Analogical reasoning in children with specific language impairment:

Evidence from a scene analogy task

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Abstract

Analogical reasoning is a human ability that maps systems of relations. It develops along with relational knowledge, working memory, and executive functions such as inhibition. It also maintains a mutual influence on language development. That is why some authors have taken a greater interest in the analogical reasoning ability of children with language disorders, and more specifically of children with Specific Language Impairment (SLI). These children seem to have weaker analogical reasoning abilities than their aged-matched peers without language disorders. Following cognitive theories of language acquisition, this analogical deficit could be one of the causes of language disorders in SLI, especially of the productivity ones. To confirm this deficit and its link to language disorders, we use a scene analogy task to evaluate the analogical performance of children with SLI and compare them to children of the same age and same linguistic abilities. Results show that children with SLI perform worse than their age-matched peers, but similar to their language-matched peers. They seem to be more influenced by an increase of the task's difficulty. The link between language disorders and analogical reasoning in SLI can thus be confirmed. A connection with the hypothesis of limited processing capacity in SLI is also considered.

Keywords: Specific Language Impairment, Language acquisition, Analogical reasoning

INTRODUCTION

Analogical reasoning in human cognition

Analogical reasoning is a human ability that allows us to map two situations, a source situation and a target one, according to the relational structure they enclose. For example, we can compare an atom with the solar system, given that the electrons revolve around the nucleus, as the planets revolve around the sun (Gentner, 1983). Analogical reasoning is a powerful tool for acquiring knowledge by different mechanisms: inference projection (from the source to the target domain), schema abstraction, difference detection and re-representation (which allows for improvement in the match by a slight modification of the relations' representations) (Gentner & Smith, 2013).

Analogical reasoning concerns the mapping of systems of relations. The attributes, or features, of the elements composing the relations should not be taken into account in making the correspondences. In our previous example, the fact that the sun and the nucleus of an atom do not look alike does not undermine the power of the analogy. However, it seems easier for children to draw an analogy, when the elements to be matched have certain features in common (Gentner & Colhoun, 2010). In fact, a close match with objects sharing relational and perceptual similarities allows children to learn gradually about more distant and even abstract relational commonalities. This process is called progressive alignment (Kotovsky & Gentner, 1996).

The influence of relational knowledge

Analogical reasoning begins in early development, or as soon as children have the relational knowledge required to process a specific analogical task (Goswami & Brown, 1990). According to Goswami's relational familiarity theory (Goswami, 1992), if a child does not have the knowledge needed to solve the task, he would fail and choose an answer at random. To the contrary, if a child possesses this knowledge, he will be able to solve an analogical task at an early age.

Gentner claims that analogical reasoning is available as soon as the child has the knowledge required to solve the task (Rattermann & Gentner, 1998). Contrary to Goswami, a child can go through a relational shift (Gentner, 1988): if he does not have knowledge of the relation in question, he will solve the task according to the perceptual features, shared by the two situations. With the necessary knowledge, he will be able to reason according to the relational structure.

Working memory and inhibition

However, relational knowledge is a necessary but insufficient condition to reason analogically (Richland, Morrison, & Holyoak, 2006). Working memory is another essential component of analogical reasoning. If we follow Baddeley's model of working memory (1986), it appears that the central executive and phonological loop are required to solve verbal analogies. To solve figural analogies, the central executive and visuo-spatial sketchpad are required, as well as the phonological loop to a lesser extent (Morrison, Holyoak, & Truong, 2001). Thus, if the central executive or phonological loop is preoccupied with an interfering task, participants will solve analogies using perceptual instead of relational similarities (Waltz, Lau, Grewal, & Holyoak, 2000).

Working memory is also central in the processing of relational complexity (Viskontas, Morrison, Holyoak, Hummel, & Knowlton, 2004; Richland et al., 2006). Relational complexity refers to the number of elements included in a specific relation. For example, a relation can be binary ('a cat chasing a mouse') or ternary ('a dog chasing a cat that is chasing a mouse'). According to Halford (1993), unary relations can be processes at one year-old, binary at two years-old, ternary at five and quaternary at eleven years-olds. Thus, the ability to process higher level of relational complexity in analogical tasks develops along with the maturation of working memory (Richland et al., 2006).

Inhibition is a central component of analogical reasoning, as it allows us to attend to the relation between two different situations, instead of considering irrelevant similarities, such as the perceptual or semantic (Thibaut, French, & Vezneva, 2010a; b). In this way, inhibition permits reason about relations, even if they are in competition with the perceptual or semantic features (Thibaut et al., 2010a; b). Thus, the maturation of inhibitory control, with that of working memory, underlies children's adult-like analogical reasoning ability.

Analogical reasoning and language development: a mutual influence

Analogical reasoning maintains a mutual influence on language development. First, language can help solve an analogy: relational language learning helps children focus on relational similarities and improve their performance in an analogical task. Some authors (Kotovsky & Gentner, 1996; Simms, 2013) taught children to sort analogical task items into categories based on relational words, such as 'even' or 'middy' (for an ABA pattern), and 'more and more' or 'lefty' (for an ABB pattern). After this training, the authors showed that children could improve their performance, even for those items containing cross-dimensional relations or conflictual information.

Other authors found that the effect of relational learning can be different according to the relational term used. Son, Smith, Goldstone, and Leslie (2012) compared the effects of training with arbitrary non-words (like 'koli' for an ABA pattern), iconic non-words ('koliko') or schema-evoking words ('sharing') pertaining to the categorisation performance of analogical items. It appeared that iconic non-words and schema-evoking words allowed children to focus on the items' relational structure, with schema-evoking words leading to greater performance. Christie and Gentner (2014) showed that associating items with the words 'same' or 'different' allowed three and four-year-old-children to improve their analogical performance. Language is, therefore, a way to improve analogical reasoning through relational language learning and categorisation.

Analogical reasoning is also involved in language development (Gentner & Namy, 2006). Analogy plays a role in vocabulary acquisition from the outset: it is the comparison of several exemplars of a new word that permits us to extract taxonomic or functional commonalities and to apply the word to new exemplars (Gentner & Namy, 1999; Taverna & Peralta, 2012; Augier & Thibaut, 2013). If a young child is shown a bicycle labelled as ‘blicket’, and is asked to find another ‘blicket,’ he will choose the perceptually similar object (such as glasses). However, if he sees two ‘blickets’ (the bicycle and a tricycle), he will choose the functionally similar object (a skateboard) (Gentner & Namy, 1999). It is a comparison of several instances that leads to structural alignment, which in turn allows him to focus on relational similarities instead of perceptual ones (Gentner & Namy, 1999; Taverna & Peralta, 2012).

Second, analogical reasoning permits acquisition of grammar (Gentner & Namy, 2006): making analogies leads to abstract constructions (constructions being units of language that vary in complexity and abstractness, Tomasello, 2009) and use novel items in a construction (Bybee, 2001). These statements have been verified through artificial grammar learning paradigms: seven-month-old infants are able to abstract a pattern they hear and apply it to new forms (Gomez & Gerken, 1999; Marcus, Vijayan, Bandi Rao, & Vishton, 1999). Goldwater, Tomlinson, Echols, and Love (2011) suggested that structural priming (i.e. repetition of the same structure across different utterances) is equivalent to making an analogy between utterances. To conclude, one core mechanism of analogical reasoning, structural alignment, is central to grammar acquisition and word learning (Gentner & Namy, 2006).

Analogical reasoning in children with language disorders

Given the link between analogical reasoning and language development, it is not surprising that some authors have taken an interest in the analogical ability of children with language disorders. Nippold, Erskine, and Freed (1988) focused on the influence of intelligence: children with language disorders had poorer analogical performance than their age-matched (A-match) peers in three types of analogy tasks (a problem solving task, a verbal analogy task, and a perceptual one); however, these differences disappeared when non-verbal IQ was controlled between groups. Furthermore, according to Masterson, Evans, and Aloia (1993), language abilities have more influence on the resolution of verbal analogies than cognitive abilities. They found that children with language disorders had poorer analogical performance than their A-match peers, but similar performance to their language-matched (L-match) peers, language ability being the best predictor of analogical performance.

More recently, some authors (Leroy, Parisse, & Maillart, 2012; Leroy, Maillart, & Parisse, 2014) examined the analogical performance of children with SLI; this is a severe and persistent language impairment in children with a preserved non-verbal intelligence. It is a neurodevelopmental disorder, which is not due to a hearing impairment, a neurological disorder, or an oro-motor dysfunction (Leonard, 2014). Leroy et al. (2012) used an A:B::C:D paradigm: children had to complete a sequence of geometric forms according to two sequences previously presented. The authors found that children with SLI performed worse than their peers of the same age and same non-verbal IQ. Moreover, the difference between the two groups was large, especially when there was no perceptual similarity to support the relational similarities. In another study (Leroy et al., 2014), the authors used the same paradigm with sequences of forms without semantic content (non-linguistic modality) and with sequences of syllables (linguistic modality). Here again, children with SLI had poorer performance than their A-match peers and were more impaired when there was no perceptual similarity in the linguistic modality. Contrary to previous studies that considered analogical difficulties to be a consequence of language disorders, Leroy et al. (2012; 2014) and their findings suggested the opposite: the analogical impairment seen in children with SLI could be one cause of their language disorders. This assumption is consistent with language specificities observed in SLI: those children have poor productivity (i.e. the ability to use novel items in specific schemes, Bybee, 2010) and tend to highly depend on received input (Jones & Conti-Ramsden, 1997). They also seem to have problems abstracting construction schemes and applying them to new instances. Given the influence of analogy on language development (Bybee, 2010), these difficulties could therefore be due to an analogical reasoning impairment.

Objectives of the study

The aim of this study is to assess analogical reasoning impairment of children with SLI, along with a task that has not been frequently used for children with language disorders, a scene analogy task. This task is different from the classical A:B::C:D task, as it contains real-life scenes from which the child must extract a specific relation. This task allows us to measure accurately the impact of both relational complexity and perceptual distraction on children's performance: while Leroy et al. (2012; 2014) brought to light the decrease of SLI children's analogical performance when there was no perceptual similarities to support relational ones, we want to evaluate the impact of perceptual contradictory information and of varying relational complexity levels on the resolution of analogies. It allows us to evaluate more accurately the variety of analogies with which children can be faced, some of them requiring working memory and inhibition resources to a larger extent. As working memory and inhibition weaknesses have been largely documented in SLI (Vissers, Koolen, Hermans, Scheper, & Knoors, 2015), varying the involvement of these functions permits a complete and precise evaluation of analogical reasoning in SLI. Furthermore, we compare performance of SLI participants to that of control children, matched in age and nonverbal IQ on the one hand and in a language measure on the other hand. To our knowledge, only one study of analogical reasoning, using verbal analogies (Masterson et al., 1993), proposed both of these matchings. We intend to compare the performance of SLI children matched in chronological and in linguistic age in a nonverbal analogical task, what will bring additional data about the link between language and analogical reasoning in a population of children with language disorders.

Our hypotheses follow:

- Children with SLI would show poorer performance than their A-match peers in a scene analogy task.
- Children with SLI would have similar performance to their L-match peers.
- Leroy and collaborators' data (2012; 2014) indicate that children with SLI would be more influenced by an increase in the task's difficulty, especially by the addition of perceptual distractors.

METHOD

Participants

Twenty children with an SLI diagnosis (14 boys and 6 girls, between 6;11 and 12;6 years) were recruited from 'language classes' in special needs schools in the French-speaking region of Belgium. The assessment of their intellectual and linguistic abilities confirmed the diagnosis of SLI, given Leonard's criteria (2014): children with SLI had a non-verbal Intelligence Quotient (IQ) (Echelle non verbale d'intelligence de Wechsler, Wechsler & Naglieri, 2009) above 82 and were -1.25 SD below the age-appropriate mean on at least two of the six language tasks described below. They did not have any hearing or oro-motor impairment and had no history of neurological disorder. All were monolinguals. Two of them could not be matched with age-controlled children due to difficulty recruiting control children corresponding both in age and nonverbal IQ.

The three major components of language, both in reception and production, were assessed: phonology, vocabulary, and morphosyntax. We evaluated receptive language with a non-word discrimination task (Epreuve Lilloise de Discrimination Phonémique*,* Macchi et al., 2012) in phonology, a word designation task (Evaluation du Vocabulaire en Images Peabody, Dunn, Thériault-Whalen, & Dunn, 1993) in vocabulary and a sentence designation task (Epreuve de COmpréhension Syntaxico-SEmantique*,* ECOSSE, Lecocq, 1996) in morphosyntax. For production aspects, we used three tasks of the L2MA2 (Batterie langage oral, langage écrit, mémoire, attention (2nd edition)*,* Chevrie-Muller, Maillart, Simon, & Fournier, 2010) or of the ELO (Evaluation du Langage Oral, Khomsi, 2001) for younger participants: a word or non-word repetition task in phonology, a word denomination task in vocabulary, and a sentence repetition task in morphosyntax.

Two control groups were recruited from French-speaking schools. The first group (*N* = 18, 6 boys and 12 girls, no gender difference with the SLI group, *Fisher p* = 0.094) or A-match controls were selected, having the same chronological age (+/- 6 months) and non-verbal IQ (+/- 8 points) as children with SLI; they were average or above average on different language measures. As in table 1a, they had similar age and non-verbal IQ as those with SLI, but differed in all language measures.

Insert table 1a here

The second group (*N* = 20, 12 boys and 8 girls, no gender difference with the SLI group, Fisher *p* = 0.73) was comprised of L-match subjects, who had the same language abilities as the SLI group, based on sentence comprehension performance (ECOSSE, Lecocq, 1996). These children were on average two years younger than those with SLI. As seen in table 1b, they differed on non-verbal IQ ($t(36) = -2.55$, $p = 0.015$) and all standardised scores of language measures, except the number of errors in ECOSSE (Lecocq, 1996) and raw scores of EVIP (Dunn et al., 1993). One of the girls from the L-match control group was discarded due to a misunderstanding of the instructions.

Insert table 1b here

None of the children from either control group was born premature, had a history of neurodevelopmental/neurological disorder, or had oral language disorders, other than articulation disorders. They had never repeated a year in school and were all monolinguals.

Informed consents were obtained from parents of all recruited children. The local Research Ethics Committee gave approval for this study, conducted according to guidelines of the Helsinki Declaration.

Materials and Procedures

To evaluate participants' analogical reasoning ability, we used a scene analogy task designed by Richland et al. (2006). This task was composed of 20 trials, each consisting of two black and white line-drawing images, presented one above the other. Both images portrayed a scene with a specific relation (for example 'a cat chasing a mouse' and 'a boy chasing a girl'). In the top picture, an arrow pointed to one element (the cat) and the child was required to point to the matching element in the bottom picture, according to the role played by the two elements in the relation (the boy). The scene analogy stimuli varied according to two dimensions: relational complexity and presence (or not) of a perceptual distractor. The items contained binary or ternary relations ('a cat chasing a mouse' versus 'a dog chasing a cat that is chasing a mouse'), with or without a perceptual distractor (figure 1).

Insert figure 1 here

The scene analogy task was administered on a 17-inch laptop computer with the E-Prime 2.0 software (Psychology Software Tools Inc., 2012, Pittsburgh, PA). The instructions were highly explicit: we explained the relations in two sample problems and added three practice trials portraying a binary or a ternary relation. Feedback was given and instructions repeated if necessary, but no feedback was given during test trials: the child pointed to his/her answer, the experimenter wrote it down and went to the next trial. After completion of the whole task, we asked each child to explain how he/she found the answer for the five most difficult items (ternary relation/perceptual distractor condition). According to Richland's protocol, four versions of the task were used and counterbalanced, so that each child was confronted with each relation once, as well as five trials of each condition. We excluded items succeeded at by less than 5% or more than 95% of participants. Only one item (succeeded at by 98% of children) was excluded from the analyses.

To evaluate the influence of inhibitory control and working memory on analogical reasoning, we administered two additional tasks. We measured the inhibition ability with a 'Go-NoGo' task (Geurten, Catale, & Meulemans, 2016): the children had to push the space bar when they saw a red cat on the screen and withhold from responding whenever a grey cat appeared. There were 40 trials presented for 350 ms with interstimulus intervals ranging from 1900 to 4100 ms. The task was administered using E-Prime 2.0 (Psychology Software Tools Inc., 2012, Pittsburgh, PA) on a 17-inch laptop computer. Instructions appeared on the screen and were read to the child. Eight example trials were completed, followed by test trials. No feedback was given for the test trial. Analyses were based on median reaction times to the 'Go' stimulus. Working memory ability was evaluated with the digit span task, administered according to standardised procedure (Wechsler, 2005): the child repeated a sequence of digits of increasing length, first forward and then backward. The span corresponded to the longest sequence to be repeated backward. All children completed three tasks in one session.

RESULTS

Comparisons with respect to the A-match group

Accuracy scores

A mixed factorial ANOVA with Distraction (2) x Relational complexity (2) as within-subject factors and Groups (SLI and A-match) as a between-subject factor was performed, based on the percentage of correct responses (i.e. relational answers). This revealed a main effect of distraction ($F(1, 34) = 19.2$, $p = 0.0001$) and relational complexity ($F(1, 34) = 16.3$, $p = 0.0003$), with the no-distractor and binary relation conditions performed better than the distractor and ternary relation conditions. This is consistent with previous studies using this task in typically- (Richland et al., 2006; Richland, Chan, Morrison, & Au, 2010) and atypically-developing children and adults (Krawczyk et al., 2010; Morsanyi & Holyoak, 2010). The ANOVA also revealed a significant main effect of group ($F(1, 34) = 6.15$, $p = 0.018$), as the children with SLI exhibited poorer performance than A-match peers. As seen in figure 2, there was also a slight trend toward a three-way interaction between Group, Distraction, and Relational complexity ($F(1, 34) = 2.95$, $p = 0.095$).

Insert figure 2 here

Errors

We separately analysed errors according to whether they were of a relational or perceptual nature, as summarised in table 2. Relational errors refer to the selection of the wrong element in the correct relation, while perceptual errors refer to the selection of the perceptual distractor. The first 2 (Group) x 2 (Distraction) x 2 (Relational complexity) ANOVA performed on the percentage of relational errors revealed a significant main effect of relational complexity ($F(1, 34) = 21.2$, $p < 0.0001$), and shows ternary relation items leading to more relational errors. The analysis revealed a main effect of group ($F(1, 34) = 4.77$, $p = 0.036$), so that children with SLI making more relational errors than the A-match control group. There was a trend toward effect of distraction ($F(1, 34) = 3.16$, $p = 0.084$), as items without a distractor led to more relational errors. No significant interactions were found (all $p > 0.10$).
The second ANOVA performed on the percentage of perceptual errors did not yield a significant main effect of either relational complexity ($F(1, 34) = 0.22$, $p = 0.64$) or group ($F(1, 34) = 0.34$, $p = 0.56$). However, there was a significant interaction between Relational complexity and Group ($F(1, 34) = 9.22$, $p = 0.005$): we conclude that children with SLI made more perceptual errors in the ternary than in the binary relation items, while no difference was encountered for the A-match control group.

Insert table 2 here

Answers' justification

In order to more thoroughly understand how the children resolved the task, we asked them how they figured out the correct answer for the five most difficult items (i.e. items with a distractor in the ternary relation condition). We counted when the child explained his correct answer, citing three elements of the relation (versus citing only two elements or using another explanation based on spatial cues). We analysed these results with a Fisher test: the proportion of these explanations was significantly different between the two groups; children with SLI used justifications with three elements of the relations less frequently (11.1% of the time) than their peers (60.8% of the time) ($p < 0.0001$). This difference can be due to the language disorders of children with SLI or to a difficulty processing ternary relations. It could also be due to both, processing and expressing ternary relations demanding too much cognitive resources for children with SLI who would simplify the task by selecting two elements among the three present in the relation.

Comparisons with respect to the L-match group

Accuracy scores

A mixed factorial ANOVA with a 2 (Distraction) x 2 (Relational complexity) within-subject factors and Group (SLI and L-match groups) as a between-subject factor, was performed with percentage of correct responses. It revealed a main effect of distraction ($F(1, 36) = 10.0$, $p = 0.003$) and relational complexity ($F(1, 36) = 33.24$, $p < 0.0001$), indicating better performance with the no-distractor trial and binary relation. The main effect of group was not significant ($F(1, 36) = 0.006$, $p = 0.94$). There was a significant interaction for relational complexity and group factors ($F(1, 36) = 4.11$, $p = 0.050$): figure 3 shows that children with SLI had decreased performance with increasing relational complexity ($p = 0.0002$). This pattern seems less pronounced in the L-match control group ($p = 0.012$).

Insert figure 3 here

Errors

The data are summarised in table 3. A 2 (Group) x 2 (Distraction) x 2 (Relational complexity) mixed factorial ANOVA was performed on the percentage of relational errors. It revealed significant effects of relational complexity ($F(1, 36) = 20.7$, $p < 0.0001$), and distraction ($F(1, 36) = 7.79$, $p = 0.008$); items measuring ternary relation and the no-distractor were more frequently subject to relational errors. The main effect of group ($F(1, 36) = 0.61$, $p = 0.44$) and all interactions were not significant. The mixed factorial ANOVA performed on the percentage of perceptual errors did not yield any significant effect or interaction.

Insert table 3 here

Answers' justification

We also analysed the proportion of correct answers' justification, containing the three-element relations with a Fisher test: it revealed no significant difference between the two groups. Although children with SLI seem to use these types of explanations less often (10.6% of the time) than their L-match peers (21.6% of the time), the difference is not statistically significant ($p = 0.18$). Here again, language seems to take an important part in the ability solving ternary relations items. However, as SLI children display an important decrease of performance when relational complexity increases, it is also possible that they have a specific difficulty in processing ternary relations items.

Working memory and inhibition

We perfomed a mixed ANCOVA using a 2 (Distraction) x 2 (Relational complexity) as within-subject factors, group (SLI and control groups) as a between-subject factor, and backward digit span and 'Go-NoGo' task's median reaction time as covariates. It revealed a main effect of group ($F(1, 43) = 4.13$, $p = 0.048$), span ($F(1, 43) = 5.01$, $p = 0.030$) and reaction time ($F(1, 43) = 7.92$, $p = 0.007$). We observed no other main effect or interaction. However, we found the influence of working memory and inhibition on analogical performance, in addition to the group effect.

DISCUSSION

According to our results, different hypotheses were partially encountered: children with SLI performed worse than their A-match peers, making more relational errors. This confirms the analogical deficit of children with SLI found in other studies: Leroy et al. (2012; 2014) showed that those children performed worse than their A-match peers in an A:B::C:D analogical task in both linguistic and non-linguistic modalities. Our results support this conclusion since the analogical reasoning deficit extends to a task using real-life scenes and varying along relational complexity and perceptual distraction levels. Furthermore, children with SLI have similar global performance to their L-match peers and justify their answers invoking the three elements of ternary relations as frequently as the L-match group. Even if this last data might be explained by an inability to process ternary relations items appropriately, the results support the assumption of a link between language and analogical reasoning in SLI (Masterson et al., 1993). However, the direction of this link is still unclear: as language use improves analogical reasoning (Christie & Gentner, 2014), language disorders could cause an analogical reasoning impairment in SLI. To the contrary, cognitive theories of language development, like the usage-based model (Bybee, 2001), assume that analogy is a core mechanism of language development: it allows for creativity and productivity in language by the use of known structures in novel utterances. Moreover, creativity and productivity are impaired in children with SLI: they use a high proportion of the same verbs as their mother, indicating an important input dependency (Conti-Ramsden & Jones, 1997). In addition, they use a limited variety of verbal forms compared to younger siblings (Jones & Conti-Ramsden, 1997). It is possible that an analogical deficit causes language disorders in children with SLI, limiting their language creativity and productivity.

Regarding our last hypothesis, it seems that children with SLI have specific trouble processing items with a higher level of difficulty: they are more impaired than their L-match peers by the relational complexity increase. To a lesser extent, they tend to have weaker performance than their A-match peers, when a high level of relational complexity and a perceptual distractor are present. They also make more perceptual errors for ternary relation items than binary relation ones (while this pattern is not encountered in A-match participants). This deficit processing at a higher level of difficulty has already been reported in other studies using variations in perceptual similarities: Leroy et al. (2012; 2014) found that children with SLI had more diminished performance with the decrease of perceptual similarities than their A-match peers in linguistic and non-linguistic analogical tasks. Consistent with these findings, the present data show that children with SLI have specific difficulties processing higher levels of relational complexity, especially when associated with a perceptual distractor. These difficulties could be related to the hypothesis of a processing capacity impairment in SLI. According to some authors (Im-Bolter, Johnson, & Pascual-Leone, 2006), SLI could be explained by a limited processing capacity: if a task is more demanding in terms of processing load, SLI children will have more difficulty in solving it. Thus, complicating or adding items, as well as using time constraints, overload their resources and impair their performance in linguistic or non-linguistic tasks. This hypothesis explains the language disorders, but also links these disorders to others difficulties seen in SLI, such as slowed processing speed (Miller, Kail, Leonard, & Tomblin, 2001), the working memory deficit (Montgomery, 2000), or the executive function impairment (Im-Bolter et al., 2006). The presence of higher-level relational complexity and perceptual distraction could have overloaded the processing skills of children with SLI, diminishing their performance to a larger extent than their peers. Moreover, as in other studies (Thibaut et al., 2010a), we saw an influence of working memory and inhibition on analogical reasoning. A connection between impairment of processing skills, working memory, inhibition, and analogical reasoning in SLI is therefore plausible.

However, there are some limitations to our study. First, our groups are relatively small, and there are matching procedure issues: SLI and L-match groups differ on non-verbal IQ, which could have had an influence on the results, as a link between IQ and analogical reasoning might exist (Nippold et al., 1988). Second, questioning the children about how they solve some of the items was interesting for an insight into the reasoning of the participants. However, it did not allow us to thoroughly analyse their related strategies. Using an analogical task with an articulatory suppression secondary task could permit us to identify the use of verbal strategies in SLI and control children: verbal strategies could explain the analogical impairment in SLI and its link to language disorders. Moreover, studies using eye-tracking technology could bring new insights into the patterns of visual exploration during such analogical reasoning tasks in children with SLI. Studies have already shown that differences exist in solving analogies between children of different ages, as well as between children and adults (Thibaut & French, 2016): children are less efficient in their items exploration and organise their search around different terms, compared to adults.

CONCLUSION

This study aimed at analysing the analogical reasoning ability of children with SLI, using a task with real-life scenes, in which participants must extract a specific relation and deal with different levels of relational complexity and perceptual distraction. Comparing children with SLI to A-match peers, we confirmed their analogical reasoning impairment. Moreover, as no global differences were encountered between SLI and L-match children, we can assume that this impairment is linked to their language disorders. However, further studies would be necessary to clarify the direction of this link: are language disorders causing the analogical reasoning impairment or is it the opposite, as recent studies and theories have suggested (Bybee, 2001; Gentner & Namy, 2006; Leroy et al., 2012; 2014)? It also seems that children with SLI are more impaired than peers when the task's complexity increases. This can be linked to the hypothesis of a limited processing capacity in SLI (Im-Bolter et al., 2006). Additional experiments should be carried on using, for example, manipulation of cognitive load, articulatory suppression, or eye-tracking technology in order to bring additional data out for the solving of analogical tasks in SLI.

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REFERENCES

Augier, L., & Thibaut, J.-P. (2013). The benefits and costs of comparisons in a novel object categorization task: Interactions with development. *Psychonomic Bulletin & Review*, *20*, 1126–1132.

Bybee, J. (2001). *Phonology and language use*. Cambridge, England: Cambridge University Press.

Bybee, J. (2010). *Language, usage and cognition.* Cambridge, England: Cambridge University Press.

Chevrie-Muller, C., Maillart, C., Simon, A.-M., & Fournier, S. (2010). *Batterie langage oral, langage écrit, mémoire, attention (2de éd.).* Montreuil, France: ECPA.

Christie, S., & Gentner, D. (2014). Language helps children succeed on a classic analogy task. *Cognitive Science*, *38*(2), 383–397.

Conti-Ramsden, G., & Jones, M. (1997). Verb use in specific language impairment. *Journal of Speech & Hearing Research, 40*(6), 1298–1313.

Dunn, L. M., Theriault-Whalen, C. M., & Dunn, L. M. (1993*). Echelle de vocabulaire en images peabody.* Toronto, Canada: Psychan.

Gentner, D. (1983). Structure mapping: A theoretical framework for analogy. *Cognitive Science*, *7*(2), 155–170.

Gentner, D. (1988). Metaphor as structure mapping: The relational shift. *Child Development, 59*(1), 47-59.

Gentner, D & Colhoun, J. (2010). Analogical processes in human thinking and learning. In B. Glatzeder, V. Goel, & A. Müller (Eds.), *Towards a theory of thinking* (pp. 35–48). Berlin, Germany: Springer Berlin Heidelberg.

Gentner, D., & Namy, L. L. (1999). Comparison in the development of categories. *Cognitive Development*, *14*(4), 487–513.

Gentner, D., & Namy, L. L. (2006). Analogical processes in learning. *Current Directions in Psychological Science*, *15*(6), 335–361.

Gentner, D. & Smith, L. A. (2013). Analogical learning and reasoning. In D. Reisberg (Ed.), *The Oxford handbook of cognitive psychology* (pp. 668–681). Oxford, England: Oxford University Press.

Geurten, M., Catale, C., & Meulemans, T. (2016). Involvement of executive functions in children's metamemory. *Applied Cognitive Psychology, 30*(1), 70-80.

Goldwater, M. B., Tomlinson, M. T., Echols, C. H., & Love, B. C. (2011). Structural priming as structure-mapping: Children use analogies from previous utterances to guide sentence production. *Cognitive Science*, *35*(1), 156–170.

Gomez, R. L., & Gerken, L. (1999). Artificial grammar learning by 1-year-olds leads to specific and abstract knowledge. *Cognition*, *70*(2), 109–135.

Goswami, U. (1992). *Analogical reasoning in children*. Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Halford, G. S. (1993). *Children's understanding: The development of mental models.* Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Im-Bolter, N., Johnson, J., & Pascual-Leone, J. (2006). Processing limitations in children with specific language impairment: The role of executive function. *Child Development, 77*(6), 1822-1841.

Jones, M., & Conti-Ramsden, G. (1997). A comparison of verb use in children with specific language impairment and their younger siblings. *Journal of Speech, Language and Hearing Research, 40*, 1298-1313.

Khomsi, A. (2001). *ELO: Evaluation du langage oral.* Paris, France: ECPS.

Kotovsky, L., & Gentner, D. (1996). Comparison and categorization in the development of relational similarity. *Child Development*, *67*(6), 2797–2822.

Krawczyk, D. C., Hanten, G., Wilde, E. A., Li, X., Schnelle, K. P., Merkley, T. L., … Levin, H. S. (2010). Deficits in analogical reasoning in adolescents with traumatic brain injury. *Frontiers in Human Neuroscience*, *4*, 1–13.

Lecocq, P. (1996). *L'ECOSSE: Une épreuve de compréhension syntaxico-sémantique.* Villeneuve-d'Ascq, France: Presses Universitaires du Septentrion.

Leroy, S., Maillart, C., & Parisse, C. (2014). Analogical mapping across modalities in children with specific language impairment (SLI). *Research in Developmental Disabilities*, *35*(9), 2158–2171.

Leroy, S., Parisse, C., & Maillart, C. (2012). Analogical reasoning in children with specific language impairment. *Clinical Linguistics and Phonetics*, *26*(4), 380–395.

Macchi, L., Descours, C., Girard, E., Guitton, E., Morel, C., Timmermans N., & Boidein, F. (2012). *Epreuve lilloise de discrimination phonologique (ELDP)*. Retrieved from http://orthophonie.univ-lille2.fr/orthophonistes/test-a-disposition-des-orthophonistes.html

Marcus, G. F., Vijayan, S., Bandi Rao, S., & Vishton, P. M. (1999). Rule learning by seven-month-old infants. *Science*, *283*(5398), 77–80.

Masterson, J. J., Evans, L. H., & Aloia, M. (1993). Verbal analogical reasoning in children with language-learning disabilities. *Journal of Speech and Hearing Research, 36,* 76-82.

Miller, C. A., Kail, R., Leonard, L. B., & Tomblin, J. B. (2001). Speed of processing in children with specific language impairment. *Journal of Speech, Language and Hearing Research, 44,* 416-433.

Montgomery, J. W. (2000). Verbal working memory and sentence comprehension in children with specific language impairment. *Journal of Speech, Language and Hearing Research, 43*(2), 293-308.

Morrison, R. G., Holyoak, K. J., &Truong, B. (2001). Working-memory modularity in analogical reasoning. In J. D. Moore & K. Stenning (Eds.), *Proceedings of the Twenty-Third Annual Conference of the Cognitive Science Society* (pp. 663–668). Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Morsanyi, K., & Holyoak, K. J. (2010). Analogical reasoning ability in autistic and typically developing children. *Developmental Science*, *13*(4), 578–587.

Nippold, M. A., Erskine, B. J., & Freed, D. B. (1988). Proportional and functional analogical reasoning in normal and language-impaired children. *Journal of Speech and Hearing Disorders, 53,* 440–448.

Psychology Software Tools, Inc. (2012). *E-Prime 2.0*. Retrieved from http://www.pstnet.com

Rattermann, M. J., & Gentner, D. (1998). More evidence for a relational shift in the development of analogy: Children's performance on a causal-mapping task. *Cognitive Development*, *13*, 453–478.

Richland, L. E., Chan, T. K., Morrison, R. G., & Au, T. K. F. (2010). Young children's analogical reasoning across cultures: Similarities and differences. *Journal of Experimental Child Psychology*, *105*, 146–153.

Richland, L. E., Morrison, R. G., & Holyoak, K. J. (2006). Children's development of analogical reasoning: Insights from scene analogy problems. *Journal of Experimental Child Psychology*, *94*(3), 249–273.

Simms, N. K. (2014). Overcoming the object bias in analogical development: Encoding time, allocation of attention, and relational knowledge. *Dissertation Abstracts International: Section B: The Sciences and Engineering*, *75*(1), no pagination specified.

Son, J. Y., Smith, L. B., Goldstone, R. L., & Leslie, M. (2012). The importance of being interpreted: Grounded words and children's relational reasoning. *Frontiers in Psychology*, *3*, 1–12.

Taverna, A. S., & Peralta, O. A. (2012). Comparación e inferencia en la categorización de artefactos no familiares: Un estudio con niños pequeños. *Psykhe*, *21*(1), 21–36.

Thibaut, J.-P., & French, R. M. (2016). Analogical reasoning, control and executive functions: A developmental investigation with eye-tracking. *Cognitive Development*, *38*, 10–26.

Thibaut, J.-P., French, R., & Vezneva, M. (2010a). The development of analogy making in children: Cognitive load and executive functions. *Journal of Experimental Child Psychology*, *106*(1), 1–19.

Thibaut, J.-P., French, R., & Vezneva, M. (2010b). Cognitive load and semantic analogies: Searching semantic space. *Psychonomic Bulletin & Review*, *17*(4), 569–574.

Tomasello, M. (2009). The usage-based theory of language acquisition. In E. L. Bavin (Ed.), *The Cambridge handbook of child language* (pp. 69–88). Cambridge, England: Cambridge University Press.

Viskontas, I. V, Morrison, R. G., Holyoak, K. J., Hummel, J. E., & Knowlton, B. J. (2004). Relational integration, inhibition, and analogical reasoning in older adults. *Psychology and Aging*, *19*(4), 581–591.

Vissers, C., Koolen, S., Hermans, D., Scheper, A, & Knoors, H. (2015). Executive functioning in preschoolers with specific language impairment. *Frontiers in Psychology, 6*, 1–8.

Waltz, J. A., Lau, A., Grewal, S. K., & Holyoak, K. J. (2000). The role of working memory in analogical mapping. *Memory & Cognition*, *28*(7), 1205–1212.

Wechsler, D. (2005). *WISC IV – Wechsler intelligence scale for children – fourth edition*. San Antonio, TX: The Psychological Corporation.

Wechsler, D., & Naglieri, J. (2009). *Echelle non verbale d’intelligence de Wechsler.* Montreuil, France: ECPA.

Table 1a: Age, non-verbal IQ, and language measures for the SLI and A-match groups.

	SLI (n=18)		A-match (n=18)		
	Mean	*SD*	*Mean*	*SD*	*Statistics*
Age *(years)*	9.64	1.63	9.59	1.66	$t(34) = 0.08$
Non-verbal IQ	95.1	9.59	97.0	8.41	$t(34) = -0.65$
ELDP *Raw score*	22.6	3.73	30.5	4.59	$t(34) = -5.70$**
Non-word repetition *Raw score*	1.72	1.13	4.56	1.50	$t(32) = -6.27$**
EVIP *Raw score*	94.8	20.9	126	23.1	$t(34) = -4.18$**
Word denomination *Raw score*	28.0	8.62	43.9	6.81	$t(32) = -5.93$**
ECOSSE *Number of errors*	12.8	6.55	5.78	3.72	$t(27) = 3.97$**
Sentence repetition *Raw score*	3.94	2.51	9.56	0.89	$t(22) = -8.89$**

Note: ** Significant at p-level < .01.

Table 1b: Age, non-verbal IQ, and language measures for SLI and L-match groups.

	SLI (n=19)		L-match (n=19)		
	Mean	*SD*	*Mean*	*SD*	*Statistics*
Age *(years)*	9.85	1.68	7.17	1.86	$t(36) = 4.65$**
Non-verbal IQ	95.10	9.49	103.95	11.79	$t(36) = -2.55$*
ELDP					
Z-score	-2.22	1.16	0.36	0.97	$t(36) = -7.43$**
(Non)word repetition					
Z-score	-1.88	0.71	0.08	0.64	$t(36) = -8.97$**
EVIP					
Raw score	95.58	20.24	90.33	25.85	$t(35) = 0.69$
Z-score	94.63	14.94	115.78	12.65	$t(35) = -4.63$**
Word denomination					
Z-score	-2.09	0.91	0.19	0.65	$t(36) = -8.91$**
ECOSSE					
Number of errors	12.84	6.33	12.95	6.91	$t(36) = -0.05$
Z-score	-1.03	1.10	0.34	0.58	$t(27) = -4.82$**
Sentence repetition					
Z-score	-4.56	1.69	0.25	0.61	$t(23) = -11.7$**

Note: * Significant at p-level < .05, ** Significant at p-level < .01.

Table 2: Mean percentage and standard deviation (SD) of each response type across conditions and groups (SLI and A-match groups).

		No distractor		Distractor	
		Binary relation	Ternary relation	Binary relation	Ternary relation
Correct relational answer	SLI	80.8 SD 21.4	70.3 SD 19.1	77.5 SD 19.3	54.4 SD 23.8
	A-match	94.4 SD 11.5	80.6 SD 14.6	77.2 SD 23.2	70.3 SD 20.0
Relational error	SLI	16.9 SD 18.8	27.2 SD 18.2	11.4 SD 15.8	18.8 SD 17.7
	A-match	4.44 SD 8.56	19.4 SD 14.6	2.22 SD 6.47	20.6 SD 17.6
Perceptual error	SLI	2.22 SD 6.47	0	10.0 SD 14.14	24.4 SD 27.1
	A-match	1.11 SD 4.71	0	19.4 SD 21.8	8.89 SD 14.1
Other	SLI	0	2.22 SD 6.47	1.11 SD 4.71	2.22 SD 6.47
	A-match	0	0	1.11 SD 4.71	0

Table 3: Mean percentage and standard deviation (SD) of each response type across conditions and groups (SLI and L-match groups).

		No distractor		Distractor	
		Binary relation	Ternary relation	Binary relation	Ternary relation
Correct relational answer	SLI	81.0 SD 21.8	67.6 SD 17.3	79.7 SD 18.9	54.2 SD 23.1
	L-match	81.3 SD 16.4	73.7 SD 19.6	70.0 SD 24.2	58.9 SD 22.2
Relational error	SLI	16.8 SD 19.4	30.0 SD 16.8	8.68 SD 14.1	20.5 SD 18.6
	L-match	15.5 SD 13.5	24.2 SD 15.2	8.68 SD 12.4	17.6 SD 15.6
Perceptual error	SLI	2.10 SD 6.31	0	10.5 SD 13.9	23.2 SD 26.9
	L-match	2.10 SD 6.31	1.05 SD 4.59	20.3 SD 25.0	22.6 SD 21.0
Other	SLI	0	2.10 SD 6.31	1.05 SD 4.59	2.10 SD 6.31
	L-match	1.05 SD 4.59	1.05 SD 4.59	1.05 SD 4.59	1.05 SD 4.59

Figure 1

Four versions of a scene analogy task's item: A= binary relation without a distractor, B= binary relation with a distractor, C= ternary relation without a distractor, D= ternary relation with a distractor (Richland et al., 2006).

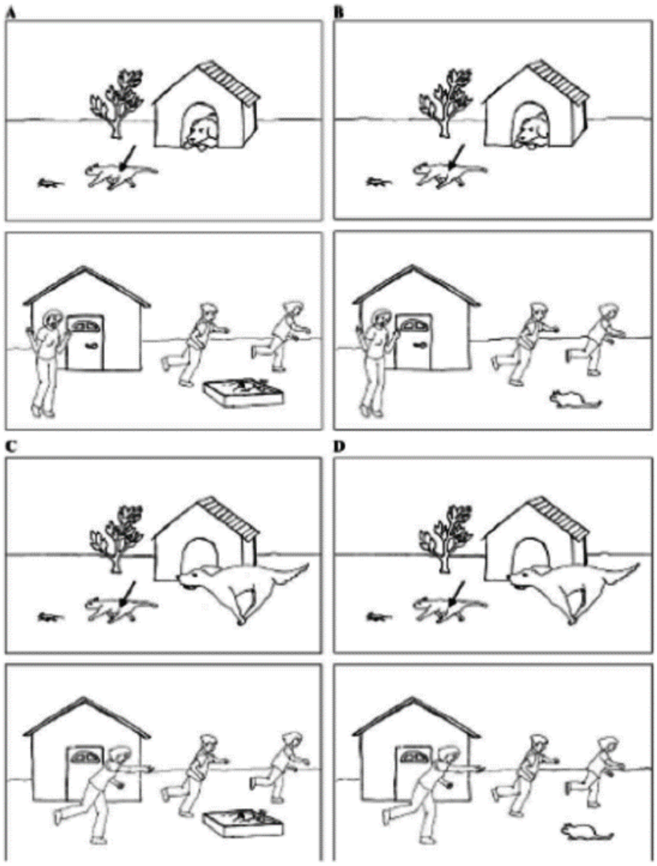

Figure 2

Percentage of correct answers as a function of relational complexity and perceptual distraction across the two groups.

Note: Bars represent the standard error.

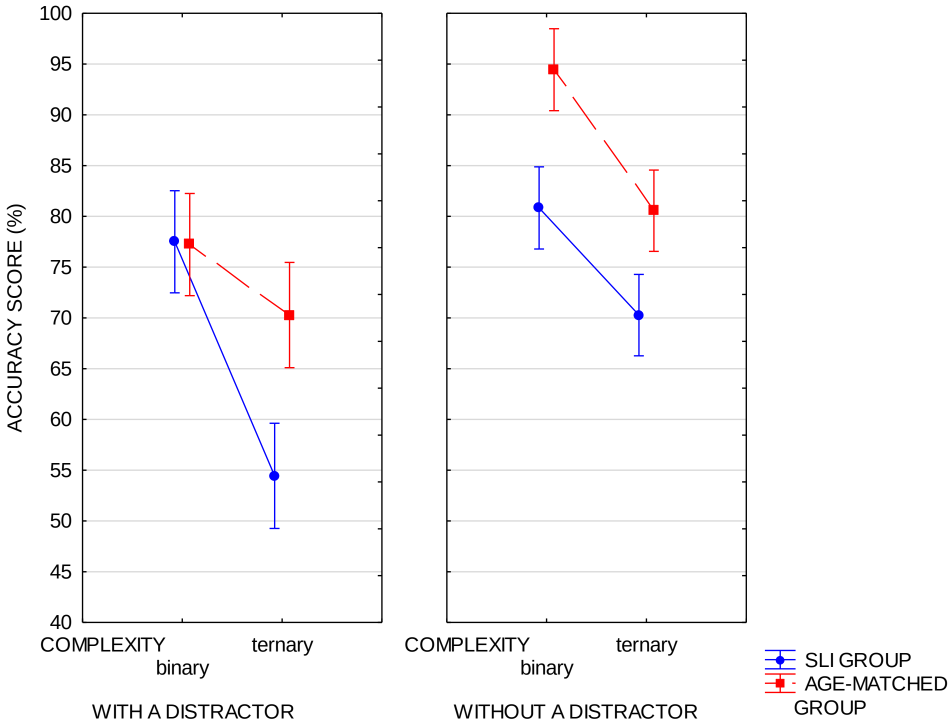

Figure 3

Percentage of correct answers as a function of relational complexity across the two groups.

Note: Bars represent the standard error.