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Visuo-spatial processing and executive functions in children with specific language impairment

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Abstract

Background—Individual differences in complex working memory tasks reflect simultaneous processing, executive functions, and attention control. Children with specific language impairment (SLI) show a deficit in verbal working memory tasks that involve simultaneous processing of information.

Aims—The purpose of the study was to examine executive functions and visuo-spatial processing and working memory in children with SLI and in their typically developing peers (TLD). Experiment 1 included 40 children with SLI (age=5;3–6;10) and 40 children with TLD (age=5;3–6;7); Experiment 2 included 25 children with SLI (age=8;2–11;2) and 25 children with TLD (age=8;3–11;0). It was examined whether the difficulties that children with SLI show in verbal working memory tasks are also present in visuo-spatial working memory.

Methods & Procedures—In Experiment 1, children's performance was measured with three visuo-spatial processing tasks: space visualization, position in space, and design copying. The stimuli in Experiment 2 were two widely used neuropsychological tests: the Wisconsin Card Sorting Test — 64 (WCST-64) and the Tower of London test (TOL).

Outcomes & Results—In Experiment 1, children with SLI performed more poorly than their age-matched peers in all visuo-spatial working memory tasks. There was a subgroup within the SLI group that included children whose parents and teachers reported a weakness in the child's attention control. These children showed particular difficulties in the tasks of Experiment 1. The results support Engle's attention control theory: individuals need good attention control to perform well in visuo-spatial working memory tasks. In Experiment 2, the children with SLI produced more perseverative errors and more rule violations than their peers.

Conclusions—Executive functions have a great impact on SLI children's working memory performance, regardless of domain. Tasks that require an increased amount of attention control and executive functions are more difficult for the children with SLI than for their peers. Most children with SLI scored either below average or in the low average range on the neuropsychological tests that measured executive functions.

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Keywords

specific language impairment; visuo-spatial working memory; executive functions; attention control

What this paper adds

Children with specific language impairment (SLI) perform more poorly than their typically developing peers on verbal working memory tasks, particularly in tasks with high executive function demands. The present study examined the effect of executive functions on visuo-spatial working memory performance in children with SLI and in their age-matched peers. The aim was to compare children's visuo-spatial processing across tasks that have been reported to require various levels of executive function involvement. The results of the present study show that children's visuo-spatial processing is highly influenced by their attention control. Children with SLI show more difficulty in visuo-spatial tasks with high executive function demands than their age-matched peers. Their weakness in attention switching and inhibition was reflected in frequent perseverations and rule violations. Clinicians, who work with children with SLI, need to consider that these weaknesses have an impact not only on these children's language learning, but also on their non-verbal problem solving performance.

Introduction

Visuospatial working memory and executive functions

One of the most widely cited working memory account in the literature is Baddeley's model (Baddeley 1996, 2000) that consists of domain-specific and domain-general components. The domain-specific systems are responsible for verbal and visuo-spatial storage, whereas the domain-general central executive system monitors the control processes and coordinates the different activities within working memory. One crucial aspect of executive functions is the ability to attend selectively to a stimulus and to inhibit the distraction of other stimuli. The newest component of this model is the episodic buffer that coordinates the different representations within the working memory system and between working memory and other cognitive functions, such as the long-term memory.

The domain-general components in Baddeley's model (central executive and episodic buffer) are similar to the executive attention conceptualization of Engle and colleagues (Engle 2002, Unsworth and Engle 2006). This latter model describes working memory as a ‘subset of activated long-term memory units’ (Unsworth and Engle 2006: 69). The present paper focuses on Engle's (2002) model, which suggests that individual differences in working memory capacity indicate variations in attention control. People with high working memory span show better abilities in attention control. They are able to maintain and quickly retrieve information when it is needed. Retention in working memory depends on both domain-specific skills and domain-general executive functions, but the extent to which these skills influence the effectiveness of retention depends on the person's ability to control attention and on task contexts. There is evidence for a stronger tie between executive functions and visuo-spatial working memory than between executive functions and verbal working memory in adults and in children (e.g. Miyake et al. 2001, Busch et al. 2005). One possible explanation is that verbal storage is assisted by various well-known processes, such as rehearsal, whereas visuo-spatial storage is more dependent on attention control (Hambrick et al. 2005). Age-related changes in visuo-spatial working memory performance are attributed to the interaction between visuo-spatial short-term memory and executive functions. Older children perform better on visuo-spatial tasks than younger participants because of the increase in executive contribution to task performance (Hamilton et al. 2003). There is evidence for dissociation between verbal and spatial working memory in school-age children (Hale et al. 1997). Children perform more poorly on spatial than on verbal working memory tasks that are equally difficult for young adults. Many visuo-spatial tasks require the mental transformation of spatial figures. Mental manipulations place high demands on executive functioning because there is a strong interference between the stimuli and the internal pictures of those items. Participants have to keep the internal representation of a given figure highly active and have to resist interference from the external visual stimuli while performing the mental manipulation (Miyake et al. 2001). Interference control develops through sixth grade, thus younger school-age children show difficulty in tasks involving mental manipulations, such as the Space Visualization task in the current study (Bjorklund and Harnishfeger 1990).

Children with specific language impairment perform more poorly than their peers on various verbal working memory tasks, particularly in those that require simultaneous processing and storage of information (Ellis-Weismer, Evans, and Hesketh, 1999, Montgomery 2000, Marton and Schwartz 2003). These children's visuo-spatial working memory has received relatively little attention in the literature.

Executive functions and SLI

In verbal working memory, children with SLI show difficulty in list recall tasks that target a number of executive functions. These children exhibit different patterns of recall than their typically developing peers. Ordinarily, performance in list recall reveals a preference for the first few items (primacy effect) and for the last few items (recency effect). Children with SLI failed to exhibit primacy and recency effects in various linguistic span tasks (Ellis Weismer et al. 1999, Marton and Schwartz 2003, Marton et al. 2006). These children were not able to switch their attention from encoding to rehearsal and vice versa. They either rehearsed the first stimuli or focused on the new incoming information. This finding indicates a weakness in simultaneous processing of information.

Children with SLI also showed poor performance in attention tasks that required working memory skills (Noterdaeme et al. 2001). In evaluating attention, the authors did not find any differences between the children with SLI and their typically developing peers on simple vigilance tasks, where children had to detect the appearance or presence of a stimulus. In a sustained visual attention task with higher working memory demands, however, the children with SLI made more errors than did the children in the control group. The authors concluded that selective and sustained attentions are particularly impaired in children with SLI when the tasks have high working memory demands. The findings appear to be, at least in part, independent of modality because children's performance pattern was similar across verbal and non-verbal tasks. In addition to verbal working memory, a few recent studies examined non-verbal cognition and/or visuo-spatial working memory in children with SLI. The results of these studies are mixed. Children with SLI performed more poorly than their typically developing peers in visuo-spatial pattern recognition and in paired associates learning. In the latter task, children were tested on matching a stimulus to a particular location (Bavin et al. 2005). In a longitudinal study, children with SLI showed difficulties and slower development in comparison to their typically developing peers in pattern recall (Hick et al. 2005). Further, children with SLI showed poor performance in colour identification using a dual processing paradigm, even when no verbal response was required (Hoffman and Gillam 2004). The study included six tasks with two recall conditions (verbal and spatial) and two presentation rates (slow and fast). The results suggest that the working memory deficit observed in children with SLI is not restricted to the verbal domain. These children have difficulty in coordinating the processing and storage functions across domains. The authors concluded that children with

SLI are not able to disperse efficiently processing across domains, which finding indicates a weakness in executive functions.

Other studies on processing rate also support a weakness in executive functions in children with SLI. These children showed slower responses in visual processing, mental rotation, and motor control relative to typically developing children (Johnston and Ellis-Weismer 1983, Schul et al. 2004). However, in simple tasks, children with SLI did not differ from their peers, e.g. in orienting their attention. Similar to the findings of Noterdaeme et al. (2001), children with SLI did not show difficulties in simple vigilance tests that were not demanding on working memory and executive functions. In contrast to the above findings, in a recent study, Archibald and Gathercole (2006) found comparable results between the children with SLI and their age-matched peers in both visuo-spatial short-term memory and visuo-spatial working memory tasks. What factors are responsible for this discrepancy across findings? One strong candidate for the differences in visuo-spatial processing is executive functions. If these tasks differed in their requirements of executive function and attention control involvement, that may explain, at least in part, the contrast among the results. Other contributing factors are differences in task types and age ranges. As mentioned above, the effectiveness of information retention is highly influenced by one's ability to control attention and by the task context. The aim of the current study was to examine how children with SLI perform in visuo-spatial tasks that vary in their executive function requirements — as suggested by adult data.

Visuo-spatial processing, working memory, and executive functions

Experiment 1 of the current study was designed to examine executive functions in visuo-spatial tasks in children with SLI and TLD. Previous results from adult participants suggested that the essential factors in spatial abilities are efficient executive functions and good maintenance of visuo-spatial representations (Miyake et al. 2001). The authors performed a latent variable analysis using various visuo-spatial tasks — Spatial Visualization, Spatial Relations, and Perceptual Speed — and found that all three tasks are demanding on executive functions and require some degree of temporary visuo-spatial storage. However, the amount of demands on executive functions placed by these tasks differed. The most demanding task was Spatial Visualization because it involved spatial transformation/mental manipulations. The least demanding task was the Perceptual Speed task that only required a brief retention of figures. Experiment 1 of the present study investigated whether children show a similar performance pattern to that of adults' in visuo-spatial tasks. In correspondence to the tests used by Miyake et al. (2001), the three visuo-spatial tasks in the present study were Space Visualization, Position in Space, and Design Copying (Ayres 1979, 1988). The first two tasks resembled the tests used by Miyake and colleagues. The Design Copying task involved different activities than the Perceptual Speed task, but both tests required brief visuo-spatial retention of the stimuli. In both tasks, when participants compare the target and the copied figures, they briefly maintain the visuo-spatial stimuli because they cannot perform the comparisons in a single eye fixation.

A further question was whether children with SLI show a deficit in visuo-spatial processing and in working memory compared to their age-matched peers. Poor performance on visuo-spatial tasks with increasing executive contributions in children with SLI would support the hypothesis that these children's weaknesses in working memory are highly influenced by their executive functions. The following research questions were examined in Experiment 1:

- Does children's performance show a gradual decrease in visuo-spatial tasks that require increased executive contributions similar to adults?
- Do children with SLI perform more poorly on visuo-spatial tasks than their age-matched peers, particularly in tasks with higher executive demands?

- Is there a difference in performance accuracy within the group of children with SLI between those participants who have been reported by their parents and teachers as being more easily distracted and those with good attention skills? Based on the attention control theory (Engle 2002), we expected that the subgroup of children with SLI with reported attention difficulties — but no diagnosis of an attention deficit disorder — would perform more poorly on the visuo-spatial tasks than the other participants.

Experiment 2 was designed to examine further attention control and executive functions in children with and without language impairment. Children were presented with two widely used neuropsychological tests: *Wisconsin Card Sorting Test — 64 Card Version* (WCST; Kongs et al. 2000) and the *Tower of London test* (TOL; Culbertson and Zillmer 2001). In addition to quantitative group differences, we examined whether children with SLI and their typically developing peers show similar error patterns (e.g. time and rule violations, impulsivity, etc.).

Experiment 1

Methods

Participants—Experiment 1 involved two groups (*n*=80) of Hungarian children: 40 children with SLI (5;3–6;10 years) and 40 chronological age-matched peers (5;3–6;7 years). All children with SLI had been diagnosed by a speech–language pathologist as language impaired, with both receptive and expressive deficits. They all attended a special kindergarten program organized for children with language disorder. Children in this special program received both individual and group therapy daily. All daily activities were focused on preparing these children for mainstream education. There is no comprehensive standardized language test in Hungarian, but all children performed about 1.5–2 years below age average on a series of Hungarian language items that targeted their vocabulary, sentence comprehension, and word recall. (See further details on participant profiles in table 1.) All participants' parents and teachers filled out a questionnaire regarding the child's overall learning skills and behaviour. Although it is typical to see disagreements among parents and teachers regarding the child's abilities and behaviour; parents and teachers in this special kindergarten group worked in a very close collaboration, so their judgements regarding these children's overall learning and behaviour did not differ. There were 19 children within the group of children with SLI whose parents and teachers reported a problem with the child's attention control (being easily distracted and/or having a shorter attention span). According to the diagnostic criteria of the American Psychiatric Association's *DSM-IV* (2000), none of these children met the diagnosis of attention deficit disorder with or without hyperactivity (ADHD/ADD).

The control group involved children who were chronological age-matched (within 3 months) peers. None of these children had a history of speech–language delay or disorder. They all attended public school and performed at age-appropriate level in both learning and behaviour. Their parents and teachers reported no history of any learning and/or attention and memory difficulties. (See participant profiles in table 1.)

None of the participants had a history of frank neurological impairment or psychological disturbance. All children were monolingual Hungarian speakers. Each child performed within the normal range on the *Snijders–Oomen Nonverbal Intelligence Test Revised* (SON-R; Snijders et al. 1989) and on the *Goodenough–Harris Drawing* test (Goodenough and Harris 1963). This latter test was administered to every participant because one of the experimental tasks — Design Copying — involved drawing. Thus, it was important to ensure that none of the participants exhibited any deficit in basic visuo-motor coordination. The focus of this paper is on executive functions and visuo-spatial working memory, therefore the groups were matched on a visuo-spatial short-term memory task (VSTM; Snijders et al. 1989; see details in table 3). The VSTM task was applied to ensure that all participants show age-appropriate visuo-spatial short-term storage. The use of this task is particularly important if we consider that non-verbal IQ scores are likely measuring executive functions to some extent. All children with and without SLI performed within the age-appropriate range on visuo-spatial short-term memory.

Stimuli—Participants were tested with three visuo-spatial tasks: Space Visualization (SV), Position in Space (PS), Design Copying (DC) (Ayres 1979, 1988). The Space Visualization task required that participants mentally rotate wooden blocks to fit pegs into various holes (see the appendix). Children responded by choosing one of two alternatives. Participants were instructed to look at both blocks before making a choice. They were also reminded that moving a block counts as a choice. The task was to find the appropriate block and put it in the form board. The task involved encoding and monitoring of spatial forms, the development of spatial representations, visuo-spatial storage, mental manipulations of various forms, resistance to interference, and response control. The following executive functions were targeted by this task: planning and behaviour monitoring, goal and subgoal maintenance, working memory, and inhibition control. As mentioned above, mental transformations involve inhibition control in the form of resistance to interference between the inner representations of the figures and the external stimuli. The Space Visualization test included 30 problems and was the most demanding on executive functions among the three experimental tasks.

The Position in Space task tests the ability to recognize the spatial relationship between figures. This task included two sections. In the first section, participants were required to match a series of figures to visually similar abstract forms (see the appendix). In this task, children were presented with four different figures as the target and they had to find the identical stimuli among a number of similar, thus distracting visuo-spatial forms. In this first part of the task, both the target and response stimuli were present when participants made their selection. The task required simultaneous processing and good visuo-spatial monitoring skills. In the second section of the same task, participants had to remember a row of figures that had been previously presented. In this second part of the task, the target items were removed before presenting the answer sheet, on which the child had to indicate the correct row of figures among other distracting stimuli. This task included 30 problems. No mental transformation was required to solve these problems, but participants needed good visuo-spatial storage, monitoring skills, and resistance to interference. Therefore, this task also required a high degree of executive contributions.

The third task, Design Copying, focused on the retention of figures. Children were asked to copy lines and abstract figures in given empty spaces. Participants were shown where to start and they were reminded that the lines cannot be erased. To perform well on this task, children needed good visuo-spatial storage and continuous monitoring and updating of their own drawings (see the appendix). Further, the task required planning and goal maintenance. This task was less demanding on working memory than the previous ones because the figures were in sight while the children drew. Although the model was always present, the task involved visual retention because children had to compare their own drawings to the model. This cannot happen in a single eye fixation. The task included 13 designs.

Procedures—All participants were tested in two sessions in their schools. Each session lasted about 45 min. To decrease experimenter bias, different research assistants participated in testing and in data analysis. The experimental tasks were administered according to the test manual (Ayres 1979, 1988). The order of presentation of the tasks was randomized to minimize the learning effect. Instructions were read from the protocol and children's performances were recorded on protocol sheets. Scoring was performed in accordance with the manual. Children's raw scores were converted into *Z*-scores according to the test's manual.

Results

Factorial and univariate ANOVAs were used to analyse the between-groups and the within-group variables. Effect size calculations were based on Cohen's (1988) categories: small effect size: $d=0.2$, medium: $d=0.5$, and large: $d=0.8$.

The overall results showed a main effect for group ($F(1, 234)=21.72$; $p<0.001$; see the descriptive statistical data in table 3), but not for task ($F(2, 234)=0.15$; $p=0.86$) and there was no group × task interaction ($F(2, 234)=0.11$; $p=0.9$). The three visuo-spatial tasks showed a correlation (SV-PS: $r=0.53$, $p<0.001$; SV-DC: $r=0.43$, $p<0.01$; PS-DC: $r=0.7$; $p<0.001$).

Children with SLI performed more poorly than their age-matched peers. A pair-wise comparison of tasks showed a group difference and medium effect sizes for each visuo-spatial task (Space Visualization: $F(1, 78)=6.11$; $p<0.05$; $d=0.53$; Position in Space: $F(1, 78)=4.73$; $p<0.05$; $d=0.49$; and Design Copying: $F(1, 78)=10.87$; $p<0.01$; $d=0.75$). The group differences for the Space Visualization and Position in Space tasks remained after using ANCOVA analyses to control for non-verbal IQ ($F(2, 76)=5.58$; $p<0.05$ for Space Visualization and $F(2, 76)=4.54$; $p<0.05$ for Position in Space). The group difference for Design Copying did not remain significant after controlling for non-verbal IQ ($F(2,76)=0.62$; $p=0.54$). One reason for this loss is that non-verbal IQ is a global score that is likely measuring executive functions, such as planning, monitoring, and updating. This result was not unexpected and this is one reason for matching the groups on visuo-spatial short-term memory.

A second analysis divided the group of children with SLI into two subgroups: children with good attention control (SLI/GA) and children with poor attention control (SLI/PA). The subgroups were established based on data from questionnaires of these children's parents and teachers. The two subgroups did not differ on the visuo-spatial short-term memory test (Snijders et al. 1989; $F(1, 38)=0.18$; $p=0.67$; $d=0.13$; see the means and standard deviations in table 3) that targeted visuo-spatial storage, but required minimal executive function involvement. Thus, if there was a difference between the two subgroups in their performance on the experimental tasks that reflected their executive functions. The subgroups of SLI children with GA and with PA showed significant differences and large effect sizes in Space Visualization ($F(1, 38)=7.68$; $p<0.01$; $d=0.88$) and in Position in Space ($F(1, 38)=7.76$; $p<0.01$; $d=0.89$; see the means and standard deviations in table 3). Children with attention control difficulties performed more poorly than their SLI peers with good attention control in those visuo-spatial tasks that are highly demanding on executive functions in adults. There was no difference between the two subgroups in Design Copying and the effect size was small ($F(1,38)=1.91$; $p=0.18$; $d=0.44$). Children in the SLI/GA subgroup performed similarly to the children with TLD in Space Visualization and in Position in Space. In Design Copying, the two subgroups of SLI did not differ from each other, but both subgroups differed from the children with TLD and the effect sizes were medium to large ($F(1, 59)=5.33$; $p<0.05$; $d=0.62$ for the SLI/GA and TLD groups; $F(1, 57)=14.77$; $p<0.001$; $d=1.07$ for the SLI/PA and TLD groups).

Discussion

The overall results of Experiment 1 showed a group effect; children with SLI performed more poorly than their age-matched peers in all visuo-spatial working memory tasks. In contrast to the findings with similar tasks in adults (Miyake et al. 2001), children's visuo-spatial performance did not differ across tasks in either group. One reason for this finding could be the difference in methods. Although the task descriptions of the present study and of the study by Miyake et al. (2001) indicated similar underlying factors, the tasks differed in their complexity and in the number of problems to be solved. Further, executive functions in these children are still developing and all visuo-spatial tasks were highly demanding on these functions. On the other hand, similar to the results of Miyake et al. (2001), all three visuo-spatial tasks showed a correlation.

The overall group effect indicates that children with SLI performed more poorly than the control participants in each visuo-spatial task. In most cases, their *Z*-scores were either at the low end or outside the average range (−1 + 1; as defined in the test's manual). The results suggest that these children's weakness in working memory is not limited to the verbal domain.

Although none of the children with SLI met the diagnostic criteria for ADHD/ADD; a number of these children showed poor attention control based on parents' and teachers' reports. This result is in line with the findings of Bishop and Norbury (2005). The authors suggest that many children with neurodevelopmental disorders including SLI show clinically significant levels of inattention and hyperactivity. Therefore, we distinguished two subgroups of children with SLI: children with good and with poor attention control. The two subgroups did not differ in visuo-spatial short-term memory, but were clearly distinguishable in visuo-spatial working memory performance on the Space Visualization and the Position in Space tasks. The children with good attention control performed similar to the children with TLD in the above tasks. In contrast, children with a weakness in attention control showed more difficulty in these visuo-spatial working memory tasks. Their scores were outside the average range in both Space Visualization and in the Position in Space tasks.

Although every participant showed an age-appropriate score in drawing (Goodenough and Harris 1963), children with SLI differed from the children with TLD in Design Copying. The two subgroups (SLI/PA and SLI/GA) did not differ from each other in this task. The group difference between SLI and TLD disappeared, however, after controlling for non-verbal IQ. This task required good visual storage and simultaneous processing. These are functions that are represented in non-verbal IQ scores as well. The findings on the Design Copying task need to be further studied. It is possible that the children with TLD had more practice in similar tasks. All children with SLI attended a special programme for children with language impairment. Thus, many of their daily activities focused on speech–language development, whereas the typically developing children may have spent more time on visuo-motor coordination tasks.

The overall findings of Experiment 1 motivated Experiment 2. Experiment 2 investigated executive functions and attention control in children with SLI with two widely accepted neuropsychological tests.

Experiment 2

Methods

Participants—The participants were 25 children with SLI and 25 children with TLD (see the participants' profile in table 4). None of these children participated in Experiment 1. Children in both groups were participants of a larger study (Marton et al. 2006).

All children with SLI had been diagnosed by a speech–language pathologist as having receptive and expressive language deficits. They all received speech–language services at the time of testing. As mentioned in Experiment 1, there is no comprehensive standardized language test in Hungarian, but all children performed about 1.5–2 years below age average on a series of Hungarian language items, such as word recall and sentence comprehension. Every participant showed a normal range of non-verbal IQ on the SON-R test (Snijders et al. 1989). Based on the findings in Experiment 1, children with reported attention control difficulties, even if they were not diagnosed with ADD/ADHD, were excluded from this study. Every child's homeroom teacher was interviewed. These interviews included various questions regarding the child's overall vigilance, sustained attention, and his/her ability to refocus attention. Only children with good attention control were included in this study.

The children with TLD had no history of speech–language and/or learning difficulties. Their academic performance was age appropriate, according to reports from parents and classroom teachers. All participants with TLD scored within the normal range in non-verbal intelligence on the SON-R test (Snijders et al. 1989). None of these children had ever received any special services. All participants were monolingual Hungarian speakers. None of the children had a history of frank neurological impairment or psychological disturbance.

Stimuli—Two widely used neuropsychological tests of attentional executive functions were the stimuli in this experiment: *Wisconsin Card Sorting Test — 64 Card Version* (WCST-64; Kongs et al. 2000) and the *Tower of London* test (TOL; Culbertson and Zillmer 2001). Although both of these tests are complex in nature and load on a number of cognitive skills, they have been found to strongly reflect task/attention switching and simultaneous processing (Miyake et al. 2000).

The WCST-64 measures executive functions with a focus on task switching across changing stimulus conditions. The test includes normative data for ages 6;6–89 years. The stimuli are multidimensional (shape, colour, number), and the subjects are expected to determine which stimulus dimension is relevant. There are four stimulus cards displaying 1 red triangle, two green stars, three yellow crosses, and four blue circles, respectively. The 64 response cards depict different numbers (1, 2, 3 or 4) of coloured (red, yellow, green, or blue) figures (stars, crosses, circles, or triangles).

The task is to match the 64 response cards with a stimulus card that — according to the child — provides the best match. Following each match, children receive feedback from the investigator as to whether the response was correct or incorrect. Participants are never explicitly told what the right sorting principle is. Once children achieve ten correct responses, the investigator changes the sorting principle without telling the child. Based on the feedback received, children have to notice when a change in sorting principle occurs, and from there on, they have to make adjustments. To perform well on this task, children need to identify the relevant dimensions and develop a representation of the problem. Participants need to select a plan, such as sorting according to colour. Then, children have to remember this plan and respond accordingly. Individuals with poor executive functions tend to perseverate on previously rewarded dimensions. Although working memory capacity has an essential role in preventing perseveration and interference from prior items, perseverations may occur for various reasons. One scenario is when the rule changes but the child fails to develop a new plan. Another problem occurs when the child forms a new plan, but fails to carry it out. Thus, perseverations may reflect either representational inflexibility (no plan change) or the lack of response control (Zelazo and Mueller 2002).

The TOL test is an assessment of the ability to maintain actively goals and other task-relevant information in distracting and conflicting contexts. This ability equals the concept of controlled attention (Miyake et al. 2001). Participants are required to move coloured beads from an initial state to a goal state. Participants move the beads on their own tower board with the goal to match the examiner's model. They need to perform mental planning before they execute the task to reach the goal. While rearranging the beads, participants are requested to follow two specific rules: (1) they are not to place more beads on any peg than it will hold; and (2) they cannot move more than one bead at a given time. To succeed on the task, participants also need to make ‘conflict moves’. These are moves that are necessary but at first glance conflict with the final state (e.g. moves that provisionally block the goal peg). To overcome these conflicts, it is essential that participants keep the goals and subgoals active (Miyake et al. 2001). This test includes normative data for children between 7 and 15 years.

Procedures—Participants were tested individually in one session in their schools. The administration and scoring of the WCST-64 and the TOL occurred according to the professional manuals. To decrease experimenter bias, the research assistants that performed scoring and data analysis did not know the participants and their language status.

Results

Three types of scores were used to evaluate children's performances on the WCST-64: total errors, perseverative errors and concept level scores. The results of one-way ANOVAs showed a group effect with each score and the effect sizes were consistently large ($F(1, 48)=17.45$; $p<0.001$; $d=1.18$ for the total errors; $F(1, 48)=9.93$; $p<0.001$; $d=0.89$ for the perseverative errors; $F(1, 48)=14.78$; $p<0.001$; $d=1.09$ for the concept level scores; see the means and standard deviations in table 5). Children with SLI made significantly more errors, showed more perseverations and difficulty with underlying concepts than their age-matched peers. According to the test's norms (Kongs et al. 2000), 44% of the children with SLI performed within the 'impaired' range, 20% below average, and 36% within the average zone. Many of these children were not able to switch once a concept was positively reinforced; this resulted in perseverations. There were also some children with SLI who were unable to develop a clear concept; they kept changing their sorting principle. In contrast, all TLD children's scores fell in the upper range of the average zone and above average (44% high average, 56% above average).

Various scores were calculated and analysed for the TOL: total score, total move, total time, initiation time, execution time, time violation, and rule violation (see the means and standard deviations in table 5). There was a main effect and a medium effect size for the total score ($F(1, 48)=5.14$; $p<0.05$; $d=0.63$). Children with SLI performed with lower accuracy than their age matched peers (48% of the children with SLI performed below the average range; 28% low average, and only 24% showed average performance). The children with TLD showed no difficulty with the task; they all performed within the average range. There was no group difference in the scores for total move, total time, and execution time ($F(1, 48)=0.13$; $p=0.72$; $d=0.1$ for total move; $F(1, 48)=1.65$; $p=0.21$; $d=0.36$ for total time; $F(1, 48)=2.35$; $p=0.13$; $d=0.43$ for execution time). Thus, the overall moves and time for solving the problems were very similar for all children. The initiation time, however, differed between the groups and the effect size was large ($F(1,48)=7.79$; $p<0.01$; $d=0.79$). Children with SLI showed more impulsive behaviours, their initiation times were shorter; children with TLD spent more time on thinking and planning; their initiation times were longer. The two groups showed almost identical scores in time violation ($F(1, 48)=0.001$; $p=0.97$; $d=0.01$), but not in rule violation ($F(1, 48)=27.42$; $p<0.001$; $d=1.48$). Children with SLI frequently violated the basic rules. The total scores and the rule violation scores show that these children had more difficulty with controlled attention and simultaneous goal maintenance than their peers. Children with SLI were less able to keep task-relevant information active in distracting contexts than children with TLD.

Discussion

Children with SLI showed a weakness in flexible task switching in the WCST-64. They produced more perseverative errors than children with TLD. Children with SLI found it difficult to switch from one sorting principle to another when the conditions changed. Once these children received positive feedback for choosing the correct sorting principle, they stayed with that principle even when the need for a new principle was indicated. This resulted in perseveration. Whether the locus of the problem is in forming a new plan following a rule change or in carrying out the newly formed plan is a question for future research. In contrast, the children with TLD showed flexible switching as the task requirements changed. This was reflected not only in their higher overall scores, but also in their higher concept generation and perseveration scores.

The findings on the TOL task indicate mixed results for the children with SLI. Children with SLI performed with more errors in visuo-spatial planning than their peers. Children with SLI made similar number of moves within the given timeframe than their typically developing peers, however, more of their moves were incorrect than that of the children with TLD. Further, there was a group effect in initiation time. Although the groups did not differ in total time, children with SLI showed shorter initiation time. The children with TLD spent more time initially on thinking and planning before initiating the first moves. In contrast, the children with SLI often started the task without thinking it over.

Another group difference occurred in the number of rule violations. Children with SLI violated the basic rules more often than the control children. This result shows their difficulty with simultaneous processing. During testing, we often observed that these children stopped for a moment, rehearsed the rule by whispering it and then continued with the problem solving process. When these children were fully immersed in the problem, they only focused on finding the right solution and forgot about the basic rules. They were not able to rehearse the rule and solve the problem simultaneously. This finding is similar to our previous results on verbal working memory: in list recall, children with SLI either rehearsed the old items or focused on the new incoming items, but were not able to perform both tasks simultaneously (Marton and Schwartz 2003, Marton et al. 2006).

General discussion

This study examined visuo-spatial processing and working memory with a focus on executive functions and attention control in children with SLI and their age-matched peers. The findings of Experiment 1 show a strong impact of attention control on visuo-spatial working memory performance. The children with SLI did not form a homogeneous group in terms of attention control in Experiment 1. Almost half of these children had been reported as being easily distracted, although they did not meet the criteria of ADHD/ADD. These children performed more poorly than their SLI/GA and TLD peers on visuo-spatial working memory tasks that required simultaneous processing of information. The groups, however, did not differ in visuo-spatial short-term memory. All participants showed average visuo-spatial short-term storage capacity. The group differences emerged in the experimental tasks that were highly demanding on executive functions. This finding supports Engle's (2002) attention control theory, in which he argues that working memory performance reflects the ability to control attention. In Space Visualization and in the Position in Space tasks children were required to perform mental transformations and/or remember abstract patterns. To perform well on these tasks, one needs good attention control. The role of simultaneous processing, attention control, and executive functions in visuo-spatial working memory may explain the mixed results in the SLI literature (Bavin et al. 2005, Hick et al. 2005, Archibald and Gathercole 2006). It is possible that the tasks across studies differed in their executive function and attention control demands.

In Experiment 2, children with SLI showed a weakness in attention control and inhibition. The results of the WCST-64 and the TOL indicated that children with SLI have difficulties in generating concepts and switching from one idea to another. These children produced more perseverative errors and rule violations than the children with TLD. Children with SLI also spent less time on thinking and planning before problem solving. All of these issues are related to executive functions and attention control. Previous research showed similar problems in verbal working memory tasks (Ellis Weismer et al. 1999, Marton and Schwartz 2003, Marton et al. 2006) where children with SLI produced a high number of interference errors and showed a deficit in simultaneous processing of information. Those interference errors indicated problems in inhibition. The findings of the present study suggest that a weakness in executive functions and in attention control have a great impact on both verbal and visuo-spatial processing and working memory in children with SLI. Future research is needed to sort out the major factors of executive functions that are responsible for these children's weaknesses. We need to examine the relationship between attention control, inhibition, and working memory in children with SLI. The current results show that perseveration is a common error in this group, however, we do not know whether it is caused by a problem in attention switching or by a deficit in inhibition. The current findings on executive functions, attention control, and visuo-spatial working memory reflect multiple deficits, but further research is needed to clarify the relationship among these factors.

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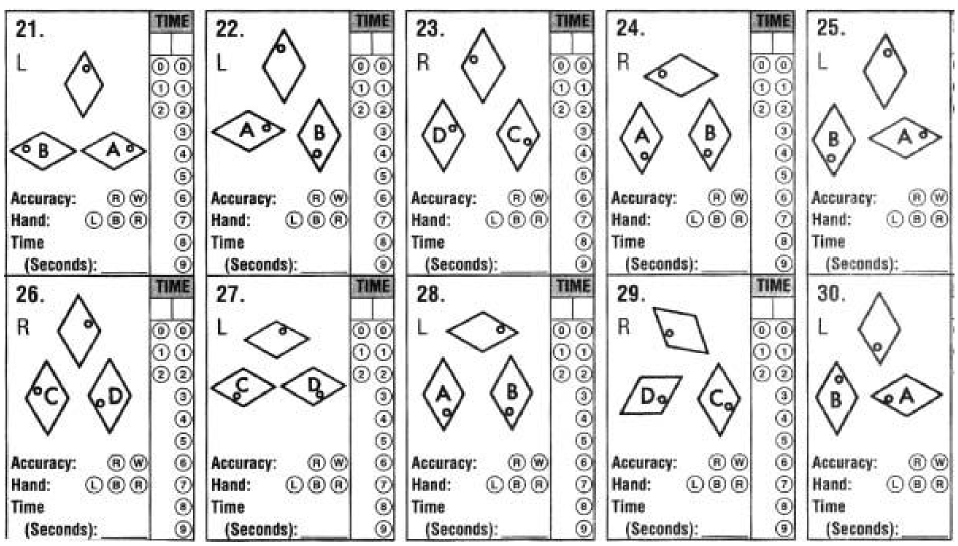
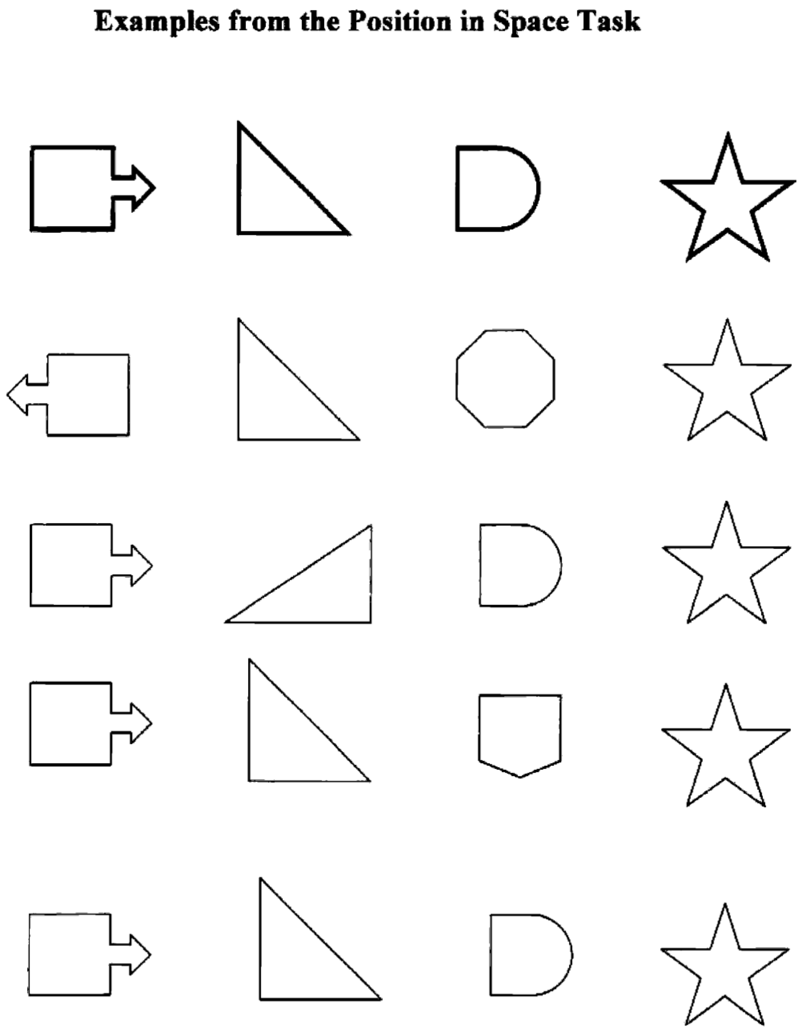
Examples from the Space Visualization task



Examples from the Position in Space task



Examples from the Design Copying task

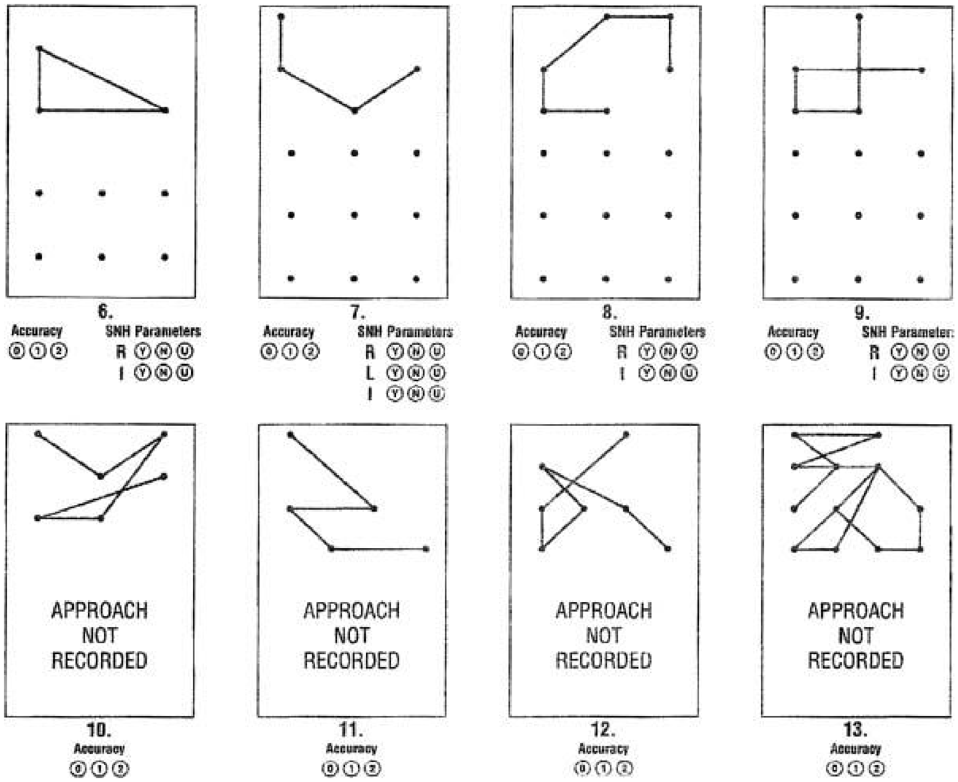


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Table 1

Participant profiles in Experiment 1

	SLI	TLD
Gender: female (*n*)/male (*n*)	12/18	12/18
Age: mean (SD)	6.33 (0.49)	6.36 (0.32)
Non-verbal IQ: mean (SD)	98.02 (9.6)	110.8 (7.3)
Drawing standard score: mean (SD)	94.32 (12.76)	105.35 (8.8)
Visuospatial short-term memory: mean standard score (SD)	24.93 (2.18)	26.5 (2.21)
Verbal working memory: mean per cent correct in listening span (SD)	30.48 (17.23)	87.14 (10.16)
Word recall: mean per cent correct (SD)	61 (8.43)	93 (9.81)
Sentence comprehension (including complex sentences: mean per cent correct (SD)	66.63 (24.37)	87.82 (18.15)

Table 2

Participant profiles for the SLI subgroups (poor attention control and good attention control)

	SLI/PA	SLI/GA
Gender: female (*n*)/male (*n*)	3/16	9/12
Age: mean (SD)	6.21 (0.52)	6.4 (0.46)
Non-verbal IQ: mean (SD)	96.32 (9.45)	99.57 (9.58)
Drawing standard score: mean (SD)	92.53 (8.27)	96.1 (10.44)
Visuospatial short-term memory: mean standard score (SD)	25.11 (2.3)	24.75 (2.05)

Table 3

Means and standard deviations of raw scores and *Z*-scores across visuo-spatial tasks in Experiment 1

	SLI						TLD	
	Total (*n*=40) raw scores	**Total (*n*=40) *Z*-scores**	**SLI/PA (*n*=19) raw scores**	**SLI/PA (*n*=19) *Z*-scores**	**SLI/GA (*n*=21) raw scores**	**SLI/GA (*n*=21) *Z*-scores**	**(*n*=40) raw scores**	**(*n*=40) *Z*-scores**
Space visualization: mean (SD)	12.8 (6.7)	−1 (1.58)	9.74 (5.99)	−1.67 (1.48)	15.57 (6.19)	−0.39 (1.44)	16.15 (5.72)	−0.2 (1.43)
Position in space: mean (SD)	10.43 (5.21)	−1.5 (1.53)	7.84 (3.8)	−1.7 (1.29)	12.76 (5.27)	−0.45 (1.51)	12.7 (4.06)	−0.36 (1.27)
Design copying: mean (SD)	5.73 (4.1)	−1 (1.12)	4.42 (3.17)	−1.37 (1.16)	6.9 (4.89)	−0.86 (1.15)	9.15 (4.41)	−0.16 (1.11)

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Table 4

Participant profiles in Experiment 2.

	SLI	TLD
Gender: female (*n*)/male (*n*)	8/17	8/17
Age: mean (SD)	9.9 (0.82)	9.8 (0.79)
Non-verbal IQ: mean (SD)	108.3 (11.72)	117.16 (9.22)
Verbal working memory: mean per cent correct in listening span (SD)	55.27 (17.87)	93.18 (7.98)
Word recall: mean per cent correct (SD)	65.37 (17.38)	91.68 (8.28)
Sentence comprehension (including complex sentences: mean per cent correct (SD)	71.57 (16.74)	92.49 (6.78)

Table 5

Means and standard deviations of standard scores in the WCST-64 and TOL tests in Experiment 2

	SLI raw scores	SLI standard scores	TLD raw scores	TLD standard scores
WCST: total errors: mean (SD)	27.96 (10.22)	88.72 (15)	17.12 (8.73)	109.68 (20.1)
WCST: perseverative errors: mean (SD)	13.92 (8.71)	96.48 (26.09)	8.2 (4.95)	119.64 (25.89)
WCST: concept level score: mean (SD)	27.76 (12.95)	88.52 (14.36)	40.4 (11.53)	105.52 (16.81)
TOL: total score: mean (SD)	2.56 (1.23)	88 (12.17)	3.24 (0.97)	95 (9.93)
TOL: total Move: mean (SD)	41.32 (12.62)	89.44 (15.73)	43.12 (14.18)	87.84 (15.73)
TOL: total time: mean (SD)	308.6 (142.38)	97.04 (14.98)	267.2 (90.99)	102.08 (12.68)
TOL: initiation time: mean (SD)	17.16 (6.32)	81.04 (4.36)	24.48 (9.33)	95.12 (5.86)
TOL: execution time: mean (SD)	291.8 (140.6)	95.2 (14.79)	243.16 (86.76)	101.2 (12.79)
TOL: time violation: mean (SD)	0.96 (1.65)	101.84 (16.93)	0.88 (1.01)	101.68 (13.68)
TOL: rule violation: mean (SD)	1.56 (1.36)	77.6 (17.26)	0.28 (0.46)	98.56 (10.12)