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Syntactic comprehension and working memory in children with Specific Language Impairment, Autism or Down Syndrome

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Abstract

This study examined syntactic assignment for predicates and reflexives as well as working memory effects in the sentence comprehension of children with Specific Language Impairment (SLI), Down syndrome (DS), high functioning Autism (HFA), and Typical Language Development (TLD). Fifty-seven children (35 boys and 22 girls) performed a computerized picture-selection sentence comprehension task. Predicate attachment and reflexive antecedent assignment (with working memory manipulations) were investigated. The results showed that SLI, HFA, and DS children exhibited poorer overall performance than TLD children. Children with SLI exhibited similar performance to the DS and HFA children only when working memory demands were higher. We conclude that children with SLI, HFA, and DS differ from children with TLD in their comprehension of predicate and reflexive structures where knowledge of syntactic assignment is required. Working memory manipulation had different effects on syntactic comprehension depending on language disorder. Intelligence was not an explanatory factor for the differences observed in performance.

Keywords

language disorder; children; syntax; working memory; specific language impairment; autism; Down syndrome

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Despite the increasing number of studies examining syntax in children with various types of language disorders, most have focused on Specific Language Impairment (SLI) and cross-population studies have received little investigative attention (e.g., Bol & Kasparian, 2009; Caselli, Monaco, Trasciani, & Vicari, 2008; Laws & Bishop, 2004; Redmond, 2004;). Understanding the similarities and differences in the syntactic abilities across populations with language disorders will permit a better characterization of each disorder and may also reveal causal connections between language impairments and related abilities.

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The linguistic profiles of the SLI, Down syndrome (DS) and autism spectrum disorder (ASD) populations have been compared primarily in literature reviews of clinical population pairs (e.g., Laws & Bishop, 2004; Rice, Steven, Warren, & Betz, 2005; Williams, Botting, & Boucher, 2008; Ypsilanti & Grouios, 2008). Most studies have used only standardized language tests and focus on expressive language, making language comprehension an even more under-researched area (see Leonard, 2009).

The need for more detailed and controlled comprehension studies is clear, especially for syntax; standardized tests generally group a variety of syntactic structures, and only an overall measure is provided. Thus far, no studies have examined syntactic assignment across these groups. Deficits in structuring syntactic representations may underlie problems in language acquisition and processing, leading to comprehension impairments. In this study, we compared the syntactic assignment in the comprehension of children with SLI, high functioning autism (HFA) and DS, focusing on predicates and reflexive pronouns along with the influence of working memory demands on the latter. We focus on the hierarchical ordering deficit (HOD) account (Cromer, 1978), an historical predecessor of the computational grammatical complexity (CGC) hypothesis (Gallon, Harris, & van der Lely, 2007; Marinis & van der Lely, 2007; van der Lely, 2005; van der Lely & Stollwerck, 1997). This theory aims to explain deficits in SLI and one of the purposes of the present study was to investigate whether it can also be applied to different clinical populations. The HOD account (Cromer, 1978) suggested that children with language impairment do not assign hierarchical structure to sentences, resulting in a *flat* or linear representation. The absence of hierarchically organized structures would account for their overall difficulties with sentence comprehension. For example, if children fail to build the hierarchical structure for the sentence *The pen under the envelope is red*, they might allow the nearest NP (*envelope*) to be the antecedent of *red*, constituting an early stage of binding (Franks & Connel, 1996). However, the HOD and the CGC theories do not consider that processing limitations, such as working memory, play a role in sentence comprehension deficits. Working memory is critical for processing language because the construction of syntactic structures rely on the relation of linguistic units in a lengthy time span (Martin & McElree, 2009; Marton, Schwartz, Farkas, & Katsnelson, 2006; McElree, Foraker, & Dyer, 2003). Therefore, the current study also tests the influence of different working memory demands on the syntactic comprehension of these clinical populations.

Syntax and Working Memory in SLI

Although children with SLI have deficits in sentence comprehension, the range of syntactic structures studied is not very broad. These children exhibit particular difficulties with syntactic structures that involve long-distance relationships such as relative clauses (Friedmann & Novogrodsky, 2004, 2007; Frizelle & Fletcher, 2014; Hestvik, Schwartz, & Tornyova, 2010) and wh-movement (Deevy & Leonard, 2004; Hansson & Nettelbladt, 2006; Marinis & van der Lely, 2007; Novogrodsky & Friedmann, 2010). However, there is a continuing debate about whether children with SLI have deficits with reflexives. Van der Lely and Stollwerck (1997) claimed that children with SLI have sufficient knowledge of the semantic conceptual properties of reflexives and theta role assignment but do not have syntactic knowledge of binding. However, their pronoun/reflexive study employed a small number of exceptionally complex sentences. The degree of language impairment was extreme in these children, with an age range (9;0–12;0) that differed substantially from the very young language-matched controls (5;0–9;0). A different study (Fortunato-Tavares et al., 2012) that avoided some of the limitations of the studies by van der Lely and colleagues found that Brazilian Portuguese-speaking children with SLI (8;0–12;0) do exhibit deficits in syntactic assignment for reflexives, but, as indicated by the error patterns, these deficits are not limited to errors in antecedent assignment, as predicted by theories such as HOD (Cromer, 1978) and its successor, the deficit in CCG hypothesis (van der Lely, 1998). In contrast, a different study reported that Hebrew-speaking children with syntactic SLI (9;0–13;0 years) have deficits only in some syntactic dependencies, not including the reflexive assignment (Novogrodsky & Friedmann, 2010). The discrepancy in the results between the studies may be due to the different subject populations employed, degree of impairment and the language characteristics. Van der Lely and colleagues recruited English-speaking children with syntactic SLI and severe language impairment, Novogrodsky and Friedmann included only Hebrew-speaking children with syntactic SLI, and Fortunato-Tavares and colleagues included Brazilian Portuguese-speaking children who did not necessarily have grammatical SLI. Furthermore, reflexives in Brazilian Portuguese are unstressed clitics, which might have posed an additional difficulty compared to the full reflexive pronouns in English and Hebrew.

Although children with SLI appear to have a more limited working memory capacity than their age-matched peers (e.g., Marton & Schwartz, 2003; Montgomery & Evans, 2009, Montgomery, Magimairaj, & Finney, 2010) few studies have investigated the association between working memory and sentence comprehension through direct manipulations of working memory demands. Children with SLI performed similarly to the typical language development (TLD) group on short object and subject wh-questions but showed poorer performance on long object questions than on long subject questions (Deevy & Leonard, 2004). In contrast, increasing the number of words in a sentence, without an increase in grammatical complexity, did not affect sentence span recall performance accuracy to the same extent as the increase in morphological complexity (Marton et al., 2006). These results and previous findings (Marton & Schwartz, 2003) suggested a greater influence of linguistic complexity than sentence length on working memory performance. Further supporting this claim, Fortunato-Tavares and colleagues (2012) found a clear influence of working memory (addition of one PP causing a greater distance between reflexive and its antecedent) on the syntactic assignment of reflexives of children with SLI and their age-matched controls.

Syntax and Working Memory in Autism Spectrum Disorder

Some recent studies have indicated a morphosyntactic deficit in the language production of children with autism (e.g., Eigst, Bennetto, & Dadlani, 2007) and in a subgroup of children with autism who have a language impairment similar to SLI (e.g., Roberts, Rice, & Tager–Flusberg, 2004). However, some morphosyntactic deficits might be related to pragmatic difficulties. Children with autism produce more ambiguous third-person subject pronouns than their typically developing peers when generating narratives, but there is no group differences when retelling stories, suggesting that their deficit lies in the pragmatic features of narratives (Novogrodsky, 2013).

Substantive syntactic impairments are also likely (Rapin & Dunn, 2003), at least in a subgroup of individuals with autism (Kjelgaard & Tager-Flusberg, 2001; Tager-Flusberg, 2012). For example, children with ASD have deficits in formulating sentences on the CELF (Landa & Goldberg, 2005), responding to wh-questions (Oi, 2008; 2010), and repeating sentences with complex syntax (Riches, Loucas, Baird, Charman, & Simonoff, 2010). However, little detail has been provided regarding the types of syntactic errors and structures that pose more difficulty to these children.

English-speaking children with autism have remarkable difficulties binding reflexive pronouns (Principle A) - suggesting that these children have no knowledge of c-command (Reinhardt, 1976). This does not seem to be caused by a general language delay or by cognitive deficits (Perovic, Modyanova, & Wexler, 2013a; 2013b). In contrast, children with ASD exhibit no deficits on the binding of personal pronouns (Principle B) when compared to controls matched on nonverbal IQ or receptive grammar (Perovic et al., 2013a; 2013b). Greek-speaking children with HFA do not exhibit problems with strong pronouns and reflexives, however they have difficulties comprehending clitics and are less accurate than vocabulary-matched typically developing controls (Terzi, Marinis, Francis, & Kotsopoulou, 2014). The discrepancy in findings between the English (Perovic et. al, 2013a; 2013b) and Greek (Terzi et. al, 2014) studies could be attributed to methodological factors, including the many grammatical differences between the two languages (for a detailed comparison see Terzi et.al, 2014). Furthermore, the study by Terzi and colleagues included only high functioning children, which was not the case in the studies by Perovic, and yet the Greek-speaking children performed more poorly.

Working memory deficits in ASD have been inconsistently reported. Some studies have found evidence of working memory deficits (Luna et al., 2002; Joseph, Steele, Meyer, & Tager-Flusberg, 2005) even when controlling for age, cognition and language (Schuh & Eigsti, 2012), whereas others have reported normal performance (Dawson et al., 2002; Koshino et al., 2005). This discrepancy could be attributed to several factors. A wide range of tasks have been used (e.g., digit-span, n-back, non-word repetition, non-word comparison) with widely varying task effects. Different control groups (typically developing and developing delayed children) and various matching procedures have been used (e.g., nonverbal IQ, language scores, and chronological age).

Syntax and Working Memory in Down Syndrome

Language deficits in DS are not consistent across language components; vocabulary is a relative strength, whereas syntax and morphology appear to be more affected (e.g., Chapman, Kay-Raining Bird, & Schwartz, 1990; Fowler, 1990; Naigles, Fowler, & Helm, 1993). Individuals with DS produce shorter and less complex sentence structures and questions/negations than typically developing individuals (Price et al., 2008). Subordinate and relative clauses and negated and passive constructions were not observed in French speakers with DS (Rondal & Comblain, 1996), deficient production of passives in English speakers with DS has been reported (e.g., Bridges & Smith, 1984; Fowler, 1990; Ring & Clahsen, 2005) and Greek speaking adolescents with DS exhibited deficient production of referential and non-referential wh-questions (Tsakiridou, 2006). However, studies of syntax and morphosyntax in DS have most often focused on spontaneous language production.

The syntactic assignment of reflexives in children with DS has been investigated with a Picture-Question Truth Value Judgment task (Perovic, 2004, 2006; Ring & Clahsen, 2005), comparable to studies of children with SLI (e.g., van der Lely & Stollwerck, 1997). The Picture-Question Truth Value Judgment task includes four question types (name-reflexive, name-pronoun, quantifier-reflexive and quantifier-pronoun) that are presented in picture match and mismatch conditions. Children with DS consistently had difficulty with syntactic binding for reflexives but not for pronouns and performed more poorly than the controls only on reflexives. Children with SLI were less accurate than controls on quantifier-pronoun (match) and name-pronoun (mismatch) conditions (van der Lely & Stollwerck, 1997; van der Lely, 1998). Thus, they appeared to have broader deficits than the reflexive deficits seen in DS. Children with DS have more difficulty with binding reflexives (Principle A) than with binding pronouns (Principle B), which is the reverse of the difficulties seen in typical acquisition, suggesting that the syntactic deficts in DS children are not only delayed, but atypical in English, Serbo-Croatian and Greek (Perovic, 2001, Perovic, 2006, Sanoudaki & Varlokosta, 2014).

Children with DS have limitations in verbal working memory (Jarrold & Baddeley, 1997; Jarrold, Baddeley, & Hewes, 1999; Lanfranchi, Cornoldi, & Vianello, 2004; Miolo, Chapman, & Sindberg, 2005; Seung & Chapman, 2004). These deficits are correlated with overall scores on standardized language tests (Chapman & Hesketh, 2001; Laws, 2004; Laws & Gunn, 2004; Miolo et al., 2005). More specifically, there is a correlation between working memory as measured by nonword repetition and word span tasks and language comprehension (Laws, 1998). Furthermore, verbal and visual working memory predicts sentence comprehension and verbal working memory accounts for almost half the variation in semantic role assignment (Chapman, Hesketh, & Kistler, 2002). As with all correlational findings, these deficits may co-occur rather than have a causal relationship.

Brazilian Portuguese Syntax

The current study was carried out with children who are monolingual speakers of Brazilian Portuguese. Therefore, some considerations about the Brazilian Portuguese syntax and the cross-linguistic differences and similarities between Brazilian Portuguese and English as well as other languages are necessary.

Brazilian Portuguese, as many other languages such as English, French and Hebrew, is a head initial language. In head-initial cases, the head precedes the complement (for example, the head *calls* precedes the NP *his mom* in the sentence *Paul calls his mom*). Brazilian Portuguese has a high attachment preference (Miyamoto, 1998) for both structures under investigation in this study, thus, it is reasonable to generalize findings from the present study to other head-initial languages with high attachment preferences. The reflexive pronouns in Brazilian Portuguese are clitics attached to the verb. Furthermore, reflexive clitics in Brazilian Portuguese are unstressed which is a different characteristic from English pronouns. See below for examples from both languages. Please note that reflexive pronouns are underlined.

The patient behind the doctor is drying himself.

O paciente atrás do médico está se secando.

'The patient behind the doctor is *self* drying.'

The use of clitic pronouns in this study may confound the difficulties of children with reflexive assignment. There are conflicting findings across languages and across clinical populations regarding clitic deficits. Although French children with SLI appear to have no deficits in comprehending reflexive clitics (Gruter, 2005; Jakubowicz, Nash, Rigaut, & Gérard, 1998) deficits have been observed in Brazilian Portuguese-speaking children with SLI for reflexives (Fortunato-Tavares et al., 2012) and in Greek-speaking children's comprehension of general clitics (Terzi, Marinis, Francis, & Kotsopoulou, 2014). Although children with TLD have less difficulty with reflexive clitics than with other clitics (Costa & Lobo, 2007; Jakubowicz & Rigaut, 2000; Silva, 2008), in the current study we will be able to examine whether the presence of clitics posed an additional challenge. By having two structures under investigation, one with reflexive clitics and the other with predicates, we will be able to analyze this effect. If the clitics posed any additional demands, we should observe lower accuracy for the reflexive than for the predicate sentence with similar (short) working memory demands.

Summary

The findings concerning syntactic deficits within and across developmental language disorders remain limited. The reported similarities between language profiles are not accurate, and it is not known whether common underlying mechanisms can be implicated. Moreover, sentence comprehension in relation to syntactic structure has received limited investigative attention, especially across groups. Thus, the current study examined the syntactic assignment of predicates and reflexives in comprehension across age-matched groups of children with SLI, HFA, DS and TLD. In addition to determining similarities and differences in sentence comprehension accuracy across these groups, the study sought to examine error patterns as a test of the HOD/CGC hypotheses. As a further test of these hypotheses, we examined the impact of working memory load in the assignment of antecedents to reflexives.

Methods

Participants

Fifty-seven children (35 boys and 22 girls) participated. Children were between 7;0 and 14;2 and composed four groups (SLI: $n = 15$; DS: $n = 15$; HFA: $n = 12$; and TLD: $n = 15$). Although the participants were not individually matched, there were no between-group differences in age ($p = .605$). The children came from homes in which Brazilian Portuguese was the only language spoken. There is no comprehensive standardized language test in Brazilian Portuguese. The most comprehensive language test available is the ABFW Child Language Test (Andrade, Befi-Lopes, Fernandes, & Wertzner, 2004), which includes

Expressive Vocabulary, Phonology, Fluency, and Pragmatics subtests. Vocabulary scores varied across groups and results are displayed in Table 1. Children that had only liquid simplification, cluster simplification or distortions on the Phonology section were included in the study (other phonological processes were considered as exclusion criteria). All children exhibited a predominance of use of verbal as compared to gesture and nonverbal communication means on the Pragmatics subtest. Depending on their clinical group, children had their IQ measured with three different tests: Test of Nonverbal Intelligence III (Brown, Sherbenou, & Johnsen, 1997), Ravens Coloured Progressive Matrices (Raven, 1993), and Wechsler Intelligence Scale for Children III (Wechsler, 2004). This difference was due to specific characteristics of each disorder and the respective routines of the laboratories where the children were recruited from. Measures of IQ provided by these tests are comparable (Banks & Franzen, 2010; Blennerhassett, Strohmeier, Hibbett, 1994). All children had normal hearing as measured by hearing screening at 25 dB HL for 500, 1000 and 2000 Hz, and all children from the clinical groups were receiving speech-language services. Recruitment of participants occurred at the Speech-Language Pathology Clinic of Universidade de São Paulo, Public Schools and advertisement.

Specific Language Impairment Group

The 15 children with SLI (nine boys and six girls) were between 8;4 and 10;6 years old (M = 9;4 years; SD = 9 months). The SLI group consisted of a subsample of a previously published study (Fortunato-Tavares et al., 2012). They had all been diagnosed by a group of Speech-Language Pathologists as specific language impaired. Children with SLI had normal nonverbal IQ performance as measured by TONI-III (Brown, et. al, 1997).

Autism Spectrum Disorders Group

The 12 HFA children were between 7;0 and 13;5 years old (*M* = 9;3; *SD* = 2;6). Boys outnumbered girls (10 boys and two girls). All children were diagnosed as having HFA by psychiatrists according to criteria proposed by DSM-IV and ICD-10. Diagnostic confirmation included the Autism Behavior Checklist (ABC; (Krug, Arick, & Almond, 2008), the Childhood Autism Rating Scale (CARS; Schopler, Reichler, & Renner, 1998), and the judgment of an experienced clinician. Participants were excluded if they had genetic syndromes or acknowledged etiology for developmental symptoms. The children were all verbal high functioning with an IQ equivalent score on the Ravens Coloured Progressive Matrices (Raven, 1993) of 80 or higher.

Down Syndrome Group

The 15 children with DS (eight boys and seven girls) were between 7;0 and 14;2 (*M* = 10;3; *SD* = 2;7). They all had abnormalities associated with Trisomy 21. All participants were free of sensory impairments that would interfere with language development and had relatively good speech intelligibility. The intelligence was tested with the WISC-III (Wechsler, 2004).

Typical Language Development Group

The 15 children with TLD (eight boys and seven girls) were between 8;5 and 10;5 years old (*M* = 9;5 years; *SD* = 7 months). Children in this group were recruited from Public Schools of the city of São Paulo. They all had scores on the vocabulary section of the ABFW Child Language Test (Andrade et al., 2004) within normal limits. All children from this group had nonverbal IQs within one standard deviation of the mean as measured by the TONI-III (Brown et al., 1997), with no history of language impairment.

Table 1 displays detailed demographic information of the participants of all four groups and the vocabulary test and intelligence measures.

Post hoc tests with Bonferroni corrections revealed that none of the groups differed in age (all $p > .05$). *Post hoc* tests with Bonferroni corrections revealed that children with DS had a significantly lower IQs than children with SLI, HFA or TLD (all $p < .001$). No other significant difference was noted. Children with SLI had significantly lower vocabulary scores than TLD ($p < .001$), HFA ($p < .001$) and DS children ($p = .40$). Furthermore, children with DS had lower vocabulary scores than TLD children ($p = .008$) and children with HFA ($p < .001$). By comparing these groups, we can explore the performance of each group on the experimental task and consider the extent to which vocabulary comprehension and IQ influence comprehension of attachment and reflexives as well as the impact of the working memory load manipulation.

Stimuli

The stimuli were the same to those used in previously published study (Fortunato-Tavares et al., 2012). Each trial consisted of one context sentence, one target sentence, and four pictures. Context sentences for both predicate attachment and reflexive assignment had the following structure: *Here is a(an) X and a(an) Z (Aqui estão a(o) X e a(o) Z)*, where X and Z were the nouns of the target sentence (e.g., *Here is a cup and a box; Aqui estão a xícara e a caixa*).

The visual stimuli each included four pictures that were presented on a computer screen: correct picture; hierarchical error picture (incorrect attachment or antecedent and correct spatial relation); preposition change error picture (correct attachment or antecedent and incorrect spatial relation); reverse error picture (incorrect attachment or antecedent and incorrect spatial relations).

There were 26 trials of predicate attachment. The target sentences had the following structure: *The X in/on/under/in front of/behind the Z is Y (O X na(o)/acima/abaixo/na frente/ atrás de Z é Y)*, where X and Z were nouns and Y was a color term (e.g., *The pen under the envelop is red; A caneta embaixo do envelope é vermelha*). The picture stimuli for the example trial are shown in Figure 1.

There were 56 trials of reflexive assignment (28 for each working memory condition). The target sentences had the following structure: *The X in/on/under/in front of/behind the Z* ***[modifier]*** *is Y (O X na(o)/acima/abaixo/na frente/ atrás de Z* ***[modifier]*** *está Y)*; X and Z were nouns and Y was a verbal phrase with a reflexive pronoun. Short and long versions of each target sentence were presented. The long version was created with the addition of a modifier phrase between the subject and the reflexive without increasing structural complexity (e.g., *The patient behind the doctor* ***[with black pants]*** *is drying himself; O* *paciente atrás do medico* ***[de calça preta]*** *está se secando).* The set of pictures for the above mentioned reflexive trial is illustrated in Figure 2.

The procedure followed that of Fortunato-Tavares and colleagues (2012). The experiment was created and presented via E-Prime (PST software, Pittsburgh, PA, USA, 1996–2006). The auditory stimuli were digitally recorded on the PRAAT software (Boersma & Weenink, 2006) by a female Brazilian Portuguese native speaker. The trials of predicate attachment and reflexive assignment were randomly presented to avoid length, order, or familiarization effects. Five practice trials were presented to each child prior to the beginning of the experiment. The sentences on the practice trials had the same structure as those in the experiment trials. Although we aimed to use the performance on these practice trials as a screening for participation in the experiment, no child was excluded for poor performance.

In each trial, a context sentence was followed by the picture stimuli and the target sentence. The four pictures were randomly positioned in each trial by E-Prime. There was no time limit for response – the four pictures remained on the computer screen until a response was detected. The type of response selected (correct, hierarchical error, preposition error, and reversed error – which included a structural assignment error as well as a preposition error) was analyzed.

Data Analysis

We used the Dirichlet-Multinomial model (e.g., Paulino & Singer, 2006), which is a generalization of the Beta-Binomial model (Molenberghs & Verbeke, 2005), an appropriate statistical model for multinomial distribution and heterogenic data across participants. The Dirichlet-Multinomial model assumes that the frequencies of each response category are generated by a multinomial model with a specific probability vector for each child and that these probability values constitute a random sample of a Dirichlet distribution. In our study, maximum likelihood methods were used to obtain the estimative of expected frequencies using a Dirichlet-multinomial model. These frequencies were compared between and within groups via Wald statistics and confidence intervals.

Results

Predicate Attachment

Figure 3 illustrates the response accuracy (in percentage) of the four groups (TLD, SLI, HFA, and DS) in the predicate attachment sentences. The children with SLI had a lower percentage of correct responses compared with their TLD controls, which had IQ and vocabulary scores higher than the SLI children. In contrast, children with SLI exhibited higher accuracy compared with both children with HFA and DS. Here we see no direct impact of IQ measures as children with SLI and HFA have an IQ strength compared to children with DS. Additionally, no direct impact is seen for vocabulary as children with SLI and DS had similar vocabulary scores and yet children with SLI outperformed children with DS; TLD and HFA children also had similar vocabulary scores but children with TLD were more accurate than those with HFA.

Between-group differences were also observed in the error analysis. It is important to point out that the reversed error also involved a hierarchical attachment error (in the example presented in Figure 1, the envelope is red also on the reversed error).

For the inferential analysis, we employed the Dirichlet-Multinomial model to estimate the probabilities of each response category (correct, hierarchical, preposition change, reversed) for each group (Table 2). The analysis via Wald statistics revealed an overall effect for group (χ^2 (9, n = 57) = 372.95, $p < .001$), indicating that the response distributions for the groups were generally different in the comprehension of syntactic constructions involving a predicate attachment.

To further investigate this effect, between-group comparisons were made to examine each response type. Significant effects were observed for the correct responses, indicating that the four groups differed in accuracy (Correct: χ^2 (3, n = 57) = 314.36, $p < .001$). The error categories also differed (Hierarchical: χ^2 (3, n = 57) = 80.20, $p < .001$; Preposition: χ^2 (3, n = 57) = 116.04, $p < .001$; Reversed: χ^2 (3, n = 57) = 760,75, $p < .001$).

Confidence Intervals (CI) were constructed to investigate differences in the proportions of correct responses of the SLI, HFA and DS groups compared with the TLD group (Figure 4). The children with SLI and HFA exhibited greater accuracy than the children with DS. The HFA and SLI groups did not differ in accuracy.

For the TLD and SLI groups, no effect of error type was observed (χ^2 (2, n = 15) = 1.03, p = .598; χ^2 (2, n = 15) = 4.48, p = .106, respectively), indicating that these children did not exhibit a significant preference for any of the error types. In contrast, error type effects were observed for the children with HFA (χ^2 (2, n = 12) = 7.48, p = .024) and DS (χ^2 (2, n = 15) = 11.22, p = .004), both exhibiting a preference for the hierarchical error.

Reflexive Assignment

Short Working Memory Condition—Figure 5 illustrates the response accuracy (in percentage) of the four groups on the short working memory condition of the reflexive assignment sentences. Similar to the predicate attachment, the children with SLI had lower accuracy compared with the TLD controls and higher accuracy compared with the HFA and DS groups, suggesting that the relative vocabulary strength of HFA and DS children had no impact on reflexive assignment.

The error analysis of the reflexive assignment sentences with a low working memory demand revealed a more homogenous distribution across the clinical groups compared with the predicate attachment sentences. The probabilities of each response category for each group estimated by the Dirichlet-Multinomial model are presented in Table 3.

The analysis via Wald statistics revealed an overall effect for group (χ^2 (9, N = 57) = 283.45, $p < .001$), indicating that the response distributions for the groups differed for the comprehension of reflexive constructions with short working memory demands. To further investigate this effect, between-group comparisons were made to examine each response type. The four groups differed in accuracy (Correct: χ^2 (3, N = 57) = 195.80, $p < .001$), and the error patterns differed (Hierarchical: χ^2 (3, N = 57) = 94.32, $p < .001$; Preposition: χ^2 (3, N = 57) = 95.83, $p < .001$; Reversed: χ^2 (3, N = 57) = 466.74, $p < .001$). Note that the reversed error also represents an incorrect syntactic assignment.

Confidence intervals (CIs) were established to examine the proportion of correct responses for the SLI, HFA and DS groups compared with the TLD group (Figure 6). Differently from the predicate attachment sentences, the CIs indicated that the children with SLI displayed greater accuracy than children with HFA and DS. In turn, the HFA and DS exhibited similar accuracies. The children with HFA and DS exhibited similar number hierarchical errors, with the SLI children exhibiting fewer syntactic errors (hierarchical and reverse) than these two groups.

For the within-group error analysis, the SLI, HFA and DS groups did not exhibit a significant preference for any of the error types (χ^2 (2, n = 15) = 3.57, p = .168; χ^2 (2, n = 12) = 3.18, p = .203; χ^2 (2, n = 15) = 5.17, p = .075, respectively). The only group that exhibited error type effects was the TLD (χ^2 (2, n = 15) = 11.38, p = .003), with a preference for the preposition change and reversed errors.

Long Working Memory Condition—Figure 7 illustrates the response accuracy (in percentage) of the four groups (TLD, SLI, HFA, and DS) for the long working memory condition of the reflexive assignment sentences. The response pattern differed from the predicate attachment and the short working memory condition of the reflexive assignment sentences. With higher working memory demands, the children with SLI were similar in accuracy to the children with HFA and DS, suggesting that IQ and vocabulary strengths and weakness are impartial when working memory demands are higher.

The error analysis of the reflexive assignment sentences with long working memory demand revealed a homogenous distribution across SLI, HFA and DS groups. Interestingly, the frequencies of the reversed errors, which include an error in hierarchical syntactic representation, were similar across the four groups, including the TLD children.

The response category probabilities (correct, hierarchical, preposition change, reversed) for each group are presented in Table 4.

The analysis via Wald statistics revealed an overall effect for group (χ^2 (9, n = 57) = 55.26, $p < .001$), indicating that the response distributions for the groups differed in the reflexive assignment with greater working memory demand. Between-group comparisons examined each response type. Significant effects were observed for the correct responses, indicating that the four groups differed in accuracy (Correct: χ^2 (3, n = 57) = 19.43, $p < .001$). Moreover, significant effects were observed in the selection of incorrect pictures across groups for the three error types (Hierarchical: χ^2 (3, n = 57) = 16.44, $p < .001$; Preposition: χ^2 (3, n = 57) = 21.74, $p < .001$; Reversed: χ^2 (3, n = 57) = 25.98, $p < .001$).

The confidence interval analysis (Figure 8) indicated a similar accuracy for children with SLI, HFA and DS in syntactic assignment for reflexives with greater working memory demands. A similar pattern was observed for the hierarchical and preposition errors, indicating the three clinical groups did not differ.

In the within-group error analysis, error type effects were observed in all groups (TLD: χ^2 (2, n = 15) = 61.43, p < .001; SLI: χ^2 (2, n = 15) = 46.85, p < .0001; HFA: χ^2 (2, n = 12) = 47.75, p < .001; DS: χ^2 (2, n = 15) = 22.79, p < .0001), with reverse and hierarchical errors the most common.

Working Memory Effect

The Wald statistics applied to the Dirichlet-Multinomial model revealed significant working memory effects for the TLD and SLI (χ^2 (3, n= 15) = 26.72, p < .001) and χ^2 (3, n = 15) = 21.87, p < .001; respectively), indicating that for these groups the increase in working memory affected the overall response patterns. In contrast, no significant working memory effect was observed for the HFA (χ^2 (3, n = 12) = 6.74, p = .081) and DS (χ^2 (3, n = 15) = 3.4, p = .335) groups. This result indicates that the responses of children from the HFA and DS group were not affected by an increase in working memory demands.

In these analyses, we compared the selection of each response type (correct, hierarchical, preposition, and reverse) across the two conditions of working memory (short and long) of the TLD and SLI groups. Differences in accuracy between the two working memory conditions were found for both groups (TLD: χ^2 (1, n = 15) = 18.61, p < .001; SLI: χ^2 (1, n = 15) = 14.88, p < .001), both of which exhibited a decrease in accuracy with an increase in working memory demands. Furthermore, both groups (TLD and SLI) exhibited increased hierarchical (χ^2 (1, n = 15) = 4.10, p = .043, χ^2 (1, n = 15) = 5.01, p = .025 respectively) and reverse (χ^2 (1, n = 15) = 69.55, p < .001, χ^2 (1, n = 15) = 95.22, p < .001 respectively) selection – both syntactic errors – in the long working memory condition. In contrast, children with TLD and SLI exhibited no significant change in the selection of the preposition error picture according to the working memory condition (χ^2 (1, n = 15) < .001, p = .990, χ^2 (1, n = 16) = 1.03, p = .31 respectively).

Correlational Analysis

A correlational matrix revealed significant correlations between intelligence measures and accuracy and between intelligence and vocabulary. We found significant positive correlations between intelligence and accuracy of predicate attachment (r_s = .633, p < .001) and between intelligence and correct assignment of antecedent to reflexive under the short (r_s = .597, p < .001) and long (r_s = .269, p < .001) working memory conditions. Vocabulary was also significantly correlated to predicate attachment (r_s = .330, p = .015). However, with the vocabulary controlled, no significant correlations were observed between intelligence measures and accuracy (p > .05).

Discussion

The comparison of diverse groups with language disorders helps determine commonalities across conditions, clarifies the symptoms, elucidates the nature of language impairments and specifies the ways in which language is vulnerable in each disorder. Furthermore, information from comparative studies of language disorders helps us understand the processes that support language and the underlying mechanisms that impair linguistic abilities in different clinical populations (Ypsilanti & Grouios, 2008). In the current study, we analyzed the syntactic assignment of predicates and reflexives as well as working memory demands on the latter in four groups of children (SLI, HFA, DS and TLD). We first discuss the syntactic comprehension on a within-group basis. Next we compare the syntactic assignment performance among the three clinical groups (SLI, HFA and DS) along with a discussion of possible confounds including IQ, vocabulary, and working memory deficits. Finally, we consider the findings in light of the HOD (Cromer, 1978) and CGC (van der Lely, 1998) hypotheses.

Syntactic comprehension: within –group comparison

All three groups with language disorders exhibited lower accuracy than the group with TLD on predicate attachment and assignment of antecedents to reflexives. This result indicates that children with SLI, HFA and DS have an overall deficit in structuring syntactic relations necessary for sentence comprehension

Studies of syntactic assignment with Brazilian Portuguese (Fortunato-Tavares et al., 2012), Czech (Smolík & Vávru, 2014), and English (van der Lely, 1998; van der Lely & Stollwerck, 1997) speaking children with SLI have revealed comprehension deficits when children have to rely on syntactic knowledge. However, the syntactic dependency deficit presented by Hebrew-speaking children with syntactic SLI does not include reflexive assignment (Novogrodsky & Friedmannn, 2010) and the comprehension of French clitic pronouns varies depending on the syntactic categories of the elements (Gruter, 2005; Jakubowikz, et al., 1998). The current findings support the claim that the syntactic assignment of reflexives is impaired in Brazilian Portuguese-speaking children and adds that the deficit is also seen in the attachment of predicates. These findings suggest that syntactic assignment abilities in SLI varies cross-linguistically.

Studies of ASD have revealed deficits in wh-question responses (Oi, 2008, 2010), sentence repetition (Riches et al., 2010), and formulating sentences (Landa & Goldberg, 2007), suggesting there is an expressive syntactic deficit despite some earlier assumptions that syntax was relatively unimpaired in this population (e.g. Pierce & Bartolucci, 1977). Our findings further support the claim that syntactic comprehension is impaired in HFA. Although the literature seems to point to a general syntactic deficit in a subgroup of children with ASD (Kjelgaard & Tager-Flusberg, 2001; Tager-Flusberg, 2012), the previous studies examined only a limited number of syntactic structures, tested primarily in tasks that required verbal responses, across a wide age range with a variety of control groups. Thus, the study of syntactic abilities in ASD is in its early stages, and further investigation is needed for a more complete picture. The current study provides evidence that children with HFA have problems comprehending sentences when hierarchical knowledge is necessary even when the vocabulary scores of HFA children are similar to those of TLD children, suggesting a possible gap between syntax and vocabulary in HFA.

The findings regarding reflexive assignment in children with HFA also warrant some cross-linguistic consideration. Findings from English-speaking children with ASD (Perovic et.al, 2013a; 2013b) revealed that children with autism have no deficits on the binding of personal pronouns (Principle B) when compared to controls matched on nonverbal IQ or receptive grammar. However, findings from Greek-speaking children with HFA (Terzi et al., 2014) indicated that these children showed difficulties when the pronouns were clitics (but not with strong pronouns), suggesting that the main problem for these children in this case are the clitics, perhaps because they are less salient perceptually. As children with HFA in the present study also presented lower accuracy than controls on the assignment of reflexive clitics, it is possible to assume that clitics are a vulnerable domain for children with HFA - so far true for Greek- and Brazilian Portuguese-speaking children. However, the question of whether this vulnerability of clitics is cofounded with syntactic deficits of children with HFA can be answered by the current study; children with HFA exhibited similar accuracy on the assignment of clitics (reflexives) and predicate attachment. If clitics had posed an additional challenge for these children, we might have observed lower accuracy for sentences containing clitics (than predicates), which was not the case.

The studies on syntactic assignment in children with DS (Perovic, 2001, 2004, 2006; Ring & Clahsen, 2005; Sanoudaki & Varlokosta, 2014) have focused on pronouns and reflexives. Children with Down syndrome have deficits in assigning reflexives, but not pronouns, to their antecedents. The absence of pronoun assignment difficulties in children with Down syndrome might be related to their vocabulary. Earlier studies suggested that lexical knowledge is sufficient for binding pronouns, while the assignment of reflexives relies mostly on syntax (van der Lely & Stollwerck, 1997); lexical cues are present and facilitate pronoun binding, whereas reflexive assignment depend on syntactic knowledge. Our findings corroborate the claim that children with DS have a deficit in assigning the correct antecedent to reflexives and add that the deficit extends to comprehension of sentences requiring the determination of predicate attachment. Similar to the reflexive conditions in the previous studies (Perovic, 2004, 2006; Ring & Clahsen, 2005), lexical knowledge alone was insufficient to attach the predicate to the appropriate noun (e.g., *The circle on the star is blue*), and children had to rely on syntactic information. The lexical strengths of these children had, therefore, no impact on results of the current study. Thus, the syntactic assignment difficulties of children with DS are not limited to reflexives. In fact, one important note is that in the current study, children with DS had above chance performance and were consistently more accurate on reflexive assignment than predicate attachment despite the randomized order, suggesting an internal validity of the data. Furthermore, the fact that predicate sentences were not longer than reflexive sentences suggests that working memory cannot explain the difference in performance between the two structures.

It is important to highlight that the children with DS, as a group, presented the greatest challenge in data collection. The highest number of children had to be tested (22) in order to achieve the desired number of participants. A number of the children with DS lost interest in the task and began playing with the researcher, having a tantrum, or failed to stay on task in other ways. Although the 15 children with DS in the study sample finished the experiment, the sessions lasted 20 to 30 minutes longer than the sessions for other groups.

Syntactic comprehension: between-group considerations

Our findings support the view that children with DS differ in their syntactic deficits from children with SLI. Parallel findings from children with DS (Perovic, 2004, 2006; Ring & Clahsen, 2005) and children with SLI (van der Lely, 1998; van der Lely & Stollwerck,

1997) revealed that children with DS and children with SLI exhibit distinct patterns of binding impairment. Children with SLI made more comprehension errors than controls on sentences with pronouns and reflexives, whereas children with DS had deficits limited to reflexives. Our study provided a direct comparison of SLI and DS groups, indicating that age-matched children with DS have deficits that exceed those of SLI both in the assignment of reflexives and in the attachment of predicates. Furthermore, children with SLI exhibited similar accuracy on predicate attachment and on reflexive assignment whereas children with DS exhibited more difficulties with predicate attachment, suggesting that these children have relatively stronger knowledge of Principle B, as has been previously indicated (Perovic, 2001).

The Recalling Sentences subtest of the CELF has yielded mixed results in the comparison of ASD and SLI groups. Some studies have found that children and adolescents with SLI exhibit poorer performance than children with ASD (Riches et al., 2010; Whitehouse, Barry, & Bishop, 2008), whereas others reported no differences (Botting & Conti-Ramsden, 2003; Lloyd, Paintin, & Botting, 2006). The uncontrolled memory demands of sentence repetition, the mix of sentence structures, and the fact that verbal responses are required may have confounded these findings. In our study, children with HFA exhibited similar performance to their SLI peers on predicate attachment. Whereas children with HFA had difficulties that exceeded those of SLI children on the assignment of reflexives, both groups performed more poorly with increased working memory demands. This pattern may extend to other aspects of syntax.

Cognitive deficits

Cognitive deficits may have amplified consequences in atypical language development. Although these consequences may define the nature of impairment, the strengths and weakness of each clinical group, and the differences in their linguistic profiles, this relationship does not appear to be as straightforward. Although it is tempting to use intelligence as an explanatory factor for the differences observed in performance given the significant correlations between IQ and accuracy in the group as a whole, certain facts suggest this might not be the case. The children with DS had lower IQs than those with HFA ($p < .001$) and SLI ($p < .001$), yet these three groups exhibited similar performance when working memory demands were higher. Second, TLD, SLI and HFA children had similar IQ, and we observed different patterns of performance across the conditions.

Working Memory

With greater working memory demands, the children with SLI (and TLD) exhibited less accuracy and made more syntactic errors, with no change in lexical (preposition) errors. For the children with SLI, increased working memory demands resulted in an accuracy similar to the children with HFA and DS. In the children with HFA and DS, no working memory effect was observed on the comprehension of syntactic structures involving reflexives.

There is no consensus about working memory deficits in ASD (Dawson et al., 2002; Joseph, Steele, Meyer, & Tager-Flusberg, 2005; Koshino et al., 2005; Luna et al., 2002; Schuh & Eigsti, 2012). In the current study, children with HFA exhibited less working memory effects than those with SLI. If we view the underlying cause of sentence comprehension deficits as multifactorial with different loadings across clinical groups, the working memory loading for HFA would be smaller than that for SLI. It is also possible that executive functions have an impact on the performance of these children; executive functions play a role in working memory performance (Marton, 2008; Marton, Campanelli, Eichorn, Scheuer, & Yoon, 2014). A key issue may be interference effects in recall that may impact sentence comprehension (Marton et al., 2014).

Children with DS have a verbal working memory deficit (e.g., Jarrold & Baddeley, 1997; Lanfranchi, Jerman, & Vianello., 2009; Miolo et al., 2005; Seung & Chapman, 2004). In the current study, working memory deficits in these children may have had an impact on sentence comprehension but because performance on the short working memory condition was already low, the between working memory conditions effect could not be observed. This may be why our findings seem to contradict the correlational studies that suggest a direct association between working memory and language in these children (e.g., Chapman & Hesketh, 2001; Laws, 2004; Laws & Gunn, 2004; Miolo et al., 2005). When working memory demands were manipulated directly in language stimuli, we found no direct effects on the comprehension of sentences with reflexives. Nevertheless, correlational findings may only reflect the comorbidity of language and memory deficits, not a direct association. The generally unsettled relation between independent working memory task performance and sentence comprehension (e.g., Caplan & Waters, 2013; MacDonald & Christiansen, 2002; McElree, 2000) has led to proposals of multiple working memory capacities that subserve language processing, to content-addressable models of working memory for sentence comprehension and to the argument that models of sentence comprehension must include working memory as an integrated component.

Hierarchical Ordering Deficit

The children with SLI or TLD exhibited no preference for errors that indicate a lack of hierarchal structure in predicate attachment (hierarchical and reversed error) contradicting the HOD/CGC hypothesis (Cromer, 1978; van der Lely 1998). However, in the children with HFA and DS, the dominant error response in predicate attachment was hierarchical, suggesting that these children did not assign hierarchical structure to predicate sentences, resulting in a linear representation and an erroneous comprehension. When considered along with their reverse error responses, the potential failure of structural assignment is even more compelling. The absence of hierarchically organized structures accounted for their difficulties with predicate comprehension. In contrast, none of the clinical groups exhibited a preference for any type of error on the comprehension of reflexive sentences with working memory conditions similar to predicate sentences. This suggests that the hypothesis of absence of hierarchical representation does not persist for all structures.

All groups preferred the hierarchical and reversed errors when comprehending reflexive sentences with higher working memory demands. Although the reversed error included a different preposition, it also included an error in syntactic assignment. Therefore, the failure in assigning the hierarchical syntactic structure to sentences containing reflexives was the main cause of miscomprehension when working memory demands were high, differently to what was observed for low demands of working memory. This suggests that the inability to form hierarchical structure in sentence comprehension may be one of a cluster of causes underlying miscomprehension.

Conclusions

Children with SLI, HFA or DS differ from TLD children in the comprehension of predicate and reflexive structures where knowledge of syntactic assignment is required.

The present data contradict the HOD/CGC hypotheses as general explanations for syntactic deficits in children with language disorders. The lack of hierarchical knowledge was not the main cause of miscomprehension in children with SLI, but it may play a role in children with DS or HFA depending on the structure under investigation.

Different working memory effects, as measured by direct manipulations of working memory on sentence stimuli, were found for children with SLI, HFA, or DS. The working memory effect on sentence comprehension is clear for children with SLI. In turn, children with HFA and DS do not exhibit a clear effect of working memory demands on sentence comprehension. There is a need to extend the findings of this off-line study to studies of language processing in these groups of children. Such studies have the potential to elucidate the role of working memory in the moment-by-moment comprehension of sentences.

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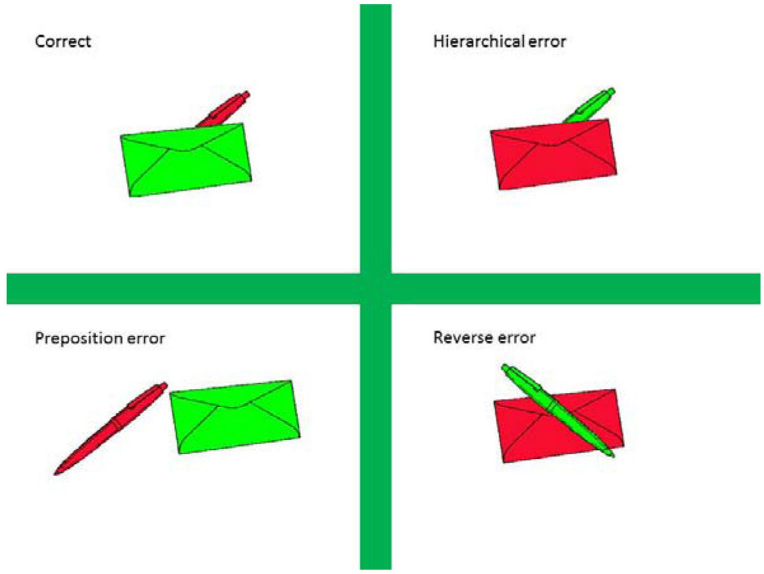

Figure 1.
Picture stimuli corresponding to the target sentence *The pen under the envelope is red* of the Predicate experiment.

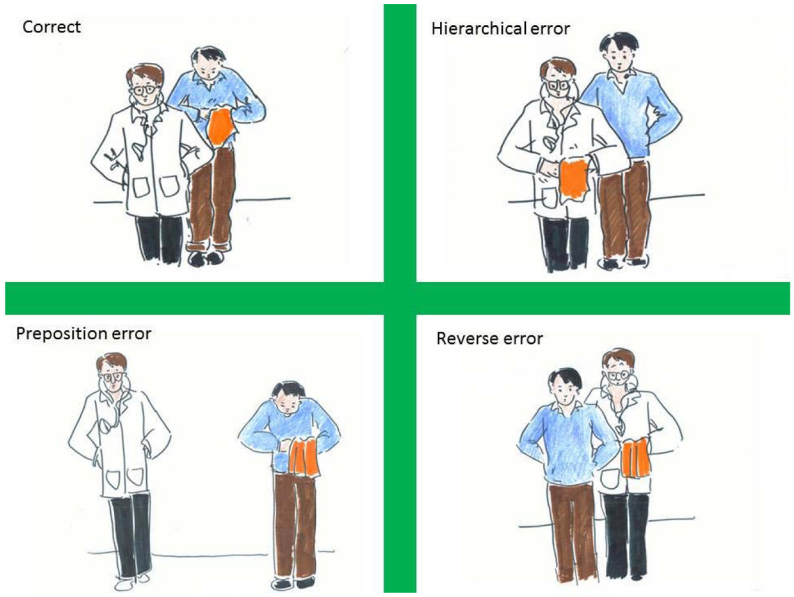

Figure 2.

Picture stimuli corresponding to the target sentence *The patient behind the doctor* ***[with black pants]*** *is drying himself* of the Reflexive experiment.

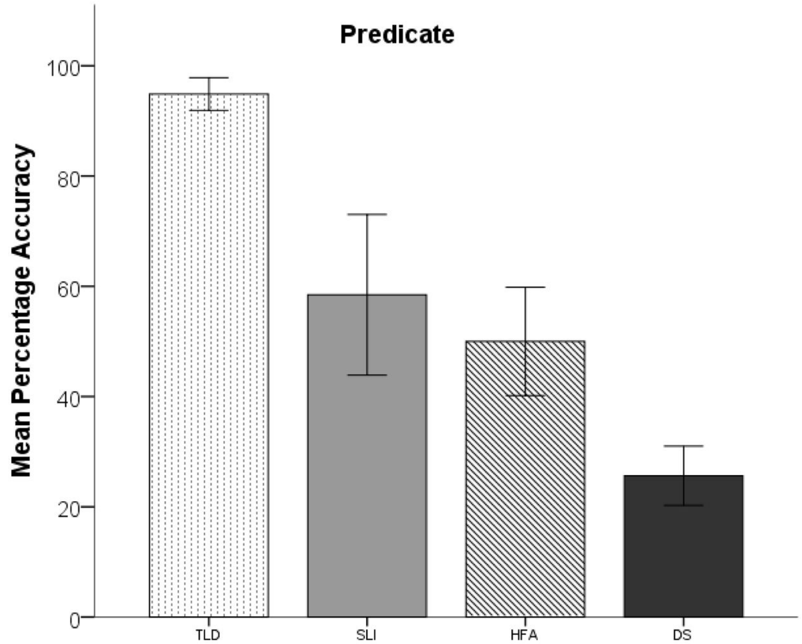

Figure 3.

Mean percentage accuracy for the four groups (TLD, SLI, HFA, and DS) in the Predicate Attachment experiment. Error bars denote 95% Confidence Interval.

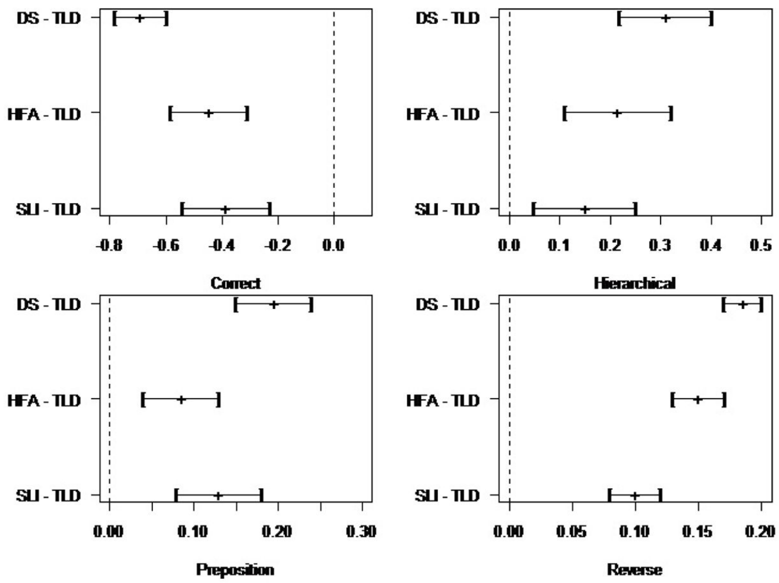

Figure 4.
Confidence Intervals of the difference in proportions according to each response type (Correct, Hierarchical, Preposition, and Reverse) for the SLI, HFA, and DS groups compared with the TLD group in the Predicate Attachment experiment.

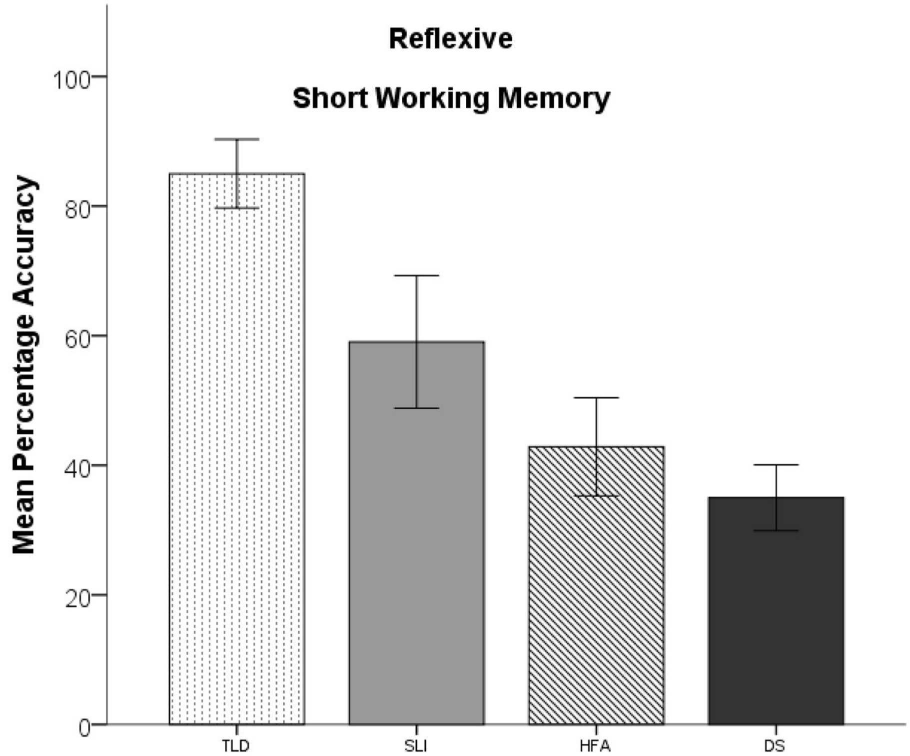

Figure 5.
Mean percentage accuracy for the four groups (TLD, SLI, HFA, and DS) on the Short Working Memory condition of the Reflexive Assignment experiment. Error bars denote 95% Confidence Interval.

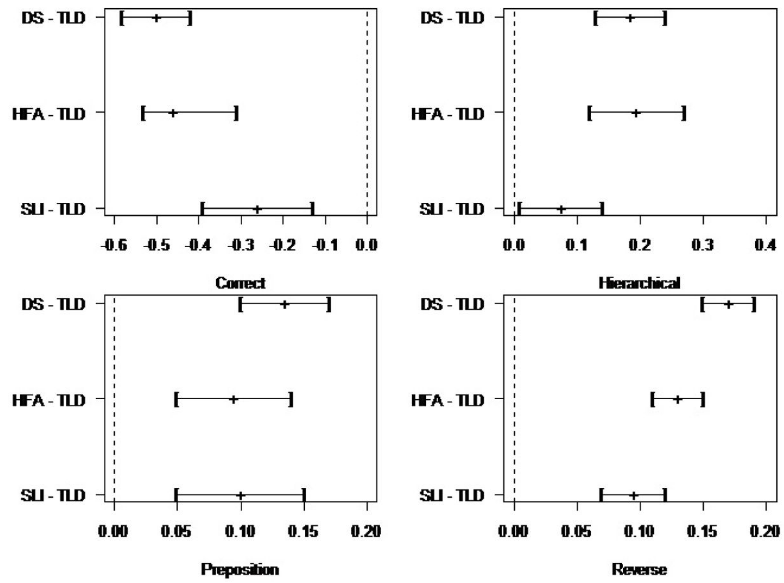

Figure 6.
Confidence Intervals of the difference in proportions according to each response type (Correct, Hierarchical, Preposition, and Reverse) for the SLI, HFA, and DS groups compared with the TLD group on the Short Working Memory Condition of the Reflexive Assignment experiment.

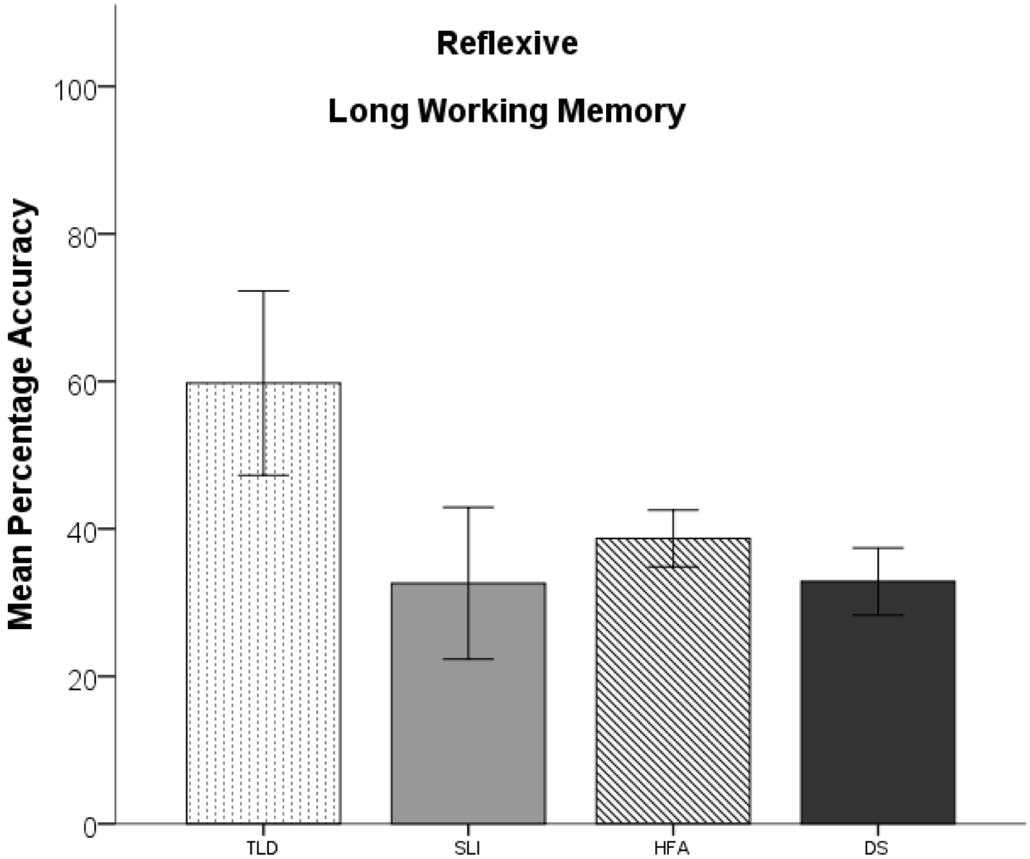

Figure 7.

Mean percentage accuracy for the four groups (TLD, SLI, HFA, and DS) on the Long Working Memory condition of the Reflexive Assignment experiment. Error bars denote the 95% Confidence Interval.

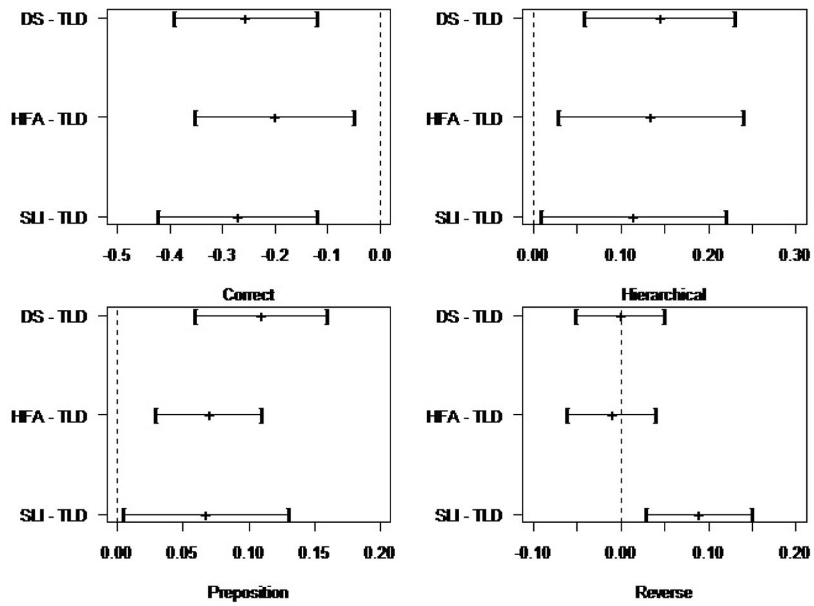

Figure 8.

Confidence Intervals of the difference in proportions according to each response type (Correct, Hierarchical, Preposition, and Reverse) for the SLI, HFA, and DS groups compared with the TLD group on the Long Working Memory Condition for Reflexive Assignment.

Table 1

Mean (standard deviations) and [range] of age, intelligence measure, vocabulary test performance and gender distribution of participants.

	SLI	HFA	DS	TLD	*F*	*p*-value
Age [range]	9;4 (0;9) [8;4 – 10;6]	9;3 (2;6) [7;0 – 13;5]	10;3 (2;7) [7;0 – 14;2]	9;5 (0;7) [8;5 – 10;5]	.620	.605
Gender (M:F)	9:6	13:2	8:7	8:7		
Intelligence	97 (5.8)[a]	93.2 (13.5)[b]	54.5 (6.9)[c]	101 (5.5)[a]		
Measure [range]	[90 – 108]	[80 – 125]	[46–68]	[94 – 110]	92.636	< .001*
Vocabulary [range]	53 (3.2) [48 – 56]	84.3 (4.4) [76 – 90]	56 (17.1) [44 – 80]	76 (3.6) [72 – 85]	51.791	< .001*

Note: age expressed in years; months;

[a]TONI-3;

[b]IQ equivalent scores of the Raven Matrices Test percentile;

[c]WISC; Expressive vocabulary scores on the ABFW test. Statistically significant p-values for one-way ANOVAs are marked with an *.

Table 2

Dirichlet-Multinomial model estimated mean (Standard Error) percentage of picture selection for the four groups (TLD, SLI, HFA, DS) in the Predicate Attachment Experiment.

	Picture Selection			
Group	**Correct**	**Hierarchical**	**Preposition Change**	**Reversed**
TLD	95 (2)	2 (1)	2 (0.5)	1 (0.3)
SLI	56 (7)	17 (5)	15 (2)	12 (1)
HFA	50 (6)	24 (4)	10 (2)	16 (1)
DS	26 (3)	33 (4)	21 (2)	20 (1)

Note: Reversed errors entail preposition and structural assignment errors.

Table 3

Dirichlet-Multinomial model estimated mean (Standard Error) percentage of picture selection for the four groups (TLD, SLI, HFA, DS) on the Reflexive Assignment Experiment with short working memory condition.

	Picture Selection			
Group	**Correct**	**Hierarchical**	**Preposition Change**	**Reversed**
TLD	85 (3)	3 (1)	6 (1)	6 (1)
SLI	58 (5)	11 (3)	16 (2)	15 (1)
HFA	43 (4)	23 (3)	15 (2)	19 (1)
DS	35 (2)	22 (2)	20 (1)	23 (0.5)

Note: Reversed errors entail preposition and structural assignment errors.

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Table 4

Dirichlet-Multinomial model estimated mean (Standard Error) percentage of picture selection for the four groups for the Reflexive Assignment Experiment under a long working memory condition.

	Picture Selection			
Group	**Correct**	**Hierarchical**	**Preposition Change**	**Reversed**
TLD	58 (5)	10 (3)	6 (2)	26 (2)
SLI	32 (4)	21 (4)	12 (2)	35 (2)
HFA	39 (4)	23 (2)	13 (1)	25 (1)
DS	33 (3)	25 (3)	16 (2)	26 (1)

Note: Reversed errors entail preposition and structural assignment errors.