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ORIGINAL PAPER

Lexical Processing in School-Age Children with Autism Spectrum Disorder and Children with Specific Language Impairment: The Role of Semantics

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Abstract Children with autism spectrum disorder (ASD) and specific language impairment (SLI) often have immature lexical-semantic knowledge; however, the organization of lexical-semantic knowledge is poorly understood. This study examined lexical processing in school-age children with ASD, SLI, and typical development, who were matched on receptive vocabulary. Children completed a lexical decision task, involving words with high and low semantic network sizes and nonwords. Children also completed nonverbal updating and shifting tasks. Children responded more accurately to words from high than from low semantic networks; however, follow-up analyses identified weaker semantic network effects in the SLI group. Additionally, updating and shifting abilities predicted lexical processing, demonstrating similarity in the mechanisms which underlie semantic processing in children with ASD, SLI, and typical development.

Keywords Autism · Specific language impairment · Lexical processing

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Introduction

Children with specific language impairment (SLI) and children with autism spectrum disorders (ASD) have been reported to display overlapping language phenotypes (Tomblin 2011). Both populations typically experience early delays in language (Dale et al. 2003; Ellis Weismer et al. 2010) and go on to have limited breadth and depth of lexical-semantic knowledge later in development (Boucher 2012; McGregor et al. 2012; Rice et al. 1990). One aim of current research is to better understand the organization of this knowledge in children with SLI and children with ASD (Alt et al. 2013; McGregor et al. 2013b; Sheng and McGregor 2010). In the current study, we investigated whether children with SLI and children with ASD have deficits in lexical-semantic processing and whether the organization of lexical-semantic knowledge differs from that of children with typical development.

Lexical-Semantic Knowledge

Lexical-semantic knowledge is frequently described in terms of breadth or depth. Breadth is often measured in the number of words an individual knows, like in receptive vocabulary assessments (McGregor et al. 2012). Depth of lexical-semantic knowledge is more difficult to quantify, but is often measured through word definition tasks, assessments indexing knowledge of multiple word meanings, or word association tasks to examine semantic networks (Boucher 2008a; McGregor et al. 2012; Norbury 2005). As lexical-semantic depth grows, children are able to use words more flexibly in various contexts. Word meanings encompass not only the meaning of the specific word, but also how it is embedded within a larger context, the knowledge domain to which the word is related (Stahl

2003). Tasks measuring depth of lexical-semantic knowledge often implement scoring schemes that indicate the thoroughness of information provided in the definition or the sophistication of word associations. Therefore, breadth and depth measurements provide different information about lexical-semantic knowledge and measuring just one may only partially capture lexical-semantic skills. For example, measuring only breadth of lexical knowledge may not provide sufficient information to identify deficits in children (Boucher et al. 2008a; Gray et al. 1999).

Lexical Knowledge in Children with ASD

Although language abilities are quite heterogeneous in children with ASD, they often display deficits in both breadth and depth of lexical-semantic knowledge. For example, they frequently have lower standard scores on measures of breadth of lexical knowledge than typically developing children (Battaglia 2013; McGregor et al. 2012; Norbury 2005). Additionally, many children with ASD have partial word knowledge. Frequently, children with ASD know dominant word meanings but are unaware of subordinate word meanings for homonyms (Norbury 2005). When asked to describe or define words, children with ASD have been found to produce rather superficial definitions (Boucher et al. 2008a; McGregor et al. 2012). Furthermore, children with ASD often demonstrate poorer understanding of how words relate to one another and have difficulties integrating new lexical-semantic information with previously learned lexical-semantic information, which further substantiates reduced semantic networks in this population (Battaglia 2013; Henderson et al. 2014; McClelland 2000).

It has been hypothesized that these observed lexical-semantic deficits may point to weaknesses in declarative memory. Boucher and colleagues propose that individuals with ASD have a declarative memory deficit, which inhibits episodic and lexical learning (Boucher et al. 2008a, b; Boucher and Mayes 2012). This theory extends beyond observations of decreased word knowledge in children with ASD and speaks to more subtle semantic impairments that are characteristic of language in higher functioning individuals with ASD despite performance that falls within the normal range on clinical language assessments (Kjelgaard and Tager-Flusberg 2001; Volden and Lord 1991). Work supporting this theory also has identified difficulties with visual recognition that is associated with conceptual-lexical knowledge in individuals with ASD, in particular in those with low functioning autism (Boucher et al. 2008a), and difficulties with integration of knowledge (Shalom 2009). Other views propose that individuals with ASD may have relative strengths in explicit or declarative learning, but atypical consolidation processes may prevent the consolidation of explicit memory and integration of lexical-semantic information (Henderson et al. 2014). In fact, Boucher and Mayes (2012) have suggested that atypical connectivity in the posterior parietal cortex or the prefrontal cortex may underlie semantic deficits in individuals with ASD.

Lexical Knowledge in Children with SLI

Children with SLI have language deficits without concomitant hearing impairments, intellectual disability, or other neurological damage (Ellis Weismer 2013; Leonard 2014). One of the most prominent clinical features of SLI is grammatical impairment (Leonard et al. 1997; Rice et al. 1999; Rice and Wexler 1996). However, children with SLI may evidence lexical impairments as well. Word learning is often depressed in preschoolers and school-age children with SLI (Gray 2003; Oetting et al. 1995; Rice et al. 1990, 1992). In addition, children with SLI are slower to name pictures and make lexical decisions (Edwards and Lahey 1996; Lahey and Edwards 1999). Although difficulties with phonological processing have been suggested to contribute to lexical task performance (Edwards and Lahey 2008), these difficulties do not seem to fully explain the lexical deficits seen in this population. Children with SLI also display difficulties learning semantic information about new words (Alt et al. 2004; Alt and Plante 2006; Kail and Leonard 1986). They produce more naming errors than their peers and provide less complete definitions for words that they misname in naming tasks (McGregor et al. 2002). Furthermore, even when linguistic demands are removed, children with SLI demonstrate weak conceptual knowledge of words (Alt et al. 2013). Although children with SLI share many linguistic features, they form a rather heterogeneous group and the extent of lexical-semantic deficits varies according to child characteristics, such as chronological age, nonverbal cognitive skills, and severity of receptive language impairment (Kan and Windsor 2010).

Organization of Semantic Knowledge in Children with ASD and SLI

Although lexical deficits in some children with ASD and SLI have been identified, only a few previous studies explored the underlying semantic organization in children with ASD and SLI (Battaglia 2013; McGregor et al. 2010, 2012). For example, McGregor et al. (2010) investigated how children organize and relate words to one another. They examined whether children understood the semantic relationship between the modifier and the head in compound words by asking children to make up compound names to describe pictures; children were also asked to parse and explain compound words. Although children with SLI performed fairly well overall, they had difficulties ordering compound words compared to vocabulary-matched children and chronologically age-matched children. Additionally, children with SLI produced poorer explanations of the modifier-head relationships than the typically developing children in both comparison groups (McGregor et al. 2010). In a repeated word association study, Sheng and McGregor (2010) examined the accessibility of semantic information in children's semantic networks. Word association responses were scored as semantic associations, "clangs", and errors. Clangs referred to responses that were related to phonological features of the target word such as words that rhymed or began with the same letter/sound. Errors were responses that were not related to the target word either semantically or phonologically. Clangs and errors are more frequent in typically developing preschoolers, but semantic responses (e.g., beach, swim) increase with age (Cronin 2002). Sheng and McGregor found that school-age children with SLI produced more clangs and errors than their chronological age-matched peers. In addition, they produced more errors than the vocabulary-matched group. They concluded that the less mature responses provided preliminary evidence that children with SLI have a deficit in lexical-semantic organization.

Additional work has examined lexical-semantic organization in children with ASD. Children with ASD have been found to produce more unrelated responses on a word association task than vocabulary-matched and chronological age-matched children (Battaglia 2013). However, a similar study found that less mature word association responses were only seen in children with ASD who have a concomitant language impairment (McGregor et al. 2012). Thus, it has been suggested that a subgroup of children with ASD have lexical-semantic deficits (McGregor et al. 2012) yet the organization of lexical-semantic knowledge may be similar to children with typical development (Battaglia 2013).

Dunn et al. (1996) administered a word fluency task to children with ASD, SLI, and typical development, who were matched on receptive vocabulary age equivalent scores and cognitive abilities. The children's responses were judged for correctness and were assigned a prototypicality score following norms from Uyeda and Mandler (1980). There were no group differences in the standard scores on the verbal fluency task; however, the ASD group produced significantly fewer prototypic category exemplars than the SLI and typically developing groups. Dunn and colleagues suggested that these findings indicate that words are organized categorically in children with ASD; however, differences in prototypicality scores may be associated with lexical access or with the organization of words within broader categories. Other studies have found that children with ASD who are matched on vocabulary do not differ in subordinate word knowledge from children with typical development or children with language and cognitive impairments (Tager-Flusberg 1985), but differences are observed in lexical access tasks (Tager-Flusberg 1991). Some have suggested that children with high functioning autism have deficits in automatic semantic processing even when there is no history of an early language delay (Kamio et al. 2007). Contrary to other studies, these examples point to differences in lexical processing in children with ASD even when compared to children with language impairment without ASD. Furthermore, although it is largely agreed that many children with ASD have atypical or immature lexical knowledge, the organization of their lexicons is not well understood.

The first goal of the present study, therefore, was to examine the organization of lexical-semantic knowledge in children with ASD, children with SLI, and children with typical development using a lexical decision task. The lexical decision paradigm serves as a means to examine lexical-semantic knowledge and processing, and is one of the most widely used tasks in psycholinguistic research (Seidenberg 1990). In a lexical decision task, the individual is presented with a stimulus item either in spoken or written form and is asked to determine whether or not it is a real word. Therefore, in order to accurately respond, one must determine whether or not the string of sounds or letters is associated with a meaning. Lexical access involves the partial activation of several lexical representations, or nodes, within one's mental lexicon. These partial activations flag potential candidates for selection. Stimulus items that are nonwords may overlap in sub-lexical features in one's lexicon (i.e., phonological overlap). Real words can vary in the number of phonological neighbors, but they can also vary in the number of semantic neighbors (Storkel 2009). One way to assess lexical-semantic organization is to examine processing of words that differ in semantic density. Words from high semantic neighborhoods, or high semantic density, are semantically associated with several words (Buchanan et al. 2001). Semantic neighbors can prime subsequent lexical decisions (Neely 1977). Moreover, words with high semantic densities facilitate lexical decisions in adults (Buchanan et al. 2001). Spreading activation models, or "more is better" models, predict that large neighborhoods should facilitate lexical access (Andrews 1997; Collins and Loftus 1975). Thus, we hypothesized that typically developing children will have better performance on words with high semantic networks than words with low semantic networks and nonwords. Due to deficits in breadth and depth of lexical-semantic knowledge, children with ASD and SLI may have worse performance overall and evidence weaknesses in online lexical-semantic processing despite being matched on a standardized assessment of receptive vocabulary knowledge. Additionally, children with ASD and SLI may not perform better on high semantic network words than low semantic network words because their lexicon may not be sufficiently integrated to yield network size facilitation effects. This study sought to contribute needed information about lexical-semantic organization and processing in children with ASD and in children with SLI (Henderson et al. 2014). Furthermore, this study was designed to examine whether the cognitive mechanisms that underlie lexical-semantic processing (focusing specifically on executive function mechanisms) are similar in children with ASD, children with SLI, and children with typical development.

Language and Executive Functions

Beyond the domain of language, deficits in other cognitive processes have been documented in children with ASD and SLI. Of note, executive functions (EF) appear to be an area of weakness in children with ASD (Joseph et al. 2005; Narzisi et al. 2013; Robinson et al. 2009). This is also true for children with SLI (Henry et al. 2012; Marton 2008; Wittke et al. 2013). Executive functions refer to several cognitive processes such as inhibitory control, updating, and shifting (Miyake et al. 2000), but they can be more generally defined as deliberate, higher-level cognitive processes that control and regulate behavior. It has been proposed that EF mechanisms interact with domain-specific mechanisms to support higher level language comprehension (Caplan 2014).

The relationship between language and cognitive control mechanisms has been documented in typically developing populations (Emerson and Miyake 2003; Fedorenko 2014). For example, the Hierarchical Competing Systems Model (HCSM) purports that language is used to manage executive control (Marcovitch and Zelazo 2009). Language facilitates the retention of information in working memory and supports subsequent actions in the absence of or in spite of environmental cues. The HCSM suggests that language enables reflection and objective conscious consideration. As would be predicted by this model, associations with vocabulary knowledge and performance on EF tasks, such as the Lexical Stroop Sort and the Dimensional Change Card Sort, are documented in the literature (Wilbourn et al. 2012). School-age children with typical development often show improved performance on EF sorting tasks when they are allowed to verbalize strategies that they are using in the task. Conversely, when language is inhibited during EF tasks, through articulatory suppression, reduced performance is seen (Russell-Smith et al. 2014). Articulatory suppression inhibits self-talk to scaffold performance on difficult tasks (Emerson and Miyake 2003). This effect, however, is not seen in children with ASD; performance in a baseline condition usually does not differ from performance in an articulatory suppression condition in children with ASD (Russell-Smith et al. 2014). It has been suggested, therefore, that children with ASD do not use inner speech to the same degree as typically developing children, which points to an atypical relationship between language and EF in children with ASD. The extent to which children with SLI use inner speech during EF tasks is not well understood. It has been suggested that personal, or inner, speech is delayed but not deviant in children with SLI and that articulatory suppression impacts performance on problem solving tasks similarly for school-age children with and without language impairment (Lidstone et al. 2012). Additional work exploring the relationship between EF and language is needed, especially in children who have typical versus atypical language development.

Successful performance on the lexical decision task may rely on cognitive control mechanisms. As described earlier, lexical access involves the partial activation of several lexical representations. Potential candidates for selection are identified in these partial activations. Inhibition of or shifting attention away from nontarget competitors and resistance to decay of the lexical stimulus item is required to ultimately arrive at a recognition and selection phase of the target lexical node. Several aspects of the lexical target are activated in this process, including phonological, semantic and syntactic properties (Neely 1977; Seidenberg 1990). Thus, lexical decision tasks require the rapid coordination of several pieces of information, which likely recruits domain-general EF mechanisms. To our knowledge, the recruitment of EF mechanisms in a language task like the lexical decision task has not been examined in children with ASD or children with SLI.

Thus, the objectives of this study were two-fold. First, the current study sought to examine lexical-semantic processing in typically developing children, children with ASD, and children with SLI by investigating how lexical processing was influenced by manipulations of the semantic network size. This first question aimed to inform our understanding of how children with ASD and SLI organize their lexical-semantic knowledge, and to examine whether there are differences in lexical-semantic organization of knowledge (vocabulary depth) compared to children with typical development, who are matched on receptive vocabulary (vocabulary breadth). Second, we explored cognitive predictors of lexical processing—specifically, EF skills—in children with typical development, ASD, and SLI. Thus, the specific research questions were:

1. Does semantic network size impact lexical processing and does it do so differentially in children with ASD, SLI, and typical development who are matched on receptive vocabulary?
2. Do executive function skills predict lexical processing abilities in children with ASD, SLI, and typical development?

Methods

Participants

Participants included eighty-five school-age children, thirty children with typical development, twenty-seven children with ASD, and twenty-eight children with SLI who were selected from a larger study examining the relationship between language and executive function concurrently and longitudinally. The children were recruited locally through community, school, and website postings. In addition, children with ASD were recruited through a research registry developed from a previous longitudinal study examining language development in toddlers with ASD. Families who agreed to be contacted about future studies received information about the current study in the mail and were given contact information to set up an appointment to participate. Children with ASD and SLI were also recruited through postings at conferences and local therapeutic clinics. All participants were monolingual English speakers per parent report. Parents of the participants with typical development reported that their child was not receiving special education services at the time of enrollment. Parents of children with ASD reported a clinical or educational diagnosis of an autism spectrum disorder for their child. Community diagnoses were primarily provided by developmental pediatricians, psychologists, neuropsychologists, or interdisciplinary teams in the educational setting. Parents provided written informed consent for their child to participate. The study procedures were approved by the university's Institutional Review Board.

According to parent report, approximately 63.5 % of participants with ASD, SLI, and typical development were Caucasian/Non-Hispanic and 16.5 % of the participants were African American, 7.1 % were Hispanic, 2.4 % were Asian American, 1.2 % were American Indian, and 9.4 % identified as being Other. Parents also provided their educational background.

Inclusionary criteria for the typically developing group included: language scores that were less than 1 standard deviation below the mean on the Clinical Evaluations of Language Fundamentals-4th edition (CELF-4; Semel and Wiig 2003), no history of special educational services, and monolingual English speaker. Children with SLI scored at least 1.25 standard deviations below the mean on one or more of the composite measures of language on the CELF-4 (i.e., Core Language, Expressive Language, or Receptive Language) or they demonstrated at least a 14 point gap between one of the CELF-4 composite measures and the nonverbal cognitive measure and had a history of, or were currently receiving language intervention services. Children in the ASD group had a documented community diagnosis of an autism spectrum disorder, met additional confirmatory criteria for the diagnosis (described below), and had no other reported disorders. All children passed a hearing screening of 1000, 2000, and 4000 Hz at 20 dB (ASHA 1997) in at least one ear, except one child with ASD. Because the parent reported no concerns of hearing loss and the child passed the hearing screening during the second visit for the larger project, this child was retained for analyses. See Table 1 for participant characteristics.

Assessments

Cognition

Children completed the Perceptual Reasoning Index from the *Wechsler Intelligence Scale for Children-IV* (WISC-4; Wechsler 2003). The Perceptual Reasoning Index consists of three subtests that measure nonverbal fluid reasoning skills. The subtests consist of: Block Design, Picture Concepts, and Matrix Reasoning, testing visual perception, visual-motor integration, visuospatial processing and coordination, and efficiency of task performance.

Language

The *Clinical Evaluation of Language Fundamentals*-4th edition (CELF-4; Semel and Wiig 2003) was administered to the children. The CELF-4 is comprised of several subtests that assess multiple domains of language. For the current study, the children completed the subtests that measure receptive and expressive syntactic and semantic language abilities.

Autism Spectrum Disorder Assessments

Parents completed the Social Communication Questionnaire (SCQ; Rutter et al. 2003), which is a screening tool for ASD. The parents of children with ASD also completed the Childhood Autism Rating Scale-Second edition, Questionnaire for Parents or Caregivers (CARS2-QPC; Schopler et al. 2010). After the first visit, an experienced psychologist reviewed the CARS2-QPC, watched a video recording of the child completing the cognitive assessment, and then completed CARS-2 High Functioning Version Rating Booklet (CARS2-HF). Typically developing

Table 1 Participant characteristics

	TD (n = 30; 17 female)		ASD (n = 27; 4 female)		SLI (n = 28; 14 female)		Group comparisons
	Mean	SD	Mean	SD	Mean	SD	
Chronological age	9.06	1.07	9.51	1.18	9.99	1.04	TD < SLI, $p < .05$; TD = ASD; ASD = SLI
Receptive vocabulary (GSV)	175.17	10.16	174.81	16.41	173.93	11.47	TD versus SLI $p = .67$, deviance ratio = 1.13 TD versus ASD $p = .91$, deviance ratio = 1.62 ASD versus SLI $p = .82$, deviance ratio = 1.43
Receptive vocabulary (SS)	106.90	14.25	103.00	16.00	97.54	11.34	TD > SLI, $p < .05$; TD = ASD; ASD = SLI
Cognition	107.57	12.14	102.59	16.47	100.64	12.53	TD = ASD = SLI, *ps* > .05
CELF-core language	104.10	10.22	84.15	16.78	83.15	11.69	TD > ASD and SLI, *ps* < .001
CELF-receptive language	104.83	12.88	85.22	16.53	86.75	13.92	TD > ASD and SLI, *ps* < .001
CELF-expressive language	104.34	10.48	86.38	16.85	82.19	12.03	TD > ASD and SLI, *ps* < .001
Maternal years of education	15.70	3.41	15.74	2.51	15.37	4.06	TD = ASD = SLI, *ps* > .05

children and children with SLI did not score above the SCQ cutoff for core autism. Children in the ASD group received a score of 25 or higher on the CARS2-HF form in addition to an in-coming community diagnosis of an autism spectrum disorder.

Receptive Vocabulary

Children's receptive vocabulary was measured using the *Peabody Picture Vocabulary Test*, fourth edition (PPVT-4; Dunn and Dunn 2007). In this assessment, children point to the picture named by the examiner. The PPVT-4 is one of the most commonly used assessments of receptive vocabulary skills in clinical and research practice, and is generally interpreted as indexing the breadth of lexical knowledge. Thus, the PPVT-4 standardized scores are ideally suited to the purpose of matching across the three groups on vocabulary breadth, enabling us to interpret children's performance on the experimental measure (lexical decision task) indexing vocabulary depth.

Experimental Task

A lexical decision task examined accuracy and speed of lexical processing. In the task, a word or a nonword was presented auditorily and children indicated whether or not the item was a real word via a button box. The stimuli consisted of forty disyllabic words and forty disyllabic nonwords. To test whether semantic network size impacts lexical processing, the words were organized according to their semantic characteristics using the University of South Florida word association, rhyme, and word fragment norms (Nelson et al. 1998). This normative resource provides a cue set size value that characterizes the number of strong associations a target word has (i.e., density of semantic network). Nelson and colleagues created the semantic cue set size values using a discrete word association task in adults (see Nelson et al. 1998 for additional details). Twenty of the words in our lexical decision task had high semantic network sizes, ranging from 20 to 33, and twenty words had low semantic network sizes, ranging from 4 to 10. All the words used in this task were words that most typically developing children acquire by the age of 5 years. The high semantic network words and the low semantic network words were matched on: word frequency, concreteness, phonological neighborhood density, and phonotactic probability. The forty nonwords followed English phonotactic rules; words and nonwords were matched on phonotactic probability. The words and the nonwords were recorded by a female speaker with a Wisconsin dialect. Stimuli were normalized to have an amplitude of approximately 63 dB. The experiment was run in E-Prime (2.0.10.242) on a PC computer. The sound stimuli were presented through the computer's speaker that attached to the bottom of the computer screen. The children responded using a button box (Cedrus RB530); accuracy and reaction time were collected for each trial.

Children were instructed to listen to each item and then decide whether or not it was a real word in English. The button box had a smiley face above one button to indicate that the item was a word and a frowning face above another button to indicate that the item was a nonword. After hearing the instructions, children participated in ten practice trials with feedback. Eighty test trials followed the practice phase. The high semantic network words, low semantic network words, and the nonwords were presented in a pseudorandomized order with no more than two words within the same category presented in a sequence. Children were able to make lexical decisions at any point in the word presentation; however, the stimuli always played to completion even if the child responded during the presentation of the stimulus.

Baseline Reaction Time

Children completed a baseline task to measure reaction time and accuracy in responding to a pure-tone beep using the button box. Tone presentations occurred after randomly varying interstimulus intervals of: 750, 1000, 1500, and 2000 ms. Children were asked to listen carefully and press a yellow button on the button box as soon as they heard the tone.

EF Tasks

The larger project included non-verbal EF tasks examining inhibition, shifting, and updating. Because the statistical model we used to address our second research question could not accommodate all the EF tasks, we used a bottom-up approach to identify the two EF tasks that were most appropriate in testing associations between lexical processing and domain-general EF mechanisms. To that end, we first conducted bivariate correlational analyses between the EF measures and lexical-decision performance, and found that tasks measuring shifting and updating were most closely associated with lexical processing performance across the three groups (rs $> .37$). The other measures only weakly correlated with lexical decision task accuracy scores (rs $< .3$). Furthermore, inhibition and shifting measures correlated moderately with each other. To prevent problems with multilcolinearity, and to follow regression predictor variable guidelines, we included only the measures of updating and shifting in the models addressing research question 2.

Shifting Children completed a nonverbal computerized version of the Dimensional Change Card Sort (Zelazo 2006) to measure shifting abilities. Children participated in two blocks where they sorted cards based on a specific dimension (e.g., color or shape). They then participated in a third mixed block where the sorting dimension alternated in an unpredictable order. Visual cues (indicating shape or color), rather than linguistic cues, were provided to indicate the sorting rule for a given trial. Shifting ability was indexed by the speed and accuracy with which the child performed in the mixed block during switched sorting rule trials.

Updating A nonverbal computerized N-back task was administered to measure updating skills. The task required participants to determine whether each trial image matched the abstract image that was presented n positions before the current trial (Owen et al. 2005). Three blocks were administered: 0-back, 1-back, and 2-back. Responses were made via a button box. An overall accuracy score and reaction time was calculated for children based on performance across the blocks.

Group Matching

Children were matched group-wise on receptive vocabulary abilities measured by a standardized assessment (PPVT-4). The PPVT-4 growth value scores were used as the matching variable. Growth value scores correspond to raw scores and measure vocabulary with respect to an absolute equal-interval scale of knowledge. Because growth scale values are more psychometrically sound, they serve as a superior value to raw scores when making statistical comparisons (Dunn and Dunn 2007). Matching procedures followed guidelines proposed by Kover and Atwood (2013) and Mervis and Klein-Tasman (2004). The groups were well matched on receptive vocabulary growth scores such that children with ASD, SLI, and children with typical development had similar receptive vocabulary growth scores, $F(2, 82) = 0.07$, $p = .932$, $\eta_p^2 = .002$.

Data Cleaning

Before conducting analyses, the data were cleaned at the trial level. Trials in which the child responded within the first 500 ms were excluded because cleaning analyses revealed that accuracies earlier than that time point were not above chance. In addition, child accuracies for each stimulus item were reviewed to identify items with consistently poor performance across children. As a result, two words with low semantic network sizes were removed from the analyses. Two additional children with ASD were not included in the current study because their accuracy performance was greater than 2.5 standard deviations from the mean across high semantic network words, low semantic network words, and nonwords. Performance on the practice items was high across the groups indicating that children quickly understood the lexical decision task procedures (TD mean accuracy = 92.72 %, SD = 6.59 %; ASD mean accuracy = 89.99 %, SD = 7.67 %; SLI mean accuracy = 88.97 %, SD = 10.68 %).

Results

Analysis Plan

Mixed effect regression models were built to examine whether semantic network size affects lexical processing. Lexical decision accuracy was examined using a mixed effect logistic regression model and reaction time was examined using a mixed effect regression model. Trial-level accuracy and reaction time served as the dependent variables for research question 1. Fixed effects included semantic network category (i.e., high semantic network, low semantic network, or nonword), group, and interactions between group and semantic network. Planned orthogonal contrasts tested for statistical differences of words (high and low) compared to nonwords and high versus low semantic network words. The random effects in the model allowed participants to vary and for participants to vary according to semantic network in accuracy and reaction time. The groups did not statistically differ on accuracy or reaction time on the baseline reaction task; therefore, no group adjustments were made to the lexical decision task data. We used linear regression models to examine whether EF skills predicted performance on the lexical decision task in the three groups. Accuracy and reaction time scores were used in the linear regression models. Across all analyses, planned orthogonal contrasts were used for group so that main effects for predictor variables represented data from all groups. See Table 2 for group performance scores.

Lexical Decision Accuracy

When comparing accuracy of lexical decisions, we found a main effect of semantic network such that children across all groups were more accurate when responding to words from high semantic networks than low semantic networks, $z = 3.417$, $p < .001$. Additionally, children were more accurate in responding to real words (high and low semantic networks) than nonwords, $z = 6.876$, $p < .001$. There were no statistically significant group effects, and there were no significant interactions of group and semantic network size (see Table 3). Although there were no interactions, visual examination of the data indicated that the semantic network effect was more robust in the TD and ASD groups than the SLI group. Descriptively, 6 of the 30 (20 %) participants with typical development and 3 of the 27 (11.11 %) participants with ASD had an average accuracy score that was higher for the low semantic network words than the high. Conversely, 10 of the 28 (35.7 %) of the participants with SLI had higher average performance on low versus high semantic network words. To further explore this, within-group mixed effect logistic regression analyses were conducted. As suspected, the typically developing, ASD, and SLI groups had higher accuracy for words than nonwords ($ps < .001$). However, only the typically developing and ASD groups were more accurate in responding to words from high semantic networks than low semantic networks ($ps < .009$); this pattern was not seen in the SLI group ($p = .502$).

Lexical Decision Reaction Time

Log transformed reaction times for correct responses served as the dependent variable in this mixed-effect linear regression model. There was a main effect of semantic network size, such that children responded faster to real words, in both the high and low semantic network categories, than nonwords, $t = -12.829$, $p < .001$. There was no difference in reaction times of responses to words with high or low semantic networks, $t = 0.810$, $p = .418$. The model did not reveal significant main effects of group or interactions of group and semantic network. As with the accuracy data, we explored within-group profiles. We originally hypothesized that children would respond the fastest to high semantic network words; this was not found in the main analysis. Thirteen of the 30 (43.33 %) participants with typical development and 12 of the 27 (44.44 %) participants with ASD on average responded more quickly to the *low* semantic network words than the high. Seventeen of the 28 (60.71 %) participants with SLI had faster average responses on low semantic network words. To further explore this, within-group mixed effect linear regression analyses were conducted. The typically developing, ASD, and SLI groups responded more quickly to words than nonwords ($ps < .001$). However, responses to high semantic network words were not significantly faster than responses to low semantic network words in the

Table 2 Lexical decision task and cognitive tasks percent accuracy

	TD		ASD		SLI	
	Mean	SD	Mean	SD	Mean	SD
High semantic network words[a]	95.71	5.42	93.80	7.33	94.29	5.34
Low semantic network words[a]	92.11	6.58	88.95	8.15	93.20	7.64
Nonwords[a]	84.57	13.71	82.71	15.43	85.98	8.10
Overall lexical decision task performance[a]	89.18	8.36	87.05	10.18	89.77	5.66
Card sort switch[a] (shifting)	72.63	15.46	67.93	16.27	65.50	13.76
Visual N-back overall[a] (updating)	79.97	8.51	76.07	13.85	82.75	7.58

[a] Accuracy

Table 3 Lexical decision task accuracy: investigating semantic network size

Fixed effect	B	Standard error	*z*-value	*p* value
Intercept	2.515	0.095	26.405	<.001
High and low words versus nonwords	0.859	0.125	6.876	<.001
High versus low words	0.604	0.177	3.417	<.001
TD versus ASD and SLI	−0.196	0.190	−1.029	.304
ASD versus SLI	−0.202	0.221	−0.914	.361
High and low words versus nonwords: TD versus ASD and SLI	−0.147	0.240	−0.613	.540
High and low words versus nonwords: ASD versus SLI	−0.284	0.320	−0.890	.373
High versus low words: TD versus ASD and SLI	−0.123	0.275	−0.445	.656
High versus low words: ASD versus SLI	0.498	0.357	1.393	.164

typically developing ($t = 0.3$, $p > .5$), ASD ($t = -0.3$, $p > .5$), or SLI ($t = 1.4$, $p > .1$) groups.

Cognitive Predictors of Lexical Decision Performance

Before examining cognitive predictors of lexical decision performance, we compared group performance on the EF measures. There were no group differences on the shifting task accuracy, $F(2, 82) = 1.66$, $p = .196$, $\eta_p^2 = .039$, or reaction time, $F(2, 82) = 1.86$, $p = .162$, $\eta_p^2 = .043$. Also, there were no group differences on the updating accuracy scores, $F(2, 82) = 2.93$, $p = .059$, $\eta_p^2 = .067$, or reaction time, $F(2, 82) = 2.42$, $p = .095$, $\eta_p^2 = .056$. A linear regression model revealed that executive function skills contribute to lexical processing abilities across all groups, $F(8, 76) = 4.29$, $p < .001$, $R^2 = 0.311$ (see Table 4). Updating and shifting accuracy explained unique variance on overall lexical decision task accuracy, $t = 2.94$, $p < .004$, $t = 3.51$, $p < .002$ respectively. There were no significant group differences (*p*s > .800) or interactions of group and EF task (*p*s > .12). Analysis of the reaction time data revealed that executive function skills contribute to lexical decision reaction times across all groups, $F(8, 76) = 3.60$, $p < .002$, $R^2 = 0.275$. Updating and shifting abilities explained unique variance on overall lexical decision task reaction time, $t = 2.37$, $p = .021$, $t = 3.87$, $p < .001$, respectively. There were no significant group or interactions of group and EF (*p*s > .339).

Discussion

The results of the current study suggest that lexical-semantic knowledge is organized similarly in children with typical development, ASD, and SLI, who are matched on receptive vocabulary knowledge. These findings are inconsistent with some previous work that suggests that children with ASD (Dunn et al. 1996) and SLI (Sheng and McGregor 2010) have an atypical organization of lexical-semantic knowledge. The previous studies used a different methodology and examined the organization of lexical-semantic knowledge through an expressive task. Our study tested lexical processing and the organization of lexical-semantic knowledge through a receptive measure. It is possible that the differences seen may stem from differences in receptive relative to expressive language abilities. Expressive tasks seem to be more taxing and are therefore more likely to yield reduced lexical-semantic performance (Gray et al. 1999). However, it is precisely for this reason that receptive tasks may be more useful for examining lexical-semantic organization in children with ASD and in

Table 4 Cognitive predictors of lexical decision task accuracy

Predictor	B	β	Standard error	*t*-value	*p* value
Updating	0.261	0.333	0.089	2.939	.004
Shifting	0.189	0.350	0.054	3.512	.001
TD versus ASD and SLI	0.002	0.010	0.017	0.096	.923
ASD versus SLI	−0.004	−0.021	0.021	−0.207	.837
Updating: TD versus ASD and SLI	0.262	0.144	0.191	1.372	.174
Updating: ASD versus SLI	−0.100	−0.054	0.215	−0.463	.645
Shifting: TD versus ASD and SLI	−0.003	−0.003	0.110	−0.027	.979
Shifting: ASD versus SLI	0.213	0.156	0.136	1.569	.121

children with SLI, as the findings are less likely to be affected by general cognitive effort, and by differences in processing capacity across groups with different language abilities.

Our results are in line with the idea that lexical-semantic knowledge in children with ASD and SLI may be immature but follows a similar organization of knowledge as in typically developing children (Battaglia 2013; McGregor et al. 2012). In fact, as a group, the children with SLI in the current study had significantly lower standard scores on the PPVT-4 than the typically developing children despite being matched on growth scale values. Although the children with SLI tended to have lower standard scores compared to the typically developing group, most children with SLI scored within a standard deviation of the mean. As a group, the children with ASD did not have significantly lower standard scores on the PPVT-4, but some individual children did score below a standard deviation of the mean which would indicate deficits in vocabulary knowledge. This is not surprising given the heterogeneity of language skills that has been documented in children with ASD (Kjelgaard and Tager-Flusberg 2001; Loucas et al. 2008).

Although there were no interactions of group and semantic network, our findings suggest a possibility that some children with language impairment have an atypical organization of lexical-semantic knowledge. While statistical analyses revealed that all groups were faster and more accurate when responding to words (high and low) than nonwords, upon visual inspection, we noticed a difference in the robustness of semantic network effects across the three groups. Additionally, standard errors increased for the interaction terms, indicating that estimated values were less precise for the disordered groups. In the follow-up analyses, we found that the typically developing and ASD groups had higher accuracy scores when responding to words from high than low semantic networks. This pattern is similar to previous findings in typically developing adults (Buchanan et al. 2001). In contrast, the SLI group had similar accuracy scores for high and low semantic network words. Reaction times did not differ between high and low semantic network words in any of the groups.

Given the exploratory nature of the follow-up analyses, our interpretation of the findings must necessarily be cautious. However, it does appear that the high semantic network words did *not* show a processing advantage over the low semantic network words for some of the children with SLI. The representations of the high semantic network words may be linked to fewer semantic neighbors in children with SLI than children with typical language abilities, and therefore, the high semantic network words may not have in fact been high semantic network words for children with SLI. As a result, responses did not indicate a benefit from spreading activation effects. This suggested explanation is plausible given the documented deficits in depth of lexical-semantic knowledge in children with SLI (Kail et al. 1984; McGregor et al. 2013a). It is unclear why similar findings were not found for the ASD group, given that they too have been found to have lexical-semantic deficits in prior work (Loucas et al. 2008). One explanation is that the children with ASD in the current study were relatively high functioning, and although their CELF-4 language scores bordered around a standard deviation below normal mean scores, it is possible that we did not include as many children with concomitant language impairments as other studies. The idea that some children with structural language impairment have an atypical organization of lexical-semantic knowledge may partly explain the inconsistent findings in the literature regarding group differences in lexical processing in children with ASD and SLI (Kamio et al. 2007; McGregor et al. 2012; Sheng and McGregor 2010; Toichi and Kamio 2001). Work from the priming and contextual facilitation literature has indicated that overall, children with ASD and SLI evidence priming effects, but their responses may still differ from typically developing control groups (Harper-Hill et al. 2014; McCleery et al. 2010; Norbury 2005; Sabisch et al. 2006).

Beyond the insights provided about semantic organization, this study also demonstrated that online lexical processing abilities did not differ in accuracy or reaction time across the diagnostic categories when children were matched on receptive vocabulary abilities. The majority of previous work examining lexical processing through various tasks in children with ASD and SLI typically identifies weaknesses in lexical processing (Leonard 2014; Norbury 2005). For example, children with ASD and SLI have been found to identify fewer subordinate word meanings (Norbury 2005) and to name pictures more slowly than chronologically age-matched peers (Henderson et al. 2011; Lahey and Edwards 1996). Furthermore, children with SLI and children with ASD who also have language impairment have been found to look at distractor images more than children without language impairment in some experimental conditions in eye-gaze tasks (Brock et al. 2008; McMurray et al. 2010). In addition, children with SLI have been found to be slower to recognize target words in sentences (Montgomery and Leonard 1998) and slower to make judgments in a lexical decision task (Edwards and Lahey 1996) compared to chronological age-matched peers.

However, other studies do not identify differences between groups with language impairments and control groups (Brock et al. 2008; Norbury 2005). For instance, in a behavioral task, Norbury (2005) found that children with SLI and children with ASD who also have language impairment had similar accuracy scores as children with typical language abilities with and without ASD in judging the appropriateness of a picture to a target word when it was presented in neutral sentences. Part of the reason for the mixed findings may be due the variety of experimental tasks used, including the focus on expressive versus receptive vocabulary. Another likely reason for the conflicting findings is that studies used different control group matching criteria. Some studies compared lexical processing abilities between children with ASD or SLI with children who were matched on chronological age, but not vocabulary knowledge (Edwards and Lahey 1996; Kail et al. 1984; McGregor et al. 2012). Although it is important to understand lexical-semantic knowledge in children with SLI and ASD relative to their typically developing peers, it is rather unsurprising to identify decreased lexical processing performance if groups are mismatched in lexical knowledge to begin with. More insight could be gained if children with ASD and SLI performed more poorly than vocabulary-matched children on an online lexical processing task. Such findings could indicate differences in the mechanisms that underlie lexical knowledge and processing in children with impairments compared to age-matched peers. Therefore, the absence of a group difference in lexical processing in the current study, despite group differences in higher-level language abilities measured by the CELF, render the main findings even more notable. Furthermore, these findings may provide additional methodological support for controlling for vocabulary knowledge when testing for group differences in lexical processing skills.

The mixed findings in the previous literature on lexical processing in groups with ASD also likely reflected language status. Although the groups were matched on vocabulary the two clinical groups scored significantly worse than the typical controls on overall language measures that also assessed grammatical skills. Individual children in the ASD group, however, varied with respect to their language abilities. Subdividing the ASD group according to the presence or absence of structural language impairment in the current study was impossible, as it would have led to small group sizes that were not matched on receptive vocabulary. Future work should explore this variable, because it is likely to reveal important information about the organization of lexical-semantic knowledge in children with ASD with and without structural language impairment.

Lastly, our findings indicate that updating and shifting abilities predict performance on lexical decisions in children across all groups. This finding contributes to our understanding of the relationship between executive functions and language mechanisms. Although the children with ASD tended to have poorer updating performance, and children with ASD and SLI tended to have poorer shifting performance, overall, groups did not differ *significantly* in EF task performance. This finding is in contrast with previous work that has revealed EF deficits in children with ASD (Bennetto et al. 1996; Landa and Goldberg 2005) and in children with SLI (Henry et al. 2012; Roello et al. 2015). However, previous work has yielded mixed findings of EF deficits in children with ASD and SLI (Griffith et al. 1999; Henry et al. 2012; Kenworthy et al. 2008). It is important to again note that our group matching criteria differed from most prior studies in that EF abilities were compared across groups matched on vocabulary level rather than age or nonverbal cognition. Given the association between components of EF and lexical processing across groups, differences in EF performance would not be expected in vocabulary-matched groups. Additionally, the lack of significant group differences in EF could potentially be because in the current study, EF abilities were measured through nonverbal tasks, whereas previous studies have relied on EF measures that incorporate language (Henry et al. 2012; Russell-Smith et al. 2014). Children with language impairments may find linguistic EF tasks more difficult than non-linguistic EF tasks, and future work should examine EF abilities in children with SLI and children with ASD using verbal versus nonverbal EF assessments, to better characterize EF abilities and the effects of language demands on EF task performance. Importantly, we observed relationships between non-verbal EF measures and lexical processing in all three groups of children.

The directionality of the relationship between language and executive functions is impossible to establish in this study. However, our findings may be interpreted to suggest that children across diagnostic categories recruit nonlinguistic mechanisms to support linguistic processing. This supports the Hierarchical Competing Systems Model in affirming that there is a relationship between language and executive function mechanisms (Marcovitch and Zelazo 2009). However, the HCSM describes the relationship between EF mechanisms and language as language supporting performance on executive function tasks (i.e., inner speech). Our findings may suggest a reverse relationship where EF mechanisms can scaffold lexical processing. As such, our work also supports suggestions that performance on language tasks can be influenced by EF abilities (Mainela-Arnold et al. 2008, 2010; Norbury 2005). This relationship was expected given that the lexical decision task required children to coordinate phonological and semantic activations and to shift attention away from distracting phonological information in order to produce accurate lexical judgments based on semantic knowledge. Connectionist models explain that there is global competition of activation in neural networks (McClelland and Elman 1986). Furthermore, processing pathways can be impacted by competing information and can be influenced by learning and attentional control (Cohen et al. 1990). Others have pointed to working memory as a key mechanism in attentional control during learning and processing (Baddeley et al. 1998; Baddeley 2003).

Unlike some studies in the literature (Joseph et al. 2005; Landa and Goldberg 2005), we found that EF task performance was related to lexical processing for the children with ASD. This aligns with other work that suggests that language interacts with inhibition abilities in a lexical Stroop task in children with ASD and children with typical development (Eskes et al. 1990; Wilbourn et al. 2012). Similar to our findings, it has been suggested that working memory, but also inhibition, affects the efficient use of resources to activate relevant information in language tasks in children with SLI (Im-Bolter et al. 2006). There were no group differences on the EF measures; therefore, it is possible that the interplay between language and EF is mostly seen in relatively high functioning children with ASD and SLI. To better understand the directionality of the relationship between domain-general executive function mechanisms and language processing, future studies should include longitudinal data, and/or employ an experimental design, training EF abilities and testing for improvements in domain-specific, language-processing tasks.

Limitations and Conclusions

This study examined lexical processing and the organization of lexical-semantic knowledge in children with ASD, SLI, and typical development. We would like to note some of the limitations that should be addressed in future work. First, although our sample sizes were substantial and we employed sensitive statistical methods that accounted for random variance, increasing sample sizes in all of the groups would allow for additional power to potentially uncover subtle differences in groups. It is possible that increased sample sizes could have provided additional power to detect subtle interactions of group and executive function skills in predicting lexical processing skills. Furthermore, an increased sample size would be particularly helpful in examining lexical-semantic organization in children with SLI given the trend for accuracy scores to be similar between high and low semantic network words. Second, future studies may wish to include a subgroup of children with ASD who have structural language impairments and a subgroup of children with ADS who do not. In doing so, it would be important to have vocabulary-matched children with typical development for both the ASD-normal language and ASD-language impaired subgroups. A study such as this could better speak to the origins of lexical-semantic deficits observed in children with ASD being rooted in autism symptomatology or comorbid language impairment (Loucas et al. 2008; McGregor et al. 2012).

Finally, our categorization of high and low semantic network size words was based on lexical characteristics developed from adult studies. Although robust differences in accuracy were seen between high and low semantic network size words in children with ASD and typical development, it would have been preferable to use semantic characteristics gathered from child studies. Unfortunately, to our knowledge, those data are not currently available. Future work in developing normative data on semantic density or semantic network size in children would benefit work exploring questions such as the one addressed by the present study.

The current study provides a novel way in which to examine receptive lexical-semantic processing and the organization of semantic knowledge in children with ASD and SLI. The findings indicate that school-age children with ASD and SLI who are matched on standardized measures of receptive vocabulary do not necessarily have an atypical organization of lexical-semantic knowledge. Furthermore, lexical processing in a lexical-decision task does not appear to be deficient in children with ASD or SLI. However, given the range of standard vocabulary scores on the PPVT-4, it is evident that children with ASD and SLI have a shared language phenotype of being at heightened risk of having vocabulary deficits. Additionally, the trend for similar accuracy on high and low semantic network words in the SLI group would suggest that lexical-semantic networks in some children with language impairments may be less interactive and/or more sparsely populated. Therefore, clinicians should monitor both breadth and depth of lexical-semantic knowledge in children with language impairments to adequately support skills necessary for academic success. Furthermore, the current study was the first study, to our knowledge, to examine the relationship between specific EF abilities and lexical-semantic processing in children with ASD and SLI. We found that shifting and updating abilities predicted lexical processing performance in children across the three groups. This finding supported previous work suggesting that domain-general executive function mechanisms support language processes; however, we suggest that this profile is shared across children in ASD, SLI, and typical development. This finding may have important clinical ramifications, as it suggests that one potential way to improve lexical-semantic functioning in children with language impairments could be through targeting domain-general EF mechanisms.

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