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Visual fast mapping in school-aged children with Specific Language Impairment

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INTRODUCTION

The purpose of this paper was to examine visual fast mapping in children with specific language impairment (SLI) as a means to better understand the nature of the disorder. Specifically, there is much to learn about how children with SLI process visual information in a task that involves memory. Although specific or primary language impairment is one of the most common communication disorders, with a prevalence of 7.4% (Bishop, 2010), it is relatively understudied (Bishop, 2010) and is not fully understood.

The ‘specific’ in SLI has been noted to be something of a misnomer, with suggestions that the nature of the problem is not limited to language, but comprises more generalized cognitive processing deficits (e.g. Just & Carpenter, 1992; Weismer, Evans, & Hesketh, 1999). Recent work has clearly implicated working memory as a cognitive component affected in children with SLI, with verbal working memory being particularly vulnerable (e.g. Alt, 2011; Archibald & Gathercole, 2006; Montgomery, Magimairaj, & Finney, 2010). However, the evidence for *visual* memory problems in this population is mixed (See Leclercq, Maillart, Pauquay, and Majerus, 2012, for a review of studies).

Visual fast mapping offers a method for examining visual working memory in children with SLI, and thus investigations of this ability should help to answer questions about whether or not the problems found in verbal working memory in children with SLI extend into the visual domain. A lack of evidence for visual working memory problems would support the view of SLI as an impairment that is primarily linguistic (e.g. Paradis, Crago, & Genesee, 2009). Conversely, evidence for visual working memory deficits would lend credence to the view of SLI as an impairment characterized by domain-general deficits (e.g., the Procedural Deficit Hypothesis; Ullman & Pierpont, 2005), although those deficits tend to be most obvious on tasks that require language processing.

Researchers have used varying methods to examine visuospatial processing in children with SLI, and their work has yielded conflicting findings. Some researchers have found no deficits (Alloway & Archibald, 2008; Archibald & Gathercole, 2006; 2006), whereas others have found evidence for problems (Bavin, Wilson, Maruff, & Sleeman, 2005; Hick, Botting, and Conti-Ramsden, 2005; Windsor, Kohnert, Loxtercamp, & Kan, 2008). These studies

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have used different approaches, examined different types of processing, and looked at different types of memory. The potential sources for the problems are also different, with some authors using their findings of group differences simply to support hypotheses about domain-general deficits (e.g. Bavin et al., 2005) and others using group differences to support claims about specific deficits. For example, Marton (2008) suggested that attentional deficits might be tied to the poor performance of children with SLI on visuospatial tasks. In contrast, Leclerq et al. (2012) suggested that the visual complexity of stimuli, defined by either visual similarity of items or the number of features within items, was responsible for children with SLI performing worse than unimpaired peers on short-term memory tasks.

Therefore, when examining these conflicting findings, it is difficult to find a trend to easily explain the differences. One attempt to summarize visual memory processes in children with SLI through meta-analysis concluded that children with SLI had ‘relatively’ intact declarative memory but showed evidence of impaired procedural memory (Lum & Conti-Ramsden, in press). Lum and Conti-Ramsden also concluded that in both the verbal and visual domains, even if children with SLI have ‘relatively’ intact declarative memory, they still need more exposures to learn than children with SLI.

Visual fast mapping is an interesting task because it provides a way to examine visual processing directly, which may help to untangle the mixed evidence on how children with language impairment perform on tasks involving visuospatial processing. It also allows a glimpse at the early stages of processing – before children with SLI have had multiple exposures that may have allowed them to catch up with their peers (if, in fact, catching up is needed).

Previous studies have documented visual fast mapping deficits in preschool children with SLI (Alt, Plante, & Creusere, 2004; Alt & Plante, 2006). However, the results of these studies were confounded by asking children to simultaneously fast-map lexical labels – a task that we know is difficult for children with SLI (e.g. Kan & Windsor, 2010). Therefore, it is unclear if deficits in visual fast-mapping found in such studies were secondary to problems with lexical learning or are a primary feature of language impairment. Our assumption is that children with SLI have the ability to perceive simple visual information as well as unimpaired peers. For example, there is no indication that children with SLI have impaired visual acuity or notably different psychophysical perception of colors compared to children without language impairment.

Visual Fast Mapping

The term fast mapping was introduced to refer to the initial stages of word learning, in which children make partial mappings of words to objects after minimal exposure to the stimuli (Carey, 1978; Carey & Bartlett, 1978). For example, the classic example from Carey’s work had children link the word ‘chromium’ to the olive color of a tray. However, fast mapping has been expanded to include other types of mapping, including visual-to-visual mapping (e.g. Wilkinson, Dube, & McIlvane, 1996). If we stick with the example of the olive colored tray, in a visual-to-visual mapping task, a child might be asked to link the tray’s color to the tray itself, but not be provided with labels for either the tray or the color.

In this case, the same criteria hold; that is, learners must link two pieces of visual information given minimal exposure to the stimuli.

The ability to quickly link visual-to-visual information is an important part of learning concepts and enriching semantics. Visual processing of nonverbal information is an important component of language acquisition. Binding words to referents is much easier when the learner can have a visual image of the referent. This is most obvious for concrete, imageable words (e.g. 'plant' as in "that green thing you are pointing to"), but it can also be helpful for concepts like prepositions (e.g. 'under' as in "see the table, and the shoes under it"), or even more abstract words (e.g. 'grief' as in "I can see from your face that this is something bad or upsetting").

Visual Processing in Working Memory

One reason people have been examining visuospatial processing, aside from its importance in language acquisition, is its relation to working memory. Working memory can be thought of as the ability to store, manage, and manipulate information (Cowan, 2008). As mentioned earlier, there is clear evidence for children with SLI showing poor verbal working memory skills (e.g. Alt, 2011; Archibald & Gathercole, 2006; Lum & Conti-Ramsden, in press; Montgomery et al., 2010). If verbal working memory is a known weakness of children with language impairment, then it is possible that visual working memory might also contribute to the profile of learning deficits observed in these children.

A quick review of some theories of working memory is in order to understand how visual processing plays into working memory. One of the most popular explanations of working memory is Baddeley's model (2003) which posits that working memory comprises a central executive, an episodic buffer, and two sub-systems: the phonological loop and visuospatial sketchpad. In this model, the central executive is responsible for attentional control. The other systems are thought to be temporary storage systems, with the phonological loop and visuospatial sketchpad relegated to modality specific information, and the episodic buffer serving as a "...more general integrated storage system" (Baddeley, 2007, p. 13) which might help integrate information from the modality-specific systems and long-term memory. The visuospatial sketchpad incorporates both visual (i.e. appearance) and spatial information (i.e. location and orientation) and is assumed to have a limited capacity and to use some rehearsal mechanisms.

An alternative conceptualization of working memory comes from Cowan (e.g. Cowan, 1999; 2008) who does not compartmentalize particular modalities to the same degree. His model includes a central executive in charge of attentional control and a focus of attention which regulates capacity limitations. Both of these interface with the current activated memory and long term memory. Some key features of this model are that the focus of attention has capacity limitations, that the focus of attention is controlled by both voluntary and involuntary processes, that awareness influences processing, and that people can habituate to features that remain relatively unchanged. In this model, both verbal and visual information can be in the focus of attention. Cowan and colleagues suggest that resources for the different modalities can be divided in a flexible manner (Morey, Cowan, Morey, & Rouder, 2011).

These models are not necessarily contradictory. Rather, each offers a unique opportunity to view possible sources of problems that may exist in the visual working memory skills of children with SLI. Baddeley's (2003) clear modularization of visual and verbal components allows researchers to suppose that a task that is clearly weighted towards one modality would in fact be reflective of primarily that modality. This would help us to determine whether the visual fast mapping deficits found in children with SLI (Alt et al., 2004; 2006) were truly related to issues with the visuospatial sketchpad or were secondary to problems that originated in the phonological loop. Visual-to-visual mapping, especially when responses are elicited and given nonverbally, calls for limited engagement of the verbal component of working memory. Even Cowan's model allows for some modality specificity. His work with colleagues provides data that show that same-modality stimuli can cause interference during the retention process (Morey et al., 2011).

Cowan's (1999) focus on attention and attentional control prompts researchers to look at a more general cognitive issue that might manifest in visual working memory difficulties for children with SLI. One metaphor frequently used to describe the focus of attention is a flashlight shining on the object of interest. If visual working memory is problematic for children with SLI, there is the potential for the problem to arise from two sources: limited capacity of attention (e.g. the flashlight's beam has an overly small circumference) or difficulty focusing on the appropriate items (e.g. beam focused on the wrong items). In Baddeley's model (2003), attentional control for visual information could be regulated by the central executive, which is a domain-general resource. Thus, a problem related specifically to attentional control could be accounted for in Baddeley's model as well.

There is reason to suspect that children with SLI would have difficulty with tasks related to attention. In a meta-analysis, Ebert and Kohnert (2011) found that there was evidence for deficits in sustained selective attention in children with primary language impairment. Importantly for this study, the deficits were found for both the auditory and visual domains, although the deficits were milder in the visual modality. Marton (2008) found visuospatial deficits in children with SLI and suggested that attentional deficits might be tied to their poor performance on the experimental visuospatial working memory tasks.

It may be that, when presented with visual tasks that involve relevant and irrelevant information, children with SLI may have difficulty selecting the relevant items on which to focus their attention and performance would suffer as a result. For example, Cowan's model suggests that habituation will happen if an object remains relatively unchanged and is unimportant to the observer, requiring less attention. However, it is up to the observer to assign importance. When there are multiple visual features to attend to, learners need to use decision-making skills to determine which stimuli to focus on. The appropriate allocation of attentional resources is a potential source of difficulty for children with SLI.

The Current Studies

The current report describes two studies that used visual fast mapping exercises as a way to examine the visual working memory skills of children with SLI in comparison to typically developing peers. The first study examined visual fast mapping given stimuli of differing visual complexity. The second examined visual fast mapping in a task designed to tax visual

working memory capacity. Fast mapping is a particularly good paradigm for measuring these immediate memory systems because it looks at the first stages of the learning process (i.e., the child's ability to notice and remember salient visual features), thus allowing insight into when deficits in associative learning involving visual processing, if any, may emerge. A deficit in capacity limitations or attention could be conceptualized in either model of working memory.

Performance on visual fast-mapping tasks that are without lexical demands should provide a better understanding of the nature of the deficits associated with SLI related to visual working memory. This approach was used in our research to allow us to examine sources for possible deficits. The results of these studies should add to the literature by examining fast mapping of visual information without explicit linguistic demands, thus avoiding confounding visual fast mapping with a known weakness. We also planned to see how performance on these tasks correlated with measures of performance on other measures known to explain performance in children with SLI, including nonverbal intelligence, language, reading, and vocabulary measures, as well as maternal level of education.

Predictions:

1. If children with SLI have domain general processing deficits, they will be less efficient at fast mapping visual features than unimpaired peers. (Experiments 1 and 2)
2. If children with SLI have limited visual working memory skills due to a diminished ability to direct attention to appropriate images (i.e., focus of attention) then children with SLI will be less efficient than unimpaired peers when asked to extract information from a visually complex scene, compared to a scene that has relatively low visual complexity. (Experiment 1)
3. If the limitation is due to an actual limited capacity for visual working memory, then children with SLI will be less efficient than unimpaired peers when asked to recall a larger number of features. (Experiment 2)

METHODS

Participants

Twenty-five 7- and 8-year-old children with SLI (15 male) took part in the study, along with 25 typically developing (TD) peers (15 male). After receiving approval from our institution's Institutional Review Board, participants were recruited from local schools and community resources such as libraries, zoos, or museums. All participants needed to pass a hearing screening, a vision screening for both color vision and near acuity, achieve a standard score of 75 or greater on the Kaufman Assessment Battery for Children –II (Kaufman & Kaufman, 2004) (to rule out intellectual disability), and per parent report, be Native English speakers and have no history of other diagnoses.

We used the core language component of the Clinical Evaluation of Language Fundamentals- 4th edition (CELF-IV) to determine language status. Using a cut-off of 85, this test has a sensitivity of 100% and a specificity of 82% (Semel, Wiig, & Secord, 2003).

Thus, all children in the SLI group achieved standard scores of 85 or less, and those in the TD group achieved standard scores of 86 or greater. We also assessed receptive vocabulary (Peabody Picture Vocabulary Test- 4th edition- Dunn & Dunn, 2007) and word reading (Test of Word Reading Efficiency-Torgesen, Wagner, & Rashotte, 1999) as descriptive measures. A summary of both groups' characteristics can be found in Table 1.

Study design – Experiment 1

In order to test the hypotheses about visual fast mapping in children with SLI, we compared their fast mapping skills to age- and gender-matched peers using a specially designed computer game involving dinosaurs. Children were asked to fast map four visual features from 10 animated vignettes involving novel dinosaurs who differed from each other visually and who performed actions on other objects (e.g., eating, crushing) for a total of 40 features (4 features × 10 vignettes). Half of the vignettes were presented with low visual complexity (i.e., there were only four visual features that varied across dinosaurs), and half with high visual complexity (i.e., there were eight visual features that varied across dinosaurs). Participants had to remember the same four features regardless of whether the vignette had high or low visual complexity. Responses were made using a touch screen in order to reduce the verbal load. Using a mixed design ANOVA, we examined two between-group variables (SLI, TD) and two sets of within-group variables: complexity (HI, LO) and feature (color, shape, what was crushed, what was eaten).

Stimuli

We used Flash (Adobe) to create novel animated dinosaurs for each of the 10 vignettes. Each vignette lasted 10 seconds and consisted of a dinosaur walking onto the screen, eating something, crushing something, and exiting the screen. Participants were asked to remember four visual features about this animated scene. Two features were intrinsic to the dinosaur (i.e. body shape, body color) and two were related to the dinosaur's actions (i.e. what it ate, what it crushed). Complexity was manipulated by the number of visual features in each vignette. In the high complexity condition the dinosaur's body had a pattern, its eye color varied, it left footprints where it walked, and it burped visibly, leaving a unique 'burp cloud' after eating. In the low complexity condition the dinosaur's body was always plain, its eyes were always black, and it never left footprints or burp clouds. See Figure 1 for an example of high and low complexity vignettes. The background for each vignette was chosen from one of ten options that had the same basic level of visual interest (e.g. desert scene with mountains and cacti; mountain scene with mountains and trees). The 10-second vignettes were intentionally silent, as we wanted to minimize the role of verbal information.

Game Structure

The basic structure of the game was that children would watch a 10 second vignette and then immediately be required to report on the visual features they saw using a nonverbal response paradigm, described below. Given that the dinosaurs were all novel, and participants only saw each vignette one time, there were no consistent associations to learn. The point of the task was to remember the visual stimuli from the vignette and be able to report on four specific features. In the high complexity condition, this had the potential of being more challenging due to the presence of additional interesting, but non-relevant features. Children

were trained how to respond to each of the four features in the training session, so the items of importance were not a surprise. The 10 vignettes (five high, five low) were presented in random order with no repetitions. Children watched all 10 vignettes in a single setting, reporting on what they remembered after each vignette. A schematic of the study design is available in Appendix A.

In order to allow participants to respond without invoking their expressive language skills, children made their choices non-verbally, using a touchscreen. The basic premise for responses was that children would see four choices for a visual feature, and they would have to select the correct choice. They had four chances to choose the correct feature and received feedback after every choice.

Children were always asked to remember the dinosaur's shape first. Children were able to change their selection as many times as they liked until they indicated their final choice by touching the "I'm done" button. After pressing the "I'm done" button, participants received feedback. If the answer was correct, an electronic dollar was added to an on-screen money bag. If the answer was incorrect, the four choices would remain onscreen, and the child would be given up to three additional opportunities to choose the correct shape. The money value of the reward was decreased (e.g. quarter, dime, nickel) with each error the child made.

Corresponding procedures were used for the color, what was eaten, and what was crushed features, which all were presented on a single screen. (See Figure 2.) Children indicated these three features in an order of their choosing. Each feature was represented by icons which participants had been trained to recognize. For example, there was a single multi-colored crayon to represent the concept of 'color' and a large foot to represent the concept of 'what was crushed'.

When children made a choice on this response screen, their selection would appear in or near the dinosaur shape in the middle of the screen. For example, if they chose 'yellow' for the dinosaur's color, the dinosaur shape would fill with yellow. If they chose a lizard under the 'eat' category, a lizard would appear near the dinosaur's mouth. As in the shape response screen, children could try out different answers as often as they liked. A choice was only counted officially once a child pressed the "I'm done" button. That button was programmed so that it would not be active until a choice had been selected for all the active features.

Children received feedback on all three features simultaneously. For example, if, after pressing the "I'm done" button for the first time, they had selected the correct color but made incorrect selections for what was eaten, and what was crushed, the color module would be greyed out, and unable to be selected. There would also be a large green check mark on the color icon, showing the child that their choice was correct and the dollar bill icon would remain under the icon. This served the purpose of not requiring children to respond correctly to a feature more than once per vignette, thus allowing them to focus on all of the features. (See Figure 2). In this example, the 'eat' and 'crush' icons and choices would remain available for the child to make a selection, and the dollar bill would change to a quarter under those icons. Nothing would be greyed out for incorrect selections, so it was

possible for children to choose the same, incorrect, choice multiple times. In other words, the computer did not help the children narrow down the selection of responses. Responses were automatically collected by the computer.

After the child had all three features correct, or had exhausted his or her four tries, the child would be taken to the money bag screen, and the money they had earned from that round would fly into the bag and be added to their running tally. Then, they would see the dinosaur's picture go into a slot in a photo album. This served as a reinforcer, to show children their progress and alert them, through the use of the empty slots, to how many additional dinosaurs they had yet to learn about.

Nature of the task

This task required participants to utilize immediate visual working memory in order to demonstrate correct recognition of four visual features (shape, color, what was eaten, what was crushed) that participants had been exposed to once, for 10 seconds. Participants were given four opportunities to choose the correct answer for each feature from a field of four choices. The outcome measure was a ratio of number of attempts used to number of features correct. Thus, a perfect ratio would be 1.0 (1 attempt needed to get 1 feature correct), and the higher the ratio, the worse the performance. This type of scoring provides more information than a simple correct/incorrect response.

Depending upon the nature of the task, fast mapping could involve just short term memory (i.e. the ability to hold information in memory for a short time (Cowan, 2008)), or it also could include working memory, or even long-term memory. To keep the focus on short term and working memory, we used novel dinosaurs whose appearance, eating, and crushing habits were not related to known facts. For example, backgrounds did not provide any important semantic information on their own; thus, a dinosaur might eat or crush a cactus, but the cactus could appear in a desert scene, mountain scene, or a beach scene. This allowed us to control for children's differing levels of semantic knowledge about dinosaurs and ecosystems. It also lessened the contribution of long-term memory to the task demands.

Although children were asked to report on the visual features directly after seeing the vignettes, this is more than a short-term memory task. It is considered a working memory task because of the need for children to prioritize information (e.g. "which feature should I report on next?") and manage possible interference. Interference was possible from several sources including extraneous information in the vignette (high complexity condition), from previous vignettes, and the incorrect options for each feature.

Minimizing Verbal Strategies

We intentionally chose items that either would be difficult to lexicalize, or for which lexicalization would have limited utility. As an example of the former, the dinosaurs' shapes were all novel, so children could not rehearse something known like "T-Rex." As an example of the latter, when remembering a dinosaur's color, it might be easy to call to mind 'green'. However, remembering 'green' is less helpful when presented with more than one choice of green in the response screen (e.g. "was it lime green or forest green?"). Additionally, other items might be green, so actually remembering the word 'green' alone

might lead a child to choose a green plant from the ‘what was eaten’ tab, rather than choosing green for the dinosaur’s body color. Another example of the limited utility of lexical labels in this task is illustrated in Figure 2, where the object ‘stapler’ appears as a choice in both the ‘what was eaten’ and ‘what was crushed’ response choices. Other ways that the use of lexical labels was limited included providing variations of the same basic type of item. For example, if a dinosaur crushed a plant, a response screen might show four different plants. Therefore, simply remembering ‘plant’ would not be enough to help. Basically, in order for lexical labels to be helpful, they would need to be so long and specific (e.g. bright yellow guy with square bumps on oval body crushed the stapler and ate the brown bug) that it would likely be easier to rely on visual memory.

Procedures

After receiving parental permission and participant assent, participants took part in the inclusionary and descriptive testing. These sessions were run by trained research assistants who worked in teams. Testing sessions took place at children’s schools, after-school placements, libraries, homes, or at the University. After eligibility was confirmed, children played the experimental computer games¹. Testing sessions lasted for roughly one hour and took 3–5 sessions per child.

Participants were trained on the fast mapping game using a known animal (a rabbit) and a familiar dinosaur (T-Rex). During the training, the game was explained to the children using pre-made animations and recordings. Children needed to prove that they understood what the icons represented and how the game worked by getting all the features of the rabbit and T-Rex correct. During training, they receive pre-recorded verbal feedback explaining why they were correct or incorrect. If a child got an answer incorrect, the vignettes were replayed before asking the child to answer again in order to ensure that their mistake was not due to memory load. This was different than during the game, when the vignette was only played once. However, we needed to ensure all participants understood the task, and what the icons meant. All children were able to pass the training. Children always played the games in the same order: Experiment 1 first and Experiment 2 last. After completion of each session children chose a small prize and stickers.

Scoring

The dependent variable for the visual fast-mapping task was ratio correct: that is, the number of attempts a child needed to choose each feature divided by the number of features correctly identified. Thus, a perfect ratio would be 1.0 (1 attempt needed to get 1 feature correct), and the higher the ratio, the worse the performance. Recall that children were given four attempts to choose the correct response and had four options. Thus, someone who had not even seen the initial stimuli could choose the correct answer by the fourth trial simply using systematic trial and error responding.

¹Children played three games, but we only report on two of them in this manuscript. Both of the games we report on also included additional measures not directly related to the visual fast mapping, thus those measure are also not reported on in this manuscript.

Analysis

In order to determine if children with SLI have domain general processing deficits as evidenced by less efficient fast mapping visual features than TD peers, we planned to look for a main effect of group. In order to determine if children with SLI had an impaired focus of attention, we planned to look for a group $\times$ complexity interaction, in which children with SLI would have significantly higher ratios (less efficient performance) than children with TD on the high complexity condition.

RESULTS FOR EXPERIMENT ONE

Using the design described above (mixed design ANOVA for ratio), we examined visual fast mapping when provided with high and low complexity visual input. Ratio was chosen as opposed to number of trials to criterion because ratio accounts for trials on which a child did not reach criterion in a direct way. We found a significant main effect for group ($F(1, 48) = 5.40, p = .02, \eta_p^2 = .10$), for complexity ($F(1, 48) = 5.60, p = .02, \eta_p^2 = .10$), and for feature ($F(3, 144) = 28.62, p < .01, \eta_p^2 = .37$). There were no significant interactions related to group (group $\times$ complexity ($F(1, 48) = 0.42, p = .51, \eta_p^2 < .01$); group $\times$ feature ($F(3, 144) = 1.16, p = .32, \eta_p^2 = .02$); group $\times$ feature $\times$ complexity ($F(3, 144) = 0.50, p = .67, \eta_p^2 = .01$). The main effects were clarified using Tukey post hoc tests with $p < .05$ for between group comparisons and t-test with Bonferroni corrections ($p < .008$) for within group comparisons for feature. Children with TD had a lower overall ratio of attempts to correct responses ($M = 1.20, SD = .10$) than the SLI group ($M = 1.34, SD = .27$). All groups were less efficient on the high complexity condition ($M = 1.31, SD = .24$) than on the low complexity condition ($M = 1.21, SD = .23$). Color ($M = 1.62, SD = .56$) stood out as the most difficult concept to map, being more difficult than shape ($M = 1.20, SD = .22$), what the dinosaur ate ($M = 1.14, SD = .25$), and what the dinosaur crushed ($M = 1.13, SD = .21$).

We checked to see which of our descriptive measures might have been correlated with average ratio. Ratio was significantly negatively correlated with age ($r = -.30, p < .05$) and maternal level of education ($r = -.33, p < .05$), meaning that the older the child, or the higher the maternal level of education, the lower, or more efficient, the ratio. The groups were equivalent in terms of age (SLI $M = 7;11, SD = 6$ months; TD $M = 7;10, SD = 6$ months). However, they did differ on maternal level of education (SLI $M = 13.28, SD = 1.4$; TD $M = 16.00, SD = 1.67$). Therefore, we re-ran the analysis with maternal level of education entered as a co-variate. It was found to be non-significant ($F(1, 45) = 0.62, p = .43, \eta_p^2 = .01$), however, when it was included as a covariate, the main effect of group difference became non-significant ($F(1, 45) = 1.21, p = .27, \eta_p^2 = .02$). Measures of vocabulary ($r = -.18$), nonverbal intelligence ($r = -.06$), language ($r = -.23$), and word reading ($r = -.22$) were all nonsignificant at $p > .05$.

Brief discussion

Using a visual fast mapping task that was designed to be as free from verbal encoding as possible, we found that children with SLI were less efficient at fast mapping and retrieving visual information than TD peers. This provides evidence for a domain general deficit involving visual working memory in children with SLI, and possibly the visuospatial

sketchpad in Baddeley's (2003) account of working memory. There was no interaction effect related to the complexity of the input. Such an interaction would provide evidence pointing to problem with focus of attention; specifically, a difficulty ignoring irrelevant stimuli. Instead, *all* participants found the visually complex condition to be more challenging than the low complexity condition. In order to explore the role of visual memory capacity, we ran an additional experiment that asked the same group of participants to fast-map eight semantic features, thus taxing their capacity.

Experiment 2

Experiment 2 was completed by the same participants who took part in Experiment 1. All children completed Experiment 2 after Experiment 1, with an intervening experiment (not reported on in this manuscript) in between. For the majority of participants, these experiments took place on different days. Experiment 2 was similar in design to Experiment 1, with two distinct differences: 1) all vignettes were high complexity and 2) children were asked to fast map eight semantic features. As in Experiment 1, they were always asked about shape first. This was followed by a screen asking them to choose the dinosaur's color, what it ate, and what it stepped on. This was followed by a separate screen asking them to select the dinosaur's foot print shape, eye color, the appearance of its burp cloud, and the dinosaur's pattern. The training was adjusted so that participants were trained on the additional icons that would be used to test memory for footprint shape, eye color, burp cloud, and pattern. The scoring was identical to the first experiment.

Analyses

In order to determine if children with SLI have domain general processing deficits as evidenced by less efficient fast mapping visual features than TD peers, we planned to look for a main effect of group. Given that this experiment was designed to tax visual working memory capacity, a group difference could also provide evidence of an actual limited capacity for visual working memory in children with SLI.

RESULTS for EXPERIMENT TWO

We included data from all but one of the participants in Experiment 1, whose data were lost due to technical problems. As in Experiment 1, we were interested in possible differences for the ratio of correct attributes to attempts. To examine this we used a mixed ANOVA with group (SLI, TD) as the between-group variable and visual feature (shape, color, what was eaten, what was crushed, footprint, eye color, burp cloud, pattern) as the within-group variable. There were no group differences ($(F(1, 47) = 2.61, p = .11, \eta_p^2 = .05)$). The actual average ratio for the SLI group was 2.0, $SD = .57$, indicating that it took children an average of two attempts to get each feature correct. The average ratio for the TD group was 1.76, with a standard deviation of .42. There was a significant effect for features ($(F(7, 329) = 36.00, p < .01, \eta_p^2 = .43)$), but no significant interaction between group and feature ($(F(7, 329) = 1.75, p = .09, \eta_p^2 = .03)$). T-tests adjusted for multiple corrections ($p < .001$) showed that shape, footprint shape, what was eaten and what was crushed were all equivalent, and significantly easier than burp cloud, pattern, and color, which were equivalent. All features were easier than eye color. Details about visual features can be found in Table 2.

The fact that three of the four easiest features were present in the first group of features prompted us to look to see if there might be differences between performances on the first versus second half of the task. A t-test for dependent samples ($t = -7.01$, $p < .01$) showed that children were significantly less efficient ($M = 2.24$, $SD = .82$) on the second half of the task than on the first half of the task ($X = 1.53$, $SD = .30$). Therefore, we re-ran our ANOVA separately by time.

For the four features we asked about first (shape, color, what was eaten, what was crushed), we did find significant effects for group ($F(1, 47) = 6.97$, $p = .01$, $\eta_p^2 = .12$) and feature ($F(3, 141) = 65.46$, $p < .01$, $\eta_p^2 = .58$). These were mediated by a group $\times$ feature interaction ($F(3, 141) = 9.68$, $p < .01$, $\eta_p^2 = .17$). Tukey unequal N post hoc testing with $p = .01$ revealed that the SLI group was less efficient than the TD group. T-tests with Bonferroni corrections for multiple comparisons ($p < .008$) showed that color was significantly more difficult than the other features, and a planned comparison ($F(1, 47) = 13.43$, $p < .01$, $\eta_p^2 = .22$) showed that the SLI group was significantly less efficient on color than the TD group. See Figure 3.

In contrast, for the four features we asked about in the second half of the experiment (footprint, eye color, pattern, burp) there were no significant findings for group ($F(1, 47) = 1.10$, $p = .29$, $\eta_p^2 = .02$) or group $\times$ feature ($F(3, 141) = .76$, $p = .51$, $\eta_p^2 = .01$). There was a significant effect for feature ($F(3, 141) = 26.49$, $p < .01$, $\eta_p^2 = .36$) and post hoc testing using t-tests with Bonferroni corrections for multiple comparisons ($p < .008$) showed that eye color ($M = 3.24$, $SD = 1.98$) was significantly more difficult than other features (pattern $M = 2.28$, $SD = 1.06$; burp $M = 2.04$, $SD = .82$) while footprint shape ($M = 1.38$, $SD = .46$) was significantly easier than other features.

We checked to see which of our descriptive measures might have correlated with average ratio for the first half of the task, where group differences were apparent. There were significant differences at $p < .05$ for vocabulary ($r = -.33$) and language scores ($r = -.36$) but not for age ($r = -.22$), maternal level of education ($r = -.27$), nonverbal intelligence ($r = -.14$), or word reading ($r = -.17$). The only measure significantly correlated with performance on the second half of the task was age ($r = -.31$) and performance on the first half of the task ($r = .55$).

DISCUSSION

Different Conditions, Different Findings

In Experiment 1, the manipulation of the visual complexity of the stimuli was meant to investigate whether or not children with SLI might have domain general problems related to visual working memory and if those problems might be related to choosing the appropriate focus of attention. The task was designed so that children were always asked about the same features, thus, to be most efficient, children should attend solely to those features, regardless of the intrigue of the others. The results did not support poor focus of attention as an issue for only the SLI group. In fact, both groups were equally distracted by the irrelevant features as evidenced by the main effect for complexity, with all children showing better efficiency on lower versus higher complexity vignettes.

However, the SLI group scored lower than the TD group overall, suggesting poor general visual working memory, with no outstanding problems with particular types of visual stimuli (of the 4 presented) relative to peers. However, poor is a relative term. The effect size for the group difference is relatively small. For example, Alt's (2011) study that found phonological working memory differences in a similar group of participants had an effect size of $\eta_p^2 = .33$. The effect sizes for visual working memory that we found are comparable to those of Bavin et al.'s (2005) findings for visual short term memory deficits, and are decidedly smaller than those found for verbal working memory deficits.

Given the results of the first experiment, we would expect to see a group difference in the second experiment, even if we would expect the difference to be smaller than one we would find for a verbal task. If children with SLI have impaired visual working memory skills, then certainly they should perform worse when their working memory capacity is taxed by asking them to remember twice as many distinctive visual features. However, this was not the case. When we examined how they performed on all eight features, there were no group differences. Was it possible that the SLI group simply improved enough with practice (Experiment 2 was actually their third experience with a semantic feature fast mapping task) to perform equivalently to peers? This is unlikely. We compared the average ratio for the high complexity condition in Experiment 1 to the average ratio for the same four semantic features in Experiment 2 (all high complexity vignettes) and found that both the SLI ($t = -2.75, p = .01$) and TD groups ($t = -2.91, p < .01$) performed significantly worse on Experiment 2 than Experiment 1. In other words, there was no improvement to explain the lack of a group difference.

We then looked at the significant findings for features in Experiment 2. There were three levels of difficulty, and they were not equally distributed across the first and second half of the experiment. There were significantly different (i.e., lower) levels of performance for all children between the first and second half of Experiment 2. This could be due to the fact that the semantic features that were asked about in the second half of the experiment were fundamentally more difficult than those asked in the first half. This is most likely the case for eye color, which was more difficult than all other features, and was perceptually the least salient, given the relatively small area of the dinosaurs' eyes. Intrinsic difficulty is certainly a possibility for the other second-half features. It is not something that we can definitively rule out because the design intentionally followed the same order of presentation: shape, choice of three features from Experiment 1, choice of remaining four features. We knew that eight features would be challenging to recall, but we wanted to be sure that we taxed the capacities of all participants. By providing the response screens in a fixed order, we provided contextual support that we hoped would strike a balance between truly taxing capacity and making the task too challenging.

Alternatively, it may be the case that capacity limitations for working memory combined with the additional interference from the completion of the first half of the task would have led to lower accuracy regardless of the order of specific semantic features. Fatigue is another possible explanation for this pattern of findings. These hypotheses will need to be empirically tested. In any case, it was clear that the second half of the task was significantly more challenging than the first half of the task for all participants.

When we examined Experiment 2 by halves, the group difference reappeared, but only for the first half. In this case, an interaction was driving the group difference: the children with SLI were notably worse than their peers on what had been the most difficult feature in Experiment 1: color. There are several possible interpretations for this finding. First, children with SLI do have visual working memory deficits when compared to children with TD, but not in all scenarios. From the overall results, we cannot say that children with SLI have a distinctly smaller visual memory capacity than children with TD. What does seem clear is that increasing memory load had a negative effect on the overall efficiency for all children, as evidenced by the overall lower accuracy on the same features tested in Experiments 1 versus 2.

There seems to be a bit of a confound in interpretation in terms of task difficulty. On the one hand, when the task was clearly more difficult (i.e. second half of the task), children with SLI performed equivalently to peers. This should not be taken to imply that a task has to be at floor level to find equivalence. Both groups learned at least 90% of the semantic features in Experiment 2 and only needed an average of 1.76–2.0 attempts to do so. Even if we look at just the second half of Experiment 2, the average ratio was 2.24 (SD = .82). While significantly worse than other conditions, this is still not floor-level performance. This particular task was more challenging for both groups of participants. However, the fact that there were not overall differences for group argues against a pure visual capacity limitation problem for children with SLI.

However, difficulty does seem to be a factor in what separates the groups for the first part of Experiment 2. In Experiment 1, children with SLI were less efficient than peers with TD across the board. In Experiment 2, the group difference was clearly driven by a specific feature: color- which was the most difficult feature to remember in Experiment 1. It may be the case that the overall increased difficulty of Experiment 2 particularly exacerbated the relative difficulty of color for the SLI group. Other researchers have found that children with LI are particularly vulnerable to task difficulty (Windsor et al., 2008). The isolation of this feature's difficulty may provide some insight into what makes it difficult. One explanation could be that color was particularly susceptible to interference. A review of Figures 1 and 2 will show that this task involved a lot of colors. The burp cloud alone in this example contains at least four colors. Additional colors are introduced in the response phase leading to potential for increased interference for color, compared to other features. Although the task was not set up to explicitly test levels of possible interference, this is one possible interpretation of the results. This is also not the first report of vulnerability to interference for children with SLI, who have been shown to be more susceptible to interference for novel word forms (Alt & Suddarth, 2012) and in processing (Mainela-Arnold, Evans, & Coady, 2008; Seiger-Gardner & Brooks, 2008) than their unimpaired peers.

Correlations

Correlations, although solely suggestive, can help spur thinking about what might explain differing outcomes on the different tasks. The first experiment was not correlated with vocabulary or language skills, which provides converging evidence that task performance was likely not reliant on lexical skills. We chose to examine maternal level of education

(MLE), which is a proxy for socioeconomic status and can often be a contributing factor to performance on language tasks (e.g. Hoff & Tian, 2005). It was significantly negatively correlated with performance, meaning that the higher the level of education a child's parent had, the lower, or more efficient, their ratio was. When MLE was included as a covariate, the main effect of group was no longer significant in Experiment 1. We have to interpret this finding with caution, given that we did not specifically design the study to manipulate MLE. One possible explanation could be that children who have mothers with higher levels of education might also have more experience with touchscreen technology and computers in general. This could lead to more efficient performance due to greater familiarity with the technology and less distraction from the novelty of the technology. This is speculation, but might explain why this correlation was found in Experiment 1, and not in Experiment 2, by which time all children had practice with the technology.

The fact that there were different correlations for the first and second halves of Experiment 2 makes it likely that, in fact, children may have been using different types of strategies for each portion of the task. Language and vocabulary scores *were* negatively correlated with performance on the first half of Experiment 2, meaning that children with stronger vocabulary and language scores had lower, or more efficient, ratios on the task. We come back to the issue of color and lexical labels. This was feature that drove the between group difference on Experiment 2. It is possible that children with TD did use lexical labels just for color on this portion of the task. To be successful, children would need to remember a phrase (e.g. "bright red dino") to deal with the issue of different shades, and colors showing up in different categories. Again, this is speculation, given that this was not something we explicitly tested. Clearly, the ideas about what these correlations signify require additional, explicit testing to determine if they are accurate interpretations.

In context of the literature

In the introduction, we pointed out the disparity in the literature regarding the status of visuospatial processing in children with SLI. The findings from the experiments in this manuscript are akin to a microcosm of the literature: some evidence for deficits, but other situations in which no deficits emerge. The literature includes a wide range of processing measures including both short-term and working memory, and examinations of visual processing as well as spatial processing, which can function independently (e.g. Baddeley, 2007). We will focus on comparisons of our findings to the studies that match most closely: those examining visual working memory processing.

That leaves us with those studies finding no visual working memory deficits for children with SLI (Alloway & Archibald, 2008; Archibald & Gathercole, 2006; 2006) and those who did find deficits (Windsor et al., 2008). First, the deficits Windsor et al. (2008) found were related to processing speed rather than to accuracy. Not having examined speed, we are left to examine why we may have found differences in accuracy when other groups have not. The most obvious difference is in the nature of the task. The groups that found no differences used tasks that primarily asked children to recall location and order of items, or that asked them about items that were largely unidimensional (e.g. shape was the relevant construct). Our tasks presented children with increased challenges in terms of type of

information to remember (i.e. multiple visual features) and increased opportunities for interference.

In terms of disambiguating the findings from previous visual fast mapping studies (Alt et al., 2004; 2006), we did find evidence suggesting primary visual fast mapping deficits in children with SLI. We found visual fast mapping deficits in this study in older children, compared to the preschoolers in Alt et al. (2004; 2006). This suggests that visual fast mapping deficits continue to be an issue into the early school years. However, the deficits are clearly not profound enough to manifest in every visual fast mapping scenario.

Conclusions

The hope when we set up our predictions was that we would verify if there were visual working memory issues for children with SLI, and if so, that we could narrow down the source of the problem. While we did find some evidence for visual working memory issues for children with SLI, and thus more support for domain general deficits, we were not able to support either of the hypotheses about specific sources of the difficulty. In manipulations meant to tax focus of attention and capacity limitations, children with SLI did not perform significantly worse than peers. Susceptibility to interference, which might be another way to examine focus of attention, seems to be a likely candidate for the between group differences, but given that the experiment was not set up to specifically examine this hypothesis, no firm conclusions can be made. More work needs to be done to tease apart what exacerbates visual processing difficulties in children with SLI, and just as importantly, to determine where their strengths in this domain lie. What does seem clear based on smaller effect sizes and the number of situations in which visual working memory deficits are not present, is that visual working memory deficits in children with SLI are less severe than verbal working memory deficits.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Figure 1.
Example of Low and High Complexity Conditions for Task 1

Figure 2.
Example of Response Screen and Response Screen with Feedback

Figure 3.
Performance of Groups by Visual Feature on First Half of Experiment 2 with Black Line
Indicating Perfect Efficiency and Higher Numbers Indicating Lower Efficiency

Table 1

Participants' Demographic Features and Means and Standard Deviations on Inclusionary and Descriptive Testing

	SLI		TD	
	Mean	Standard Deviation	Mean	Standard Deviation
Age (years; months)	7;11	0;6	7;10	0;6
* Maternal Level of Education	13.28	1.40	16.00	1.67
* CELF-IV	74.87	5.87	103.60	8.31
* PPVT-IV	90.64	10.51	112.32	9.75
* K-ABC-II	97.08	13.79	113.12	17.36
* TOWRE	87.33	15.31	104.04	14.79

* groups are significantly different from each other at $p < .05$

Note: CELF-IV= Clinical Evaluation of Language Fundamentals-4th edition; PPVT-IV= Peabody Picture Vocabulary Test- 4th edition; K-ABC-II= Kaufman Assessment Battery for Children- 2nd edition. TOWRE = Test of Word Reading Efficiency

Table 2

Means and Standard Deviations for Ratios for Different Visual Features in Experiment Two

Visual Feature	Mean	Standard Deviation
What was crushed ¹	1.22	.27
Shape ¹	1.27	.30
What was eaten ¹	1.30	.40
Footprint shape ¹	1.38	.46
Burp Cloud ²	2.04	.82
Pattern on Dinosaur's Body ²	2.28	1.06
Color ²	2.32	.88
Eye color ³	3.24	1.98

Features with ¹ were learned more efficiently than features with ² or ³ ($p < .001$). Features with ² were learned more efficiently than features with ³ ($p < .001$).