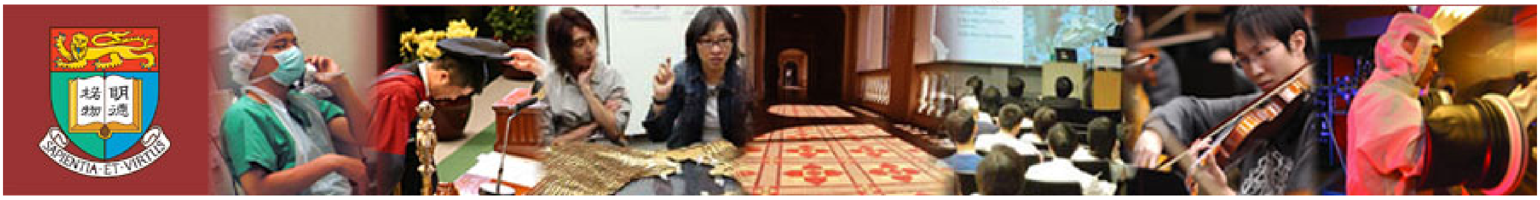

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Visuospatial and verbal short-term memory correlates of vocabulary ability in preschool children

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Abstract

Background: Recent studies indicate that school-age children's patterns of performance on measures of verbal and visuospatial short-term (STM) and working memory (WM) differ across types of neurodevelopmental disorders. Because these disorders are often characterised by early language delay, administering STM and WM tests to toddlers could improve prediction of neurodevelopmental outcomes. Toddler-appropriate verbal, but not visuospatial, STM and WM tasks are available. A toddler-appropriate visuospatial STM test is introduced.

Methods: Tests of verbal STM, visuospatial STM, expressive vocabulary and receptive vocabulary were administered to 92 English-speaking children aged 2-5 years.

Results: Mean test scores did not differ for boys and girls. Visuospatial and verbal STM scores were not significantly correlated when age was partialed out. Age, visuospatial STM and verbal STM scores accounted for unique variance in expressive (51%, 3%, 4% respectively) and receptive vocabulary scores (53%, 5% and 2% respectively) in multiple regression analyses.

Conclusion: Replication studies, a fuller test battery comprising visuospatial and verbal STM and WM tests, and a general intelligence test are required before exploring the usefulness of these STM tests for predicting longitudinal outcomes. The lack of an association between the STM tests suggests the instruments have face validity and test independent STM skills.

Visuospatial and verbal short-term memory correlates of vocabulary ability in preschool children

Introduction

Neurodevelopmental disorders, including specific language impairment (SLI), autism spectrum disorders (ASD), attention deficit hyperactivity disorder (ADHD), developmental dyscalculia (DD), dyslexia and intellectual disability (ID) are increasingly described within multifactorial models or multicomponent cognitive models (e.g., Alloway, Seed & Tewolde, 2016; Moyle, Stokes & Klee, 2011). Such models reflect the complexity of genetic and environmental aetiologies and behavioral phenotypes of these disorders (e.g. Bishop, 2009; Zahir & Brown, 2011). These multicomponent models provide a framework for investigating behavioral phenotypes to distinguish between or conceptualise profiles of developmental disorders or identify commonalities across disorders, identify behavioral risk factors and early predictors of later developmental outcomes, and identify cognitive impairments and strengths that might benefit from targeted intervention to improve developmental trajectories (e.g., Wener & Archibald, 2011). Increasingly these cognitive impairments and strengths are viewed through models of working memory. Recent research suggests that children's performance on tests of working memory differentiates types of neurodevelopmental disorders (e.g., Alloway et al;, 2016; Redmond, Thompson & Goldstein, 2011).

Although different models of working memory have been proposed (e.g., Baddeley & Hitch, 1974; Cowan, 1998; Ericsson & Kintsch, 1995), Baddeley and Hitch's (1974) tripartite model, modified by Baddeley (2000), and described as having "the best fit in children" (Giofrè, Mammarella & Cornoldi, 2013, p. 301) is adopted here. Baddeley's model has served as the conceptual framework within which relationships among memory components have been studied (e.g., Archibald & Gathercole, 2006a). The model has four components: a command system (the central executive) that controls allocation aspects of attention (focusing, dividing and switching attention), and three slave systems controlled by the central executive: the phonological loop, visuospatial sketchpad and an episodic buffer. The phonological loop performs the functions of rehearsing and briefly storing incoming verbal information; the visuospatial sketchpad performs a similar function for visual and spatial information. Both perform short term memory (STM) functions. The episodic buffer provides an interface between verbal and visual modalities and a pathway to and from long term memory. Here we focus on the functions of the slave systems.

Distinguishing types of neurodevelopmental disorders

Parents early concern about their child's late achievement of developmental milestones is highly correlated with the later diagnosis of a child's neurodevelopmental disorder (e.g., Richards, Mossey & Robins, 2016). Richards et al., (2016) reported that the most common concern of parents was their child's lateness in speech/communication development, and the authors cautioned professionals to take parent concern seriously during the diagnostic workup. An early language delay may be indicative of any one of several neurodevelopmental disorders (Buschmann et al. 2008). However the success of predicting neurodevelopmental outcomes at 4-5 years from early language ability in toddlers is "at best moderately successful" (Newbury, Klee, Stokes, & Moran, 2016, p. 1) not only because of the range of possible neurodevelopmental outcomes, but also because such outcomes have been reported in 40-70% of children with an early language delay (Moyle, et al., 2011). In the search for robust predictors of later neurodevelopmental outcomes inveestigators have begun to explore the value of tests of verbal STM and WM because they may differentiate between types of neurodevelopmental disorders.

Identification of developmental profiles, comorbidity, and distinctions among neurodevelopmental disorders have been explored via between-group comparisons of scores on tests of verbal STM, verbal working memory (WM), visuospatial STM and visuospatial WM. For the sake of brevity only exemplar studies are reported here with a focus on SLI, ADHD, ASD and ID. For at least a decade, we have known that children with SLI have weaker verbal, but not visual, STM abilities compared with their neurotypical peers (Archibald, 2017; Archibald & Gathercole, 2006a, 2006b; Archibald & Joanisse, 2009; Henry & Botting, 2017). However, a recent meta-analysis provides evidence of a visuospatial as well as a verbal STM deficits in children with SLI (Vugs, Cuperus, Hendriks, & Verhoeven, 2013). Children with SLI appear to recruit visual information to aid recall, given their relative strength in visual WM and difficulty in verbally recoding input (Botting, Psarou, Caplin, & Nevin, 2013).

Not only do children with SLI perform differently from their neurotypical peers on tests of STM and WM, but they also perform differently from children with other neurodevelopment disorders. Redmond et al. (2011) reported that children with ADHD scored higher than children with SLI on a test of verbal STM. Alloway et al. (2016) subsequently reported that measures of visuospatial and verbal STM and WM distinguished among groups of school-aged children with ASD, SLI, ID and neurotypical development to varying degrees. Effect sizes for group differences on each measure were calculated (Ellis, 2009) from the summary data presented in Alloway et al. and are presented in Table 1. The results present an interesting picture of differing STM and WM strengths and weaknesses across neurodevelopment disorders. Children with neurotypical development scored higher than ASD and ID groups on all dimensions. The verbal tasks (STM and WM) distinguished between neurotypical and SLI groups. The visuospatial STM tasks distinguished between the SLI and ASD groups (T. P. Alloway, personal communication, October 26, 2016). The visuospatial tasks (STM and WM) distinguished between the SLI and ID groups. The WM tasks distinguished between the ASD and ID groups. Together the findings from these research teams indicate that STM and WM tasks may differentiate between neurodevelopment disorders, prompting us to include STM and WM tests in our test battery in the search for early predictors of later neurodevelopment status.

STM and WM as predictors of neurodevelopmental outcome

A strong concurrent relationship exists between emerging language skills and verbal STM ability (Gathercole, Alloway, Willis, & Adams, 2006; Newbury, et al., 2016). Using a verbal STM test developed for toddlers (Stokes & Klee, 2009), Newbury et al. (2016) reported that verbal STM scores were highly correlated with receptive and expressive language scores ($r(75) = .81$, $r(75) = .66$) at 2-2.5 years of age and with receptive and expressive language scores on the Preschool Language Scale-4 (Zimmerman, Steiner & Pond, 2002) at 3.5 years ($r(75) = .70$ and $r(75) = .68$, respectively). On the other hand, Archibald and Gathercole (2006c) found that visuospatial STM ability was not significantly correlated with vocabulary scores in 45 children aged 4-12 years when age was partialed out, with $r(43) = .11$ and $r(43) = .28$ for expressive and receptive vocabulary tests respectively.

Turning to predictive relationships, morphosyntactic abilities at 4 and 5 years are highly correlated with verbal STM scores at 2-3 years (Chiat & Roy, 2008). Newbury et al. (2016) designed a task of verbal WM for toddlers and reported that children's scores at 2 years were strongly correlated with expressive and receptive language outcomes at 3.5 years (correlations of $r(75) = .71$ and $r(75) = .72$ respectively). Not only are verbal STM and WM test scores predictive of later language outcomes, they are also correlated with children's reading and mathematics abilities (Gathercole, et al. 2016). So too are visuospatial STM and WM scores (Gathercole et al., 2016; Mammarella, Hill, Devine, Caviola, & Szucs, 2015). In addition visuospatial STM scores at 4.5 years are associated with mathematics scores at 7 years (Bull, Espy, & Wiebe, 2008) and children with dyscalculia scored significantly lower than their neurotypical peers on tests of visuospatial STM and WM (Mammarella, et al., 2015).

Relationships among WM constructs

An important dimension of the tripartite WM model is the degree to which a) verbal and visuospatial STM constructs are related, and b) STM and WM constructs are related within the verbal and visual domains. Examination of these relationships sheds light on whether these are general or specific cognitive constructs. Alloway, Gathercole and Pickering (2006) reported that bivariate correlations of visuospatial and verbal STM scores were more highly correlated for older children than younger children ($r(211) = .39$, $r(208) = .30$ and $r(283) = .21$ for 9-11 years, 7-8 years and 4-6 years respectively). That is, the strength of the relationship increases in older children. Conversely, visuospatial STM and WM were more strongly related in the youngest group relative to the two older groups. These investigators suggested that younger children draw more heavily on general executive resources than older children in visuospatial STM tasks.

In summary, children's scores on verbal STM and WM and visuospatial STM and WM tests have strong concurrent associations with mathematic and reading ability, and the verbal, but not visuospatial, domain is also strongly associated with concurrent vocabulary scores. Tests of all four STM and WM constructs may be useful in distinguishing among children having different kinds of neurodevelopmental disorders. Finally, as mentioned above, an expressive language delay can presage a range of neurodevelopment outcomes. Administering STM and WM tests to 2- to 3-year-old children may provide an indication of later neurodevelopment status, reading and mathematics abilities. In order to test this, age-appropriate tests tapping all four memory components are needed for use with toddlers. To our knowledge, although toddler-appropriate tests of verbal STM and WM are available, there is no test of visuospatial STM appropriate for toddlers, a gap that this study aimed to fill.

The current study

This study explored the relationship between visuospatial and verbal STM scores in children aged 2-5 and the association of these STM abilities with vocabulary scores, age and sex. A test of verbal STM (Test of Early Nonword Repetition, TENR) was designed to be appropriate for children as young as 2 years (Stokes & Klee, 2009). Originally the TENR consisted of 15 nonwords: three nonwords of one syllable and four nonwords of two, three and four syllables that the child was asked to imitate after hearing a single exemplar. Here we report on an extended version of the TENR consisting of 20 items, including the addition of one single-syllable nonword and four five-syllable nonwords (Test of Early Nonword Repetition-Revised; TENR-R; Stokes & Klee, 2011). The revised version extended the difficulty of the test to prevent ceiling scores in older children.

In order to test visuospatial STM in toddlers we introduce a new measure: the Fish Visual Patterns Test (ViP). Tests of visuospatial STM (e.g., spatial span) for use with children vary on whether there is a sequential-spatial component or a simultaneous-spatial component (Mammarella & Cornoldi, 2005). Published tests suitable for use with children served as a starting point for the design of the new test. For example, Alloway et al. (2006) used three visuospatial tests for 4- to 11-year-old children, including the Dot Matrix Test, the Mazes Memory Task, and the Block Recall Task. The Dot Matrix Test is a sequential-spatial task. The child sees red dots in a 4x4 matrix of squares for 2s, and then has to tap the correct box to recall the dot’s position in a backwards sequence. The Mazes Memory Task and the Block Recall Task require the child to trace a just-seen path through a maze or to tap blocks in the same sequence as the examiner (thus the latter is a sequential-spatial task). The Corsi Block-

Tapping Test (e.g. Milner, 1971) requires sequential-spatial processing, whereas the ViP requires simultaneous-spatial processing (Della Sala, Gray, Baddeley, Allamano, & Wilson, 1999). The Direction Span Test (Lecerf & Roulin, 2006) is a test of visuospatial WM, not of visuospatial STM. All of these tasks require the child to perform a motor task – tapping out a movement sequence, ticking off squares on a grid, copying a path through a maze – and some have a sequential component. The requirement to copy the examiner's movements, and the sequential component of some of these tests increase the task response processing load, rendering them less useful for toddlers.

Our criteria for a test of visuospatial STM suitable for use with toddlers was that the demands on language comprehension were minimal, the task response was constrained, and that it was engaging. With these in mind, and the Dot Matrix Task as a starting point, the ViP was developed and piloted for use with toddlers. The ViP is described in detail in the Methods section. As this was the first investigation of the ViP, two scoring methods were compared. Giofrè and Mammarella (2014) reported that the results for a visuospatial STM task varied as a function of total (absolute credit scores, ACS) versus partial test scoring (partial credit scores, PCS). We hypothesised that PCS would yield significantly higher percentage correct scores than ACS (Giofrè & Mammarella, 2014). In addition, we tested whether the different scoring methods affected the correlations among the variables, and the amount of variance accounted for in the outcome variables.

Aims

The current study examined the relationships among vocabulary abilities, visuospatial STM and verbal STM scores, age and sex in preschool children. The research questions were:

1. Are visuospatial and verbal STM scores significantly correlated in children aged 2-5 years, and are STM scores significantly correlated with expressive and receptive vocabulary

scores? Following Alloway et al. (2006) we hypothesised that (1) visuospatial and verbal STM scores would be weakly correlated in preschool children and (2) verbal, but not visuospatial, STM scores would be moderately correlated with vocabulary scores, even when age was partialled out.

2. What proportion of variance in vocabulary scores is accounted for by visuospatial and verbal STM scores, age and sex? The hypothesis was that verbal, but not visual, STM would account for a significant amount of variance in vocabulary scores (Archibald & Gathercole, 2006c; Newbury et al., 2016) as would age, but not sex (Alloway et al., 2006).

Method

Participants

There were 93 (46 girls) children aged 24-63 months (*Mean* = 44.02, *SD* = 10.17) in the original sample. The children were recruited from a university participant research pool of willing parents/families and by distributing flyers to local kindergartens and schools. All children were monolingual native New Zealand-English speakers, and none had a hearing impairment, visual impairment, or suffered from a significant medical, neurological or psychological problem according to parent reports. Parental written consent was obtained for each child participating in the study and children gave verbal assent. Participants were excluded from the study if they were not monolingual English speakers or scored below standard scores of 85 on either of the vocabulary tests. One child was excluded from the analysis because his expressive vocabulary standard score was 2 *SD* below the test mean. Parents completed a short demographic questionnaire concerning the child's birth order, siblings, ethnicity, medical conditions and language(s) spoken at home. The study was approved by the University of Canterbury Human Ethics Committee.

Procedures and materials

All participants were seen individually in a quiet area at the University's Child Language Centre, or their home or school/kindergarten, depending on parental preferences. The tests were administered by the third and fourth authors. All assessments were completed within a one hour session. The four tests described below were administered in the following order to all children: the Fish Visual Patterns Test (ViP; Stokes & Klee, 2011)[1], the Expressive One Word Picture Vocabulary Test (EOWPVT; Brownell, 2000a), the Test of Early Nonword Repetition-Revised (TENR-R; Stokes & Klee, 2011)[2], and the Receptive One Word Picture Vocabulary Test (ROWPVT; Brownell, 2000b). The expressive vocabulary test was administered before the receptive vocabulary test to avoid priming responses on the receptive vocabulary test.

EOWPVT and ROWPVT. As there were no published tests of New Zealand (NZ) English vocabulary, American English tests were used. The EOWPVT included 190 full-color picture plates presented individually for the participant to name. Four pictures were replaced to make them more recognizable to NZ children: *corn* was replaced with *carrot*, *wagon* with *stroller*, *racoon* with *possum* and *America/US(A)/United States (of America)* with *New Zealand*. The ROWPVT included 190 full-color picture plates presented individually to the participant. Each plate showed four pictures and the child selected the picture most associated with the word spoken by the examiner. In this test, *faucet* was replaced with *tap*. Standardised test instructions were followed. The administration of each vocabulary test took approximately 20 minutes. Both tests were standardized on more than 2,400 children and adults aged 2-103

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[1] The original paper version of the visual patterns memory test was developed by Jennifer Pleass (MSc student) and the first author for a student coursework MSc project at Newcastle University, UK. The computerised test, developed by the first and second authors, is described in this study.

[2] Both tests are freely available from the first author, and both are suitable for Windows-based computers and tablets.

years in the USA. Psychometric properties are sound, with reported internal consistency of *r*=.93 and *r*=.94, and a test-retest correlation of *r*=.98 and .97 for expressive and receptive tests respectively.

TENR-R. The revised version of the Test of Early Nonword Repetition (TENR-R; Stokes & Klee, 2011) was administered (Table 2). The 20 nonwords were presented by computer to each child. Recordings of the nonwords spoken by an Australian-English-speaking female adult were embedded into a PowerPoint presentation with each nonword naming a cartoon character. When the child imitated the nonword, the examiner advanced the presentation to the picture of the character. The instructions to the child were: “We are going to see some funny people. They will come when you say their name. Let’s practice.” Before testing commenced, a practice phase was administered, which included as many attempts as the child needed. In this study, one to three practice trials were needed.

The test started by presenting four one-syllable nonwords, followed by two-, three-, four- and five-syllable nonwords, for a total of 20 nonwords. Each audio-recorded nonword was presented once. The administration of the TENR-R took approximately 10 minutes. An Olympus Digital Voice Recorder WS-450S with an external microphone was used to record the child’s spoken responses. Immediately after the session, the nonwords were transcribed by the examiner using the IPA (Handbook of the IPA, 1999). Transcriptions included all vocalisations and nonword repetition attempts made by the child. Responses were scored as incorrect on a phoneme-by-phoneme basis if the phoneme produced by the child differed from the target phoneme. For cases in which a child’s spontaneous speech pattern on the picture-naming test (EOWPVT) indicated that a specific sound was consistently substituted with another sound (e.g. [t] for /k/), substituted phonemes on the TENR-R items were counted as correct. The child scored one point for each correct consonant and vowel produced in the correct sequence.

Phoneme omissions were scored as incorrect; however, no deductions occurred for phoneme additions, consistent with prior studies (Archibald & Gathercole, 2006a). The third and fourth authors transcribed 10% of each other's recordings and point-to-point agreement was calculated.

The ViP. (Stokes & Klee, 2011) was designed to assess children's ability to recall the location of an object in visual grids of increasing size. Pictures of fish in fish bowls were presented on a computer (or tablet) touch screen, and the fish disappeared after a 5s presentation (see Figure 1). The child was required to recall the location of the fish by touching the appropriate fish bowls. Positive reinforcement was provided in the form of a plopping sound, regardless of the accuracy of the child's response. If the child's response was correct, the fish re-appeared in the bowl. The number of attempts was equal to the number of target fish, so if the participant chose the wrong bowl, a fish appeared automatically in a correct bowl. This avoided gaining credit for guessing across multiple attempts.

Three practice trials, consisting of four bowls and one fish, had to be completed successfully before the task commenced to ensure the child saw the fish, understood the task, and responded appropriately to the instructions. Practice trials could be repeated any number of times to ensure three successful completions. The average number of practice trials for the current study was not noted. The task was demonstrated to the child first and the child was encouraged to imitate the demonstration. The child was also told: "There is the fish. He is swimming, swimming, swimming away. You bring him back. Touch his bowl." The combined visual and verbal instructions helped ensure that the child understood the task.

Twelve test trials were presented, three trials at each level. Each level had two rows that varied in the number of fish bowls: 2 rows x 2 bowls with two fish, 2 rows x 3 bowls with three fish, 2 rows x 4 bowls with four fish and 2 rows x 5 bowls with five fish (Figure 1). To maintain interest a new fish species appeared at each level. As complexity increased, the experimenter pointed this out by specifying how many fish were swimming, for example: “Oh look, lots of fish this time…. you find them” or “Now there are three fish. Watch carefully. Oh they’re gone. Can you bring them back?” Once three practice trials were successfully completed, the test trials began.

The software allows users to select from random and pre-set pattern presentation, automatic or manual advancement of presentations, the duration of pattern exposure time, delay duration after the child’s response, and pause duration between the presentations. In this study, the patterns of fish locations were random, advancement was automatic, presentation duration was 5s, the delay after the response was 2s, and the pause between presentations was 2s. Once the fish disappeared, the test did not progress until the child touched a fish bowl. There was no time within which the child had to make his/her first response. Once the first touch occurred, the child had to finish his/her selection within the set duration. Scoring was automated and saved to a .csv file, and the test took 10 minutes to administer. Two scoring methods were used. In the first, one point was scored for each correct trial for a maximum score of 12 (absolute credit score, ACS, Giofrè & Mammarella, 2014). The second awarded one point for each fish correctly found for a maximum of 42 (partial credit score, PCS, Giofrè & Mammarella, 2014).

Results

There was 82% agreement in broad phonetic transcription at the segment level between the two independent transcribers across the TENR-R transcripts. The differences in scoring were due to vowel disagreements. Descriptive statistics for the study variables appear in Table 3. There was only one floor score, for the visuospatial STM test, and two children achieved the maximum score. The PCS percentage correct scores were higher than the ACS scores (*t*(91)=

19.53, $p < .001$, 95% *CI* for the difference in means = 20.04 - 24.57). There was no significant difference between boys and girls on any of the test scores (Table 3).

Research question 1

Research question 1 asked (1) if visuospatial STM and verbal STM scores were significantly correlated in children aged 2-5 years, and (2) if the STM scores were significantly correlated with expressive and receptive vocabulary scores in these participants. There were significant bivariate correlations among all variables. The correlations remained significant apart from the partial correlation between visual and verbal STM scores once age was partialled (Table 4). Confidence intervals (CIs) for bivariate correlations were calculated using the “cor.test” function of R (R Core Team, 2016); CIs for partial correlations were calculated with an R function written by Bonett (2016).

Research question 2

Research question 2 asked what proportion of variance in vocabulary scores was accounted for by visuospatial and verbal STM scores, age and sex. Multiple regression analyses were run twice to compare the effect of ViP-ACS and ViP-PCS (Tables 5 and 6). Age, TENR-R and ViP scores accounted for significant amounts of variance in expressive vocabulary scores (53%, 5% and 2% respectively for ACS scores, and 53%, 3% and 2% respectively for PCS scores). Sex did not account for a significant proportion of the variance. Age, the TENR-R, and the ViP accounted for significant amounts of variance in receptive vocabulary scores (51%, 5% and 2% respectively for ACS scores, and 51%, 4% and 3% respectively for PCS scores). Sex did not account for a significant proportion of the variance.

Discussion

Relationship between visuospatial and verbal STM tests

The first hypothesis was that visuospatial and verbal STM memory scores would be weakly but significantly correlated, beyond shared variance accounted for by age (Alloway, et al., 2006). The results did not support this hypothesis. The correlations between visual and verbal STM were not statistically significant once age was partialed out, neither for ACS nor PCS scoring methods (r = .16 and r = .15). The lack of an association suggests that the instruments have face validity and that the test separates STM skills. The current results are not surprising given that Alloway et al.'s (2006) bivariate correlations increased in strength from 4-6 years to 9-11 years (*r* values of .21, .30 and .39), indicating a strengthening association in older children. It is possible that significant correlations between visuospatial and verbal STM scores would be reported for a larger sample size of children aged 2-5, akin to the very large sample of older children in Alloway et al., (2006).

The tests were designed to allow preschool children to participate and maintain attention to the test. The ViP Test may be likened to the computerised Dot Matrix test except that its stimuli were constructed to hold the interest of toddlers and preschoolers (fish in fish bowls rather than red dots in squares), and the test does not have a sequential component. Note that ViP stimuli were arranged in two straight rows, unlike the 4x5 grid of the Dot Matrix Task. Since the stimuli remained on the screen for 5s, older children may have been able to verbally recode the visual patterns (e.g. 'top row bowls 3 and 4, bottom row bowl 5'), which in turn assisted recall. However although we saw no explicit evidence of this (such as whispered rehearsal) during the experiment, we cannot exclude the possibility. It would be useful to replicate the study and ask the older children what they did, if anything, to try to remember the location of the fish.

Relationship between visuospatial and verbal STM scores and expressive and receptive vocabulary scores

The hypothesis was that verbal, but not visuospatial, STM scores would be significantly associated with vocabulary scores once age was partialed out (Archibald & Gathercole, 2006c). The hypothesis was partially supported. Both STM tasks were significantly correlated with expressive and receptive vocabulary scores. A stronger test of the relationships is to examine how much variance in vocabulary scores is accounted for by the STM tasks once age and sex are accounted for. Both STM tasks accounted for significant but modest amounts of unique variance in both expressive and receptive vocabulary scores. The expressive vocabulary test required the child to name a picture without a verbal prompt other than the test instruction to name the picture. The receptive vocabulary test required the child to scan four pictures and to select the one named by the examiner. Higher visuospatial and verbal STM scores were associated with higher scores on picture naming and name comprehension. Performance on both tasks could have been influenced by the visual properties of the stimuli, implicating visual object recognition abilities or general intelligence. In Alloway et al. (2006), visuospatial STM and visuospatial WM were more strongly related in their youngest group relative to the two older groups, suggesting that younger children may draw more on general executive resources than older children in STM tasks. It is possible that the STM tasks accounted for portions of the variance in expressive and receptive vocabulary scores because the tests drew on WM or general executive resources. We can neither confirm nor refute this as neither WM nor general intelligence tests were administered.

A final hypothesis was that the results of the ViP task would vary as a function of scoring method (after Giofrè & Mammarella, 2014). The hypothesis was supported only in that the percentage of correct scores was higher using the PCS than ACS scoring, as reported by

Giofrè and Mammarella (2014). However the scores accounted for similar amounts of unique variance in vocabulary scores, indicating no substantive difference in scoring methods.

Contributions of this research

Early language delay in toddlers is a common problem and may be indicative of several neurodevelopmental disorders (Buschmann et al., 2008). Predicting the probable nature of a later developmental disorder at the time when an early language delay is identified has proved to be elusive. In Alloway et al's study of school-aged children, children with SLI had a relative strength in visuospatial memory tasks and a weakness in verbal memory tasks. Children with ID performed poorly on all tasks. Children with ASD had low-average scores in the four tasks but only differed from the children with SLI on the Visual STM task. As Table 1 indicated, the school-aged children with neurotypical development scored significantly higher than all three groups of children with atypical development (SLI, ASD and ID) on the Verbal STM and WM tasks. Administration of the verbal STM task at 2-3 years may be indicative of a future neurodevelopment disorder, confirmed at 4-5 years, but would not indicate the possible nature of the disorder. The verbal WM test differentiated between children with ASD and ID, but did not differentiate between SLI and ASD nor SLI and ID. Adding a test of Visual WM to early screening may differentiate the children with eventual SLI from those with ID but not those with ASD. It seems that only the visual STM test differentiated between the children with SLI and the children with ASD. Administration of all four tests to children with a language delay at 2-3 years may improve the predictive validity of early indicators of the nature of an eventual atypical developmental outcome at 4-5 years.

The test of visuospatial STM introduced here appears to be suitable for the above purpose. Strengths of the new test include the lack of ceiling and floor effects, the lack of a significant sex effect on test scores, and the success in maintaining the attention of pre-school children. Replication of this study with larger samples is welcome.

Limitations and further research

In future studies, an intelligence test could be administered to explore how general cognitive abilities affect results. At least two studies with young children have found that visuospatial STM is related to intelligence (Hornung, Brunner, Reuther & Martin, 2011; Giofrè et al., 2013; see Giofrè & Mammarella, 2014). Tests of visuospatial and verbal WM could be added to the model to assess the relative contributions of WM and STM to vocabulary scores. At present, we have tests of visuospatial and verbal STM, as well as verbal WM, for toddlers but not visuospatial WM.

In this sample of children aged 2-5 years, visuospatial and verbal STM skills were associated with vocabulary skills beyond associations accounted for by sex and age. Further studies that examine the concurrent relationships among visuospatial and verbal STM tasks, visuospatial and verbal WM tasks, and vocabulary scores in young children are warranted given the findings of the concurrent and predictive relationships between verbal STM and WM and language abilities in young children (Newbury et al., 2016). Finally, given the usefulness of this quartet of variables in distinguishing among neurodevelopmental disorders in school-aged children (Alloway et al., 2016; Redmond et al., 2011), it may be worthwhile to examine the success of these new tests in predicting developmental outcomes from early language delay.

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Figure 1. Examples from the Fish Visual Patterns Test (ViP; Stokes & Klee, 2011), illustrating test items for two fish in 2 rows x 2 bowls.

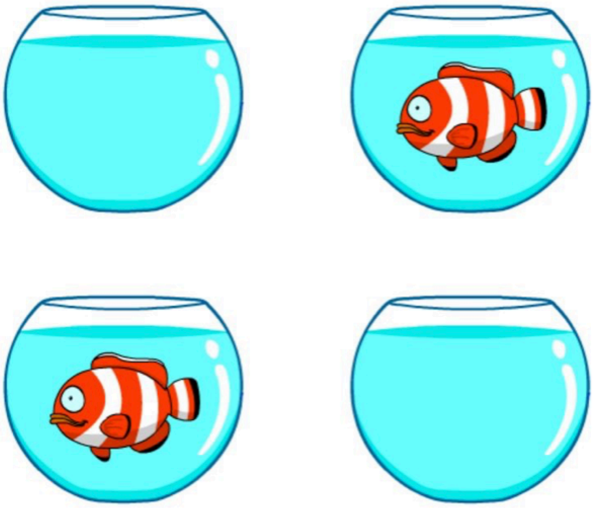

Table 1

Effect Sizes for Between-Group Comparisons on Visual and Verbal STM and Visual and Verbal WM Across Groups of Children With Neurotypical Development (NT), Specific Language Impairment (SLI), Autism Spectrum Disorders (ASD), and Intellectual Disability (ID)

	NT > SLI	NT > ASD	NT > ID	SLI > ID	SLI > ASD	ASD > ID
Visual STM	-0.39	0.72*	1.18*	1.67*	1.08*	-0.34
Visual WM	0.67	0.88*	1.95*	1.13*	0.43	0.90*
Verbal STM	0.94*	0.94*	1.36*	0.57	0.14	0.34
Verbal WM	1.26*	1.08*	2.52*	1.17	0.02	0.76*

Note. > indicates the direction of the difference. Effect sizes = Hedges' g, * statistically significant group difference, p< .05. Effect sizes were calculated (Ellis, 2009) from data in Alloway, Seed, and Tewolde (2016).

Table 2

Items of the Test of Early Nonword Repetition – Revised (TENR-R; Stokes & Klee 2011)

1 syllable	2 syllable	3 syllable	4 syllable	5 syllable
mad	kougə	moukəri	pɜːduləmeip	giləmafukou
neit	dafi	doupəlut	fenəraizek	lɜːteidikunei
paim	lɜːpou	bæləkɒn	wugəlæmIk	golumɜːfinai
bouk	fupɪm	fisaimɒt	lɒdənætɪʃ	bafumouwudi

Note: Items represented using the IPA (International Phonetic Alphabet; International Phonetic Association, 1999).

Table 3

Summary Statistics for the Study Variables (N = 92), with Statistical Tests of Differences Between Girls and Boys

Variable	Mean	*SD*	Minimum	Maximum
Age in months	44.02	10.17	24	63
Girls (n = 46)	44.17	9.66	24	60
Boys (n = 47)	43.87	10.76	24	63
F(1,90) = .02, *p* = .89				
EOWPVT raw score	51.14	18.08	12	101
Girls	51.70	16.33	19	85
Boys	50.59	19.84	12	101
F(1,90) = .09, *p* = .77				
ROWPVT raw score	56.15	16.66	19	104
Girls	57.89	14.85	25	87
Boys	54.41	18.30	19	104
F(1,90) = 1.00, *p* = .32				

Table continues

Variable	Mean	*SD*	Minimum	Maximum
TENR-R PCC	71.97	17.7	17	99
Girls	73.30	17.92	17	98
Boys	70.64	17.58	17	99
F(1,90) = .52, *p* = .47				
ViP-ACS percentage score	58.60	21.35	0	100
Girls	61.59	19.04	8	100
Boys	55.60	23.25	0	100
F(1,90) = 1.83, *p* = .18				
ViP-PCS percentage score	80.9	14.23	21	100
Girls	83.49	11.68	50	100
Boys	79.31	16.10	21	100
F(1,90) = 3.14, *p* = .08				

Note. TENR-R = Test of Early Nonword Repetition – Revised (Stokes & Klee, 2011), EOWPVT = Expressive One-word Picture Vocabulary Test (Brownell, 2000a), ROWPVT = Receptive One-word Picture Vocabulary Test (Brownell, 2000b), ViP = Fish Visual Patterns Test (Stokes & Klee, 2011), ACS = absolute credit scores, PCS = partial credit scores, PCC = percentage of phonemes correct.

Table 4

Correlations Among Age, Expressive and Receptive Vocabulary Scores and Short-Term Memory Scores (N=92) with 95% Confidence Intervals

	EOWPVT	ROWPVT	TENR-R	ViP-ACS	ViP-PCS
Age	0.73**	.72**	.53**	.69**	.70**
	[.62, .81]	[.60, .80]	[.37, .67]	[.57, .79]	[.58, .79]
EOWPVT		.82**	.54**	.67**	.64**
		[.73, .88]	[.38, .67]	[.53, .77]	[.50, .74]
ROWPVT	.62**		.56**	.64**	.64**
	[.47, .73]		[.40, .68]	[.50, .74]	[.50, .75]
TENR-R	.26*	.30*		.47**	.46**
	[.06, .44]	[.10, .47]		[.29, .61]	[.29, .61]
ViP-ACS	.33*	.28*	0.16		.89**
	[.13, .50]	[.08, .46]	[-.05, .35]		[.83, .92]
ViP-PCS	.26*	.27*	0.15	.78**	
	[.05, .44]	[.07, .45]	[-.06, .34]	[.68, .85]	

Note. Values above the diagonal are bivariate correlations (Pearson's *r*), and those below are partial correlations controlling for age. Age in months, TENR-R = Test of Early Nonword Repetition – Revised (Stokes & Klee, 2011), EOWPVT = Expressive One-Word Picture Vocabulary Test (Brownell, 2000a), ROWPVT = Receptive One-Word Picture Vocabulary Test (Brownell, 2000b), ViP = Fish Visual Patterns Test (Stokes & Klee, 2011). *p < .05.

Table 5

Forward Regression Model Statistics Predicting Expressive Vocabulary Scores (EOWPVT)

Model		*Coefficients*		
	$\triangle R^2$	*B*	*SE B*	β
Step 1	0.53			
Constant		-6.00	5.79	
Age in months		1.30	0.13	0.73
Step 2				
Constant	0.58	-4.60	5.520	
Age in months		0.92	0.17	0.52
ViP-ACS		0.26	0.08	0.31
Step 3	0.60			
Constant		-10.27	6.01	0.45
Age in months		0.79	0.18	0.28
ViP-ACS		0.23	0.08	0.17
TENR-R		0.17	0.08	

Note. EOWPVT = Expressive One-Word Picture Vocabulary Test (Brownell, 2000a), ViP-ACS = Fish Visual Patterns Test (Stokes & Klee, 2011), absolute credit score.

Table 6

Forward Regression Model Statistics Predicting Receptive Vocabulary Scores (ROWPVT)

Model		*Coefficients*		
	$\triangle R^2$	*B*	*SE B*	β
Step 1	0.51			
Constant		4.50	5.45	
Age in months		1.17	0.12	0.72
Step 2	0.56			
Constant		-2.66	5.77	
Age in months		0.96	0.14	0.59
TENR-R		0.23	0.08	0.25
Step 3	0.58			
Constant		-0.79	5.68	
Age in months		0.73	0.17	0.44
TENR-R		0.20	0.08	0.21
ViP-ACS		0.18	0.08	0.23

Note. ROWPVT = Receptive One-Word Picture Vocabulary Test (Brownell, 2000b), ViP-ACS = Fish Visual Patterns Test (Stokes & Klee, 2011), absolute credit score.