalling information as young as 5 years of age (Johnston, Johnson, & Gray, 1987), so it may be beneficial to start teaching some children with LI executive functioning strategies in the primary grades. They also may need intervention to help them learn to sequence, organize, and self-monitor when communicating oral and written information.

Since the children with LI performed poorly on a task that possibly required integration of phonological and visuospatial memory, speech-language pathologists should perhaps be cautious when using clinician-directed visual cueing strategies and when teaching children with LI to use visually-based self-cueing strategies to recall linguistic information. Dynamic assessment may reveal that some children respond better to other methods of clinician-directed cueing and self-cueing (i.e., contextual-based). Further, the rate of presentation results suggest that both children with LI and children with typically developing language may benefit from having visually presented sequential information presented at a slow rate in language therapy and in the classroom.

Limitations of this study included the small number of participants, the possibility that the children could have been at different points in their perceptual learning curves when measurement began, and the possibility that the children's motor execution of the movements could have influenced the performance of the groups on the experimental task. To address these limitations, future research will need to include larger participant groups and the use of span tasks rather than serial memory tasks with set number of items. Research studies investigating the recall of movements will need to use an output method, such as choosing between pictures of movements, that does not incorporate motor execution. A task that incorporates the recall of movements will additionally need to be examined using a dual-processing paradigm to reveal if significant interference occurs when participants are performing a secondary phonological, visual, or motor task. This dual-processing paradigm will allow us to examine whether the task primarily uses the phonological loop, the visuospatial sketchpad, or another motor or kinesthetic memory entity not currently included in the Baddeley WM model to encode and store the movement stimuli.

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