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ScienceDirect
Journal of Communication Disorders 43 (2010) 77–91
Journal of Communication Disorders

The contribution of processing impairments to SLI: Insights from attention-deficit/hyperactivity disorder

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Received 24 March 2009; received in revised form 14 August 2009; accepted 14 September 2009

Abstract

Slowed speed of processing and impaired rapid temporal processing (RTP) have been proposed to underlie specific language impairment (SLI), but it is not clear that these dysfunctions are unique to SLI. We considered the contribution of attention-deficit/hyperactivity disorder (ADHD), which frequently co-occurs with language impairments, to performances on processing tasks. School-aged children who had SLI without concurrent ADHD ($n = 14$), ADHD without concurrent SLI ($n = 14$), and typical development (TD, $n = 28$) performed two nonverbal speeded tasks and one auditory RTP task. RTP impairments were found in many children with SLI and ADHD, and some children with TD. Children with ADHD demonstrated slower processing speed than children with SLI or TD. Overall, findings questioned the uniqueness of these processing dysfunctions to language impairments and the validity of the behavioural paradigms traditionally used to estimate processing dysfunctions. Accounts of SLI should be further scrutinized by considering the influence of other disorders.

Learning outcomes: Readers will (1) become familiar with areas of overlap between SLI and ADHD, (2) understand some of the confounds associated with behavioural measures of processing speed in children, and (3) recognize the value in testing models of language disorders by including participants with other types of disorders.

Recent research investigating children with specific language impairment (SLI) has focused on specific perceptual or cognitive processing impairments, with a view toward finding fundamental causal mechanisms and markers of this disorder (Conti-Ramsden, Botting, & Faragher, 2001). Through pursuit of these objectives, a number of processing dysfunctions have been identified as possible markers of SLI, including impaired speed of processing (Kail, 1994; Lahey, Edwards, & Munson, 2001; Miller, Kail, Leonard, & Tomblin, 2001; Montgomery, 2005) and rapid temporal processing (Benasich, Thomas, Choudhury, & Leppanen, 2001; Tallal, 2000). The proposed link between these processing dysfunctions and language disability is drawn primarily from the fact that the children with SLI under study have, by definition, impaired linguistic functioning. Although this is a reasonable inference, a more intricate test of the proposed causal link between processing and language would be to examine the target processes in groups of children

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0021-9924/$ – see front matter
doi:10.1016/j.jcomdis.2009.09.003

with other forms of impairments that do not involve language. Because this issue has received limited attention in the literature to date, we sought to explore the contributions of SLI and Attention/Deficit Hyperactivity Disorder (ADHD), a behavioural disorder that frequently co-occurs with language impairments (Baker & Cantwell, 1991; Beitchman, Hood, Rochon, & Peterson, 1989), to two aspects of processing proposed to be impaired in SLI: speed of processing and rapid temporal processing.

1. Processing dysfunctions in SLI

Slowed speed of processing and impaired rapid temporal processing have both been proposed to be causally connected to impaired language development and functioning. For example, in the generalized slowing account, children with SLI are thought to have a central dysfunction that involves slowing across all aspects of mental processing (Kail, 1994; Miller et al., 2001; Windsor & Hwang, 1999). Irrespective of the nature or complexity of the task, children with SLI are proposed to be slower than their peers by a constant factor. The time-dependent nature of speech is thought to make language development especially vulnerable to the effect of slow information processing (Miller et al., 2001). In the rapid temporal processing (RTP) dysfunction account (which some have argued to be subsumed under generalized slowing, see Montgomery & Windsor, 2007), children with SLI are proposed to have a central impairment in processing quick transitions in sensory input (Benasich et al., 2001; Tallal, 2000). The inability to process rapidly changing elements within the speech signal is viewed as a key contributor to language impairments, because a number of phonemic contrasts are signalled within extremely brief time frames. Thus, an underlying RTP impairment is proposed to interfere with development of the phonological system, and, consequently, spoken and written language (Tallal, 2000).

Although empirical evidence exists to support the presence of these processing dysfunctions in children with SLI, the models remain open to debate and controversy. The statistical analysis methods used to support the generalized slowing hypothesis have been challenged, with other analysis methods pointing to process-specific, not generalized, slowing in SLI (Windsor, Milbrath, Carney, & Rakowski, 2001). Although some have concluded that the evidence for a RTP dysfunction in language disorders is compelling (Farmer & Klein, 1995; Habib, 2000; Leonard, 1998), others have failed to find differences between children with SLI and children with typical language development in RTP (Heltzer, Champlin, & Gillam, 1996; McArthur & Bishop, 2001; Rosen, 1999). In addition, some authors have argued that this dysfunction is not specific to input that is rapid, but rather may reflect a broader based impairment in auditory processing (Heltzer et al., 1996; Rosen, 1999). Others have argued that RTP impairments may not be causally linked to language impairments (Bishop, Carlyon, Deeks & Bishop, 1999). Counterarguments to these criticisms have included the fact that RTP dysfunctions do appear in at least a subset of children with language disorders (McArthur & Bishop, 2004) and the fact that failures to identify this dysfunction in some children with language impairment may reflect inadequate measurement sensitivity or maturational changes across different age groups that have been studied (Bishop & McArthur, 2005; Joanisse & Seidenberg, 1998; McArthur & Bishop, 2005).

An additional source of debate arises from the potential confounds introduced by the behavioural paradigms typically used for measuring the processes of interest. Such confounds have been at the forefront of the controversy surrounding the RTP account. Because RTP paradigms place demands on higher level processes (e.g., attention, memory, learning), it is arguably difficult to attribute poor performance directly to impaired RTP. Indeed, Bishop et al. (1999) suggested that poor performances by children with SLI on RTP tasks might reflect attentional problems. Moreover, Ludlow, Cudahy, Bassich, and Brown (1983) found impaired performance on a task measuring RTP in a group of six children with ADHD who did not have concurrent SLI or learning disabilities. Although similar concerns have not been central to the critiques of other processing accounts of SLI, a confounding influence of higher level processes is certainly a plausible issue for studies examining these accounts as well.

2. The role of ADHD

Little research has explored whether the aforementioned processing dysfunctions are indeed *unique* to disorders of language, one of the precursors to proposing causality. Evidence for an impaired aspect of processing in children with SLI relative to children with typical development does not establish whether the process contributes to impaired language development. It is also important to determine that the dysfunctional process is associated with SLI and not another co-occurring disorder in the sample. The high rates with which other developmental and behavioural disorders occur in the SLI population (Baker & Cantwell, 1991) suggest that this possibility cannot be readily dismissed. It is also important to determine whether children with other disorders besides SLI have dysfunctions in the basic process. If a processing dysfunction is found in children who do not have a core linguistic impairment, it is difficult to argue that the dysfunction is central to impaired language development or is a marker of SLI.

ADHD commonly co-occurs with language impairments, thus warranting attention when considering the uniqueness of specific processing dysfunctions to SLI. ADHD is the most common psychiatric/behavioural disorder of childhood, affecting roughly 3–7% of school-aged children (Polanczyk & Jensen, 2008). Children with ADHD present with persistent problems in one or both of two behavioural symptom clusters: inattention and hyperactivity-impulsivity. These symptoms are demonstrated at a frequency and severity that is judged to be inappropriate for the child's level of development and are associated with impairment in daily functioning (American Psychiatric Association, 2000). Of importance here, 20–40% of children with language impairments also have ADHD (Baker & Cantwell, 1991; Beitchman et al., 1989) and 40–60% of children with ADHD have language impairments (Cohen, Davine, Horodezky, Lipsett, & Isaacson, 1993; Oram, Fine, Okamoto, & Tannock, 1999).

Few investigators have examined the possible role of other disorders, including ADHD, when examining processing dysfunctions in SLI. Despite prior concerns about the role of attentional problems in RTP task performance, investigators have not been consistent in determining the degree of ADHD co-occurrence in their SLI samples or controlling for its potential influence on their findings. Moreover, examinations of children with ADHD suggest that RTP dysfunctions (Ludlow et al., 1983) and slowed processing speed (e.g., Carte, Nigg, & Hinshaw, 1996; Kunsti & Stevenson, 2001; Scheres, Oosterlaan, & Seregeant, 2001; Weiler, Holmes Bernstein, Bellinger, & Waber, 2000) may also be present in this population.

We aimed to contrast the contribution of SLI and ADHD to performances on three measures previously used in the literature to examine processing dysfunctions in children with SLI: two nonverbal speed of processing tasks varying in degree of cognitive load and one auditory rapid temporal processing task. To do so, we tested processing speed and RTP in three groups of children who showed: (1) receptive-expressive SLI without concurrent ADHD, (2) ADHD without concurrent SLI, and (3) typical language and behaviour development. In line with current theories of SLI, we predicted that children with SLI who did not have ADHD, but not children with ADHD who did not have SLI, would show impaired performance on our processing tasks relative to children with typical development.

3. Method

3.1. Participants

Fifty-six children from a large metropolitan area participated: 14 children (3 girls) with receptive-expressive SLI, 14 children (4 girls) with ADHD, and 28 children (8 girls) with typical language and behaviour development (TD). Participants ranged in age from 6 years, 5 months to 11 years, 3 months. The groups did not differ in age (see Table 1). Most children were recruited and tested within a suburban school board. Five children with ADHD were referred by two paediatricians, and two children with ADHD and two children with TD by personal contacts. These nine children were tested in their home, their paediatrician's office, or a university clinic.

The relatively small size of our groups with SLI and ADHD reflects the challenges in recruiting children who met our rigorous inclusionary criteria (described below), which were designed to focus on the receptive-expressive type of language impairment and to exclude the presence of other disorders (e.g., ADHD + SLI). Originally, 27 children who met referral criteria for the group with SLI and 21 for the group with ADHD were identified. Of these, 13 candidates for the group with SLI were subsequently excluded, the majority due to evidence for an expressive, but not receptive, language impairment (10), and the remainder due to behaviour suggestive of an autism spectrum disorder (1), behaviour ratings suggestive of ADHD (1), and presence of a chromosomal disorder (XYY; 1). Seven candidates for the group with ADHD were excluded due to below average performances on the language measure.

All included participants passed a pure-tone hearing screening (30 dB tone presented bilaterally at .5, 1, 2 and 4 kHz) and had no known sensory, neurological or major psychiatric disorder (e.g., autism, psychosis). Most participants were native English speakers. Three children had a native language other than English (Spanish for one child with SLI, Punjabi for two children with TD) but had been attending an English primary school for at least four years and were reported by parents to speak English as their primary language.

No participant had evidence of a global cognitive impairment. *Wecshler Intelligence Scale for Children – Third Edition* (*WISC-III*; Wechsler, 1991) Performance IQ (PIQ) scores were obtained from the student records of 11

Table 1
Comparisons of groups with SLI, ADHD and TD on Age, IQ, language and behaviour.

	Group 1 SLI	Group 2 ADHD	Group 3 TD	*df*	*F*	*p*	η^2	Post hoc
Age (years)	9.6 (1.3)	9.0 (1.4)	9.7 (1.2)	2,53	1.8	.181	.06	–
WISC-III performance IQ	96 (14)	101 (13)	–	21	$t = -1.1$	.308	$d = .36$	
CELF-3								
Receptive language	74 (8)	96 (10)	108 (12)	2,53	46.8	<.001	.64	1 < 2 < 3
Expressive language	75 (8)	96 (16)	105 (13)	2,53	26.1	<.001	.50	1 < 2, 3
CPRS-R[a,b]								
ADHD index	56 (11)	72 (13)	46 (5)	2,46	32.1	<.001	.58	2 > 1 > 3
DSM-IV inattentive	55 (11)	66 (14)	47 (6)	2,46	16.0	<.001	.41	2 > 1 > 3
DSM-IV hyperactive-Impulsive	56 (13)	74 (14)	50 (7)	2,46	20.1	<.001	.47	2 > 1,3
CTRS-R[a]								
ADHD index	56 (9)	73 (12)	48 (8)	2,53	25.4	<.001	.52	2 > 1,3
DSM-IV inattentive	57 (9)	68 (10)	48 (7)	2,53	19.1	<.001	.45	2 > 1 > 3
DSM-IV hyperactive-impulsive	53 (9)	71 (14)	48 (8)	2,53	20.6	<.001	.47	2 > 1,3

Note: *CELF-3* and WISC-III performance IQ scores are standard scores ($M = 100$, $SD = 15$). *CPRS-R* and *CTRS-R* scores are *T*-scores ($M = 50$, $SD = 10$).

[a] MANOVA, $F(12,84) = 5.1$, $p < .001$.

[b] *CPRS-R* was not returned for one child with SLI, two children with ADHD, and four children with TD.

children with SLI and 12 children with ADHD. Scores ranged from 81 to 124 for children with SLI and 85 to 128 for children with ADHD. The groups did not differ in PIQ scores (See Table 1). The remaining children with SLI and ADHD had PIQ scores of at least 80 based on referral criteria, but their parents did not return consents to obtain the specific scores. Nonverbal intelligence scores were not available for children with TD. However, they were presumed to have adequate cognitive functioning because parents reported no history of developmental, learning, or behaviour problems, and neither parents nor teachers reported any current concerns about learning or behaviour. To reduce the chances of recruiting children with above average intelligence, teachers were specifically requested to refer only those children who were average achievers, that is, those who were meeting, but not exceeding, grade expectations.

In an initial session, the *Clinical Evaluation of Language Fundamentals – 3rd edition* (*CELF-3*; Semel, Wiig, & Secord, 1995) was administered to all children. Parents completed a developmental history questionnaire and the *Conners' Parent Rating Scale - Revised* (*CPRS-R*; Conners, 1997; Conners, Sitarenios, Parker, & Epstein, 1998a). Teachers completed the *Conners' Teacher Rating Scale - Revised* (*CTRS-R*; Conners, 1997; Conners, Sitarenios, Parker, & Epstein, 1998b). Three scales from the *CPRS-R* and *CTRS-R* were used to examine the presence of behaviours associated with ADHD: the Conners' ADHD Index, the *DSM-IV* Inattentive scale, and the *DSM-IV* Hyperactive-Impulsive scale. These scales have been shown to successfully discriminate children with ADHD from controls (*ES*, $d \geq 3.0$; Brown et al., 2001).

3.1.1. Language impairment status

Children with SLI (a) had a history of language delay by parent report, (b) were diagnosed with or suspected by school personnel of having a receptive-expressive language impairment, and (c) received a *CELF-3* Receptive Language Score (RLS), Expressive Language Score (ELS), and Total Language Score (TLS) below 85. Children with ADHD and TD (a) had no history of language delay by parent report, (b) were not diagnosed with or suspected of having a language impairment, and (c) received *CELF-3* RLS, ELS and TLS scores $\geq$ 85.

3.1.2. ADHD status

Children in the group with ADHD (a) had a current diagnosis of ADHD made in the school or community by a psychologist or physician, (b) received *T*-scores at or above 65 (i.e., at least 1.5 *SD* above the mean) on at least two of the three subscales of the *CPRS-R* or *CTRS-R* (which is considered to be a clinically relevant elevation in behaviour; Conners, 1999), and (c) were not taking medication for treatment of ADHD or were taking a medication (e.g., Ritalin[TM]) that could be safely stopped for the two testing sessions. Parents and teachers of children taking medication for treatment of ADHD were asked to base their ratings on observations of the child off medication only. Children in the groups with SLI and TD (a) were not diagnosed with or suspected of having ADHD and (b) received *T*-scores below 65 on at least two of the three subscales of the *CPRS-R* and *CTRS-R*.

As expected, the groups with SLI, ADHD and TD differed significantly on all *CELF-3* scales and *CPRS-R*/*CTRS-R* subscales (all $F \geq 16$, all $p < .001$; see Table 1). Post hoc analyses of group performances on each measure using Tukey's HSD revealed the pattern of group differences expected based on the inclusionary criteria, apart from two exceptions. First, the group with ADHD had significantly lower *CELF-3* RLS than the group with TD ($p = .015$). Nonetheless, no child with ADHD met our criterion for a language impairment and the mean standard score of the group with ADHD ($M = 96$) fell in the average range (i.e., 85–115). Second, children with SLI had significantly higher ratings than children with TD on the parent ($p = .047$) and teacher ($p = .012$) *DSM-IV* Inattentive scales and the parent ADHD Index ($p = .008$). However, no child with SLI met our criterion for ADHD and the group mean *T*-scores for children with SLI ($M = 55$–57) were in the average range (i.e., *T*-score of 40–60) for all three of these scales.

3.2. Experimental procedures and measures

In a second session, children completed three tasks administered using a laptop computer with peripheral numeric keypad. For all tasks, children were instructed to retain one or both thumbs resting on the required key(s) so that reaction times did not include movement time, which can confound reaction time measurement (Lee & Miller, 1995). A Latin Square design counterbalanced order of task presentation to the extent possible given the group sizes.

3.2.1. Auditory repetition test (ART)

The ART is proposed to measure rapid temporal processing. It is a modified version of the Repetition Test (Merzenich et al., 1996; Miller, Jenkins, Merzenich, & Tallal, 1995; Tallal & Piercy, 1973a; Tallal et al., 1996). The ART was selected over other measures of RTP because it uses an adaptive staircase procedure (described below) to determine the minimum separation needed between two tones for the child to successfully replicate the tone sequence, and thus adjusts to individual variations in performance. Auditory stimuli consisted of two computer-generated sine waves with fundamental frequencies of 1 kHz (Tone 1) or 2 kHz (Tone 2) and 10-ms linear rise/fall times. Four durations used in prior RTP studies (20-, 40-, 75-, and 150-ms) were recorded for each tone at a 44,100 Hz sampling rate using a 16-bit mono digital-to-analogue converter. Stimuli were delivered using E-Prime Beta 4.0 (1999) over *Telephonics TDH-39P* headphones at 70 dB SPL.

The ART began with a two-part training phase using 150-ms tones in which the child received verbal feedback on response accuracy, and demonstration of the correct response when necessary. First, children were trained to press separate keys for Tone 1 and Tone 2, with single, randomized trials of the tones presented until a criterion of 10 out of 12 consecutive correct responses was reached. Second, participants responded by key press to two-tone sequences with a constant interstimulus interval (ISI) of 800-ms between the tones. Following a demonstration of the four possible combinations, tone pairs were randomly presented until 10 out of 12 consecutive correct responses were made.

In the testing phase, the shortest time interval the child needed to judge the order of tone pairs was determined at each of four tone durations. Initially, a 150-ms tone pair separated by an ISI of 250-ms was presented. The next tone pair was presented 1 s after the participant's response. In accordance with a 2-up/1-down adaptive staircase procedure, the ISI was decreased after two consecutive correct responses and increased after any single incorrect response. This allowed determination of the child's temporal threshold, that is, the shortest ISI at which the child could successfully replicate the sequence. The following ISI steps were used: 10-25-50-100-150-200-250-300-350-400-450-500-600-700-800-ms.[1] The temporal threshold was defined as the ISI at which the 4th decrease-to-increase reversal occurred (i.e., the fourth time that a correct response to a specific ISI was followed by an incorrect response to the next shortest ISI). Two consecutive incorrect responses at an ISI of 800-ms or two consecutive correct responses at 10-ms terminated testing. Once the threshold for 150-ms tones was determined, the procedure was repeated using 75-, 40-, and 20-ms tones.

3.2.2. Simple reaction time (SRT) task

The SRT task, developed by Miller et al. (2001), is a nonverbal speeded task intended to place minimal demands on cognitive processing, putatively reflecting basic speed of central nervous system functioning (Montgomery & Windsor, 2007). In this task, the child was required to strike a single key in response to a signal as quickly as possible.

[1] Although past research also included ISIs of 0- and 5-ms, *E-Prime* Beta 4.0 was unreliable at these intervals.

First, the word ''Ready'' appeared on the screen. Then, after a delay interval of either 1-, 2- or 5-s, randomly presented, three asterisks appeared and the child pressed a blue key. Participants were instructed to respond as quickly as possible, but without striking the key before the signal appeared. Six practice trials and 24 test trials (8 at each delay) were presented.

3.2.3. Visual search (VS) task

The VS task is a nonverbal speeded task that requires more complex non-linguistic processing than the SRT task. It is commonly used in the cognitive development literature (see Kail, 1991) and has been used to evaluate processing speed in children with SLI (Leonard et al., 2007; Miller et al., 2001). The stimuli consisted of six simple, non-representational line drawings. First, the child was presented with a target figure in the upper left hand corner of the screen. Next, five figures appeared in a row to the right of the target. The child then scanned the five figures from left to right and responded by key press whether or not the target was present in the array. If one of the five forms matched the reference form, the child pressed the green key. If no match was found, the child pressed the red key. Participants were instructed to respond as quickly as they could without making a mistake. Six practice trials and 36 test trials (six trials for each of the six conditions) were presented. The conditions reflected each of the five possible positions of the target in the array and the absence of the target.

3.3. Analysis

Prior to statistical analysis, invalid trials were removed from the SRT and VS Task response sets. Invalid trials were responses deemed to be too short to be valid (i.e., <300-ms for SRT, <500-ms to VS; based on inspection of group means and SDs in prior investigations of school-aged children on these tasks) or excessively long (i.e., 3 *SD* above the child's own mean). To identify outliers, RT means and *SD*s for each child were calculated for the SRT Task as a whole and within each of the six conditions for the VS Task, and individual responses greater than 3 *SD* above the child's own mean were removed (Osborne & Overbay, 2004). Error trials (e.g., indicating the target was absent when it was present) were also removed from the VS Task response set.

Repeated measure ANOVAs (with group as the between-participants factor and condition as the within-participants factor) were used to examine the (a) ART number of trials and temporal thresholds at each of four tone durations, (b) SRT task reaction times (RT) at each of three stimulus delays, and (c) VS task RTs for each of six target positions. Where Mauchly's test of the sphericity assumption was significant, the Greenhouse and Geisser adjustment was used to test the within-participants effects. The remaining group comparisons were conducted using univariate ANOVAs. Post hoc comparisons were conducted for significant between-subjects effects using Tukey HSD and for significant within-subjects effects using Bonferroni.

4. Results

4.1. Experimental measures

4.1.1. Auditory repetition task (ART)

Children with SLI required significantly more trials to learn the tone-button associations (Phase One training) than children with TD (see Table 2). Two children with SLI did not successfully complete the Phase Two training despite continued feedback and coaching. Therefore, their data were excluded from subsequent analyses of the ART task. The remaining children with SLI required more Phase Two training trials in order to learn to press the buttons in response to two-tone sequences than children with TD. For total test trials required to reach threshold, there were no significant effects or interactions.

Analysis of ART thresholds across the four tone duration conditions revealed significant main effects of group, $F(2,51) = 8.7$, $p = .001$, $\eta^2 = 0.26$, and tone duration, $F(1.9,98.2) = 12.1$, $p = .000$, $\eta^2 = 0.19$, but no significant group by duration interaction, $F(3.8,98.2) = 1.3$, $p = .277$, $\eta^2 = 0.05$. Both children with SLI and children with ADHD had significantly longer temporal thresholds on the ART than children with TD, and did not differ from one another. In other words, the groups with SLI and ADHD required significantly longer gaps between the two tones in order to successfully process and recreate the sequences. For all children, the mean threshold for the 150-ms tone duration condition was significantly shorter than those for the 75-, 40- and 20-ms conditions, which did not differ significantly.

Table 2
Performances of children with SLI, ADHD and TD on experimental measures.

	Group 1 SLI	Group 2 ADHD	Group 3 TD	*df*	*F*	*p*	η^2	Post hoc
Auditory Repetition Test (ART)								
No. phase one practice trials	27 (23)	23 (28)	12 (3)	2,53	3.4	.040	.11	1 > 3
No. Phase Two practice trials[a]	24 (18)	21 (13)	15 (6)	2,51	3.4	.040	.12	1 > 3
No. trials[a]	40 (23)	38 (25)	35 (20)	2,51	.4	.668	.02	n/a
Threshold (in ms)[a]	351 (365)	420 (334)	92 (156)	2,51	8.7	.001	.26	1,2 > 3
Simple reaction time (SRT) task								
Percent invalid trials	3 (5)	6 (8)	1 (3)	2,53	3.2	.047	.11	2 > 3
RT (in ms)	689 (117)	841 (176)	614 (125)	2,53	12.6	<.001	.32	2 > 1 > 3
Visual search (VS) task								
Percent invalid trials	0 (0)	10 (16)	3 (12)	2,53	2.8	.068	.09	n/a
Percent errors	6 (5)	8 (10)	6 (7)	2,53	1.1	.352	.04	n/a
RT (in ms)	1884 (320)	2036 (436)	1620 (388)	2,53	6.2	.005	.19	2 > 3

[a] $n = 12$ for group with SLI due to exclusion of two participants who could not complete Phase Two training.

4.1.2. Simple reaction time (SRT) task

The children with ADHD had significantly more invalid responses than the children with TD. Group comparison of RTs across the three conditions revealed significant main effects for group, $F(2,53) = 12.6$, $p = .000$, $\eta^2 = 0.32$, and delay, $F(1.7,90) = 12.5$, $p = .000$, $\eta^2 = 0.19$, but no significant interaction between group and delay, $F(3.4,90) = 1.1$, $p = .371$, $\eta^2 = 0.04$. Both the children with SLI and the children with ADHD showed significantly slower RTs than children with TD on the SRT. Moreover, the group with ADHD was slower than the group with SLI. Across the groups, responses were slower for the 1-s delay condition than the 2- or 5-s delay conditions, which did not differ.

4.1.3. Visual search (VS) task

The groups did not differ significantly in number of invalid or error responses. Analysis of the RTs of the groups across the six position conditions revealed significant main effects of group $F(2,53) = 6.18$, $p = .004$, $\eta^2 = 0.19$, and position $F(4.1,215) = 78.2$, $p < .001$, $\eta^2 = 0.60$, but no significant interaction, $F(8.1,90) = 1.3$, $p = .252$, $\eta^2 = 0.05$. Children with ADHD were significantly slower than children with TD on this task. For all children, RTs slowed progressively as the distance between the sample and target figures increased, with the longest responses seen when the target was absent. The RTs for many of the positions differed significantly in this regard, although there was no significant difference between RTs to targets that were in the first and second position, second and third position, or last position and absent.

4.2. Individual performances

Group comparisons provide some information about the extent to which processes are or are not dysfunctional in SLI and ADHD. However, they do not provide information about individual performances within each task or about the ability of each experimental measure to differentiate children with and without SLI, or with and without ADHD. To explore individual performances, normative information was estimated using data from the children with TD. Because performances on the experimental variables change with age, means and *SD*s were obtained for younger (6–9-year olds; $n = 15$) and older subgroups (10–11-year olds; $n = 13$) of the children with TD. A conservative cutoff point of 2 *SD* above the mean (i.e., indicating well below average performance) was determined and the performance of each participant with SLI or ADHD was compared to this normative value. Each TD child's mean score was removed from the TD group means and SDs to which that child was compared. This allowed for an unconfounded determination of whether the child's score was more than 2 SDs below the mean of other children in the group with TD.

On the ART, a large proportion of the children with SLI (nine out of fourteen, including two who could not complete training) and half of the children with ADHD (seven out of fourteen) were identified as having significant impairments in RTP (see Fig. 1). Four of the 28 children with TD performed below expectations on this task. Only one child with SLI and two children with TD had slowed speed on the SRT task, in contrast to almost half (six) of the children with ADHD. Individual performances on the VS task were less discrepant across the groups, with no large portion of

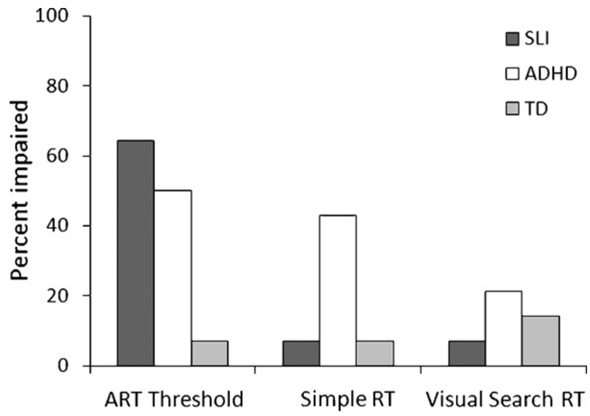

Fig. 1. Percentage of children with SLI, ADHD and TD who demonstrated impaired performance (at least 2 SD below the mean) on experimental measures.

children in any group showing significantly slowed speed on this task (one child with SLI, three with ADHD, four with TD).

5. Discussion

We have argued that, prior to considering processing dysfunctions as contributors to impaired language development and markers of SLI, it was important to determine whether these dysfunctions were indeed *unique* to children with linguistic impairments. Through minimizing the possible confounding influence of ADHD in a sample of children with SLI, and exploring these processes in children with ADHD who did not have SLI, we have unveiled new questions about the uniqueness of processing dysfunctions to SLI. In line with current theories of SLI, we predicted that children with SLI who did not have ADHD, but not children with ADHD who did not have SLI, would show slowed processing speed and dysfunctional RTP relative to children with TD. Although our results did provide clear evidence for the presence of impaired RTP in a substantial portion of children with SLI (64%), we also identified RTP impairments in a large portion of children with ADHD (50%), as well as in a few children with TD (14%). Performances of the three groups of children on speed of processing tasks followed a different pattern. Contrary to predictions, it was the group with ADHD, not the group with SLI, that demonstrated the greatest degree of slowing and had the highest proportion of individual children with significant slowing on nonverbal timed tasks. Children with SLI were slower as a group than their peers with typical development on the simpler of the two speeded tasks, but they remained significantly faster than children with ADHD, and only one child with SLI demonstrated well below average speed on this task. Moreover, the children with SLI were not significantly slower than children with TD on the more complex speeded task. Overall, we failed to provide evidence that RTP dysfunctions and slowed speed of processing are specifically linked to language impairments, and raised questions about the suitability of some of the traditional psycho-behavioural tasks that have been used to estimate processing dysfunctions in the literature to date.

5.1. The contribution of rapid temporal processing dysfunction to SLI

Although a number of prior studies have provided evidence that RTP dysfunctions are present in SLI (e.g., Tallal & Piercy, 1973a, 1973b; Tallal, Stark, Kallman, & Mellits, 1981; Tallal, Miller, & Fitch, 1993), our study was the first to explicitly minimize the possible confounding influence of ADHD in a sample of children with SLI. This methodological feature is key because it has been suggested that co-occurring attention problems may have influenced past findings of poor RTP task performances in children with SLI (Bishop et al., 1999; McArthur & Bishop, 2001). The current findings suggested that co-occurring ADHD does not specifically account for the poor RTP performances of children with SLI, because significant RTP impairments were evident in many children with SLI who did not have ADHD. This finding in isolation would suggest that poor RTP in children with SLI may indeed be linked to their impaired language functioning. However, our findings also indicated that it is certainly possible for the presence of ADHD to be associated with impaired performance on RTP tasks. We found impaired Auditory Repetition Test performance in a significant portion of children with ADHD, suggesting that RTP dysfunctions may also be evident in at least a subgroup of children with ADHD, even when they do not have core linguistic impairments. Under this interpretation, the role of RTP dysfunctions as a marker of SLI, or at the very least, the face validity of traditional behavioural measures of RTP, appears questionable. Future research directly comparing larger groups of children with SLI and ADHD on multiple measures of rapid temporal processing may provide further clarification of the uniqueness of RTP dysfunctions to SLI, their potential role in ADHD, and the validity of paradigms like the Auditory Repetition Test. Indeed, recent advances in the use of magnetoencephalography (MEG) and electroencephalography (EEG), which allow for the use of passive (and, arguably, pre-attentive) paradigms, have begun to prove particularly informative in this regard (Bishop & McArthur, 2004, 2005; McArthur & Bishop, 2004, 2005, Oram Cardy, Flagg, Brian, Roberts, & Roberts, 2005; Oram Cardy, Flagg, Roberts, & Roberts, 2008). In particular, several studies have provided evidence for atypical neural responses to auditory RTP stimuli in children and adolescents with language impairments using passive event-related potential and MEG paradigms in which the children are not required to respond (Bishop & McArthur, 2004; McArthur & Bishop, 2005; Oram Cardy et al., 2005). Neural investigations of RTP in children with ADHD have not yet been conducted, but would clearly be valuable.

5.2. The contribution of slowed speed of processing to SLI

Numerous studies have suggested that children with SLI are slowed in their speed of processing (see Leonard et al., 2007; Montgomery & Windsor, 2007), but it has not been clear whether ADHD has played a role in these findings, and the extent to which slowed speed of processing is linked with linguistic impairments, as opposed to other forms of impairments. In the present study, the children with ADHD were in fact significantly slower than children with SLI and TD on the SRT task, and slower than the children with TD on the VS task. It might be argued then, that past findings of slowed processing speed in SLI have been confounded by co-occurring ADHD in the samples, and that it may be principally children with ADHD, not children with SLI, who have slowed processing speed. By extension, it is possible that slowed processing speed does not make a significant or direct contribution to impaired language development.

Although longer RTs are intuitively suggestive of slowed processing speed, an alternate interpretation is also plausible. Longer response times on timed tasks might be secondary to higher individual response variability in some children (Leth-Steensen, Elbaz, & Douglas, 2000). Children with intact internal processing speeds whose responding is intermittently delayed due to some other dysfunction (e.g., altered attention, decreased arousal, impaired timing estimation) can present with not only longer mean RTs for the entire task but also higher individual variability in response speed throughout the task (Castellanos & Tannock, 2002; Johnson et al., 2007; Williams, Strauss, Hultsch, Hunter, & Tannock, 2007). The pattern of group *SD*s on the speeded tasks could support this interpretation; the children with ADHD had the highest *SD*s in both the SRT and VS tasks. It is possible that the higher group mean *SD*s reflect extreme trial-to-trial variability in the response speed of individual children with ADHD, that is, children in the group with ADHD had high intra-individual *SD*s, leading to overall longer reaction times and higher group mean *SD*s. In the event that this interpretation is correct, it raises the possibility that speed of processing tasks are limited in their ability to provide a true index of the speed at which the actual processes of interest occur in children with ADHD. Instead, they may represent the outcome of interference with this processing by other dysfunctions that may lie at the heart of this disorder. It is important to note that it is equally plausible that a higher group mean *SD* merely reflects a wide variation of response speeds across children with ADHD (i.e., high inter-individual variability). Specific calculation of intra-individual variation in speed of responding on reaction time tasks by individual children would be required to tease this out, which is beyond the scope of the current paper. However, it is an important issue for future consideration when discussing slowed processing speed in children with different disorders.

5.3. Insights from ADHD

Had the current investigation been completed using the traditional comparison groups of solely children with SLI and children with typical development, the conclusions would be notably different. The data would have been taken to provide evidence in support of both slowed processing speed and dysfunctional RTP in children with SLI. Together, these data may have been used to support the proposal that poor RTP performances merely exemplify a broader rate-limiting mechanism in SLI, rather than a dysfunction restricted to the processing of rapid transitions in sensory input

(Montgomery & Windsor, 2007). The poor performances of the children with SLI across these measures would continue to be linked with their language impairments, and future research using similar paradigms would be supported.

Considered in concert with the performances of the group with ADHD, however, the responses of the groups with SLI and TD point to different conclusions. Although the impairments of the children with SLI and ADHD appeared relatively similar in the realm of RTP, their abilities measured by the speed of processing tasks were more divergent, with the children with ADHD demonstrating more obvious slowing. These findings raise the possibility that poor performance on the Auditory Repetition Test may have resulted from different origins in the children with SLI than in the children with ADHD. For example, if slower mean RTs on the processing speed tasks for the children with ADHD indeed reflect extreme individual response variability, it is possible that the poor ART performances in this group reflect the very same interference. In this case, longer thresholds on the ART may not reflect impaired RTP in children with ADHD, which may in fact be intact in this group. By contrast, longer thresholds in the children with SLI may truly represent a dysfunctional ability to process rapid transitions. This conclusion is partly supported by recent evidence for atypical neural RTP responses in children and adolescents with language impairments using passive paradigms (Bishop & McArthur, 2004; McArthur & Bishop, 2005; Oram Cardy et al., 2005). These paradigms have yet to be applied to children with ADHD who do not have language impairments. However children with Asperger Syndrome, who fall on the autism spectrum but do not have core linguistic impairments, demonstrated intact RTP on a passive MEG task (Oram Cardy et al., 2005), supporting the potential of such paradigms to differentiate children with and without language impairments across different developmental and behavioural disorders.

Slowed processing speed in the children with SLI, while present on a simple RT task putatively representing the speed of basic CNS functioning (Montgomery & Windsor, 2007), did not appear to be a particularly striking impairment in individual children with SLI. With only 7% of these children showing a large degree of slowing (more than 2 SD slower than the mean), this did not appear to be as extensive an impairment in SLI as evident on the RTP task, where 64% of children with SLI were well below the mean. The possibility of this form of slowed processing being linked to impaired language development seems less certain, particularly in the face of more dramatic evidence for slowing in the group with ADHD but no linguistic impairments. However, the same argument applied to the RTP data should be considered here; it is possible that the slowing seen in the children with SLI was more reflective of a fundamentally slowed internal processing speed whereas the slowing in the children with ADHD was secondary to inconsistent control of attention or arousal.

Alternatively, it is also possible that the degree of slowing seen in the children with SLI on the SRT task, which was slower than children with TD but faster than children with ADHD, may be related to the same mechanism as suggested for the group with ADHD, but to a lesser extent. Although no child with SLI met criterion for diagnosis of ADHD, slightly elevated ratings relative to controls were evident on some of the behaviour rating scales, particularly on the scales reflecting the inattention symptom cluster. This pattern has been noted in other studies of children with SLI (e.g., Redmond, 2004). As discussed in further detail below, it is possible that the ratings reflect genuine but subclinical levels of inattention in the children with SLI, and that this slight inattention impacted speeded task performance. The reaction time *SD* for the group with SLI does not appear to support this conclusion, but more specific examination of the role of intra-individual response variability in SLI and ADHD is certainly warranted.

5.4. Language and behaviour in SLI and ADHD

Given the hypotheses set out for this study, specific attention was directed toward excluding the co-occurrence of ADHD and SLI in each of our clinical groups. By definition, no child with SLI had a community diagnosis of ADHD or met our criteria for ADHD on behaviour rating scales, and no child with ADHD had a community diagnosis of SLI or performed below average on the *CELF-3*. Despite these efforts, there were indications that certain aspects of language and behavioural functioning may be subtly affected in children with ADHD and SLI, respectively. The children with ADHD had significantly lower (albeit average) receptive language skills than children with TD, and the children with SLI had significantly higher (albeit average) ratings on some of the behaviour scales, principally those centered on inattention.

One possible account for these findings is that language and behaviour overlap in SLI and ADHD reflects limitations of the diagnostic measures used for their identification. In examining individual items on the ADHD-associated scales of the *CPRS-R* and *CTRS-R*, it might be argued that certain behaviours could be attributable to receptive language impairment rather than primary problems with focus and cognitive effort in some children (Redmond, 2002). It does not seem unusual that parents or teachers would observe that a child with receptive language problems ''gets distracted when given instructions to do something'' or ''does not seem to listen to what is being said to him/her.'' Indeed, Redmond (2002) recommended that behaviour ratings of a child with SLI should be considered in light of the child's linguistic proficiency, particularly when there is disagreement among informants and the child's reported behaviour problems are restricted to the attention realm. Similarly, ADHD-associated behaviours may exert a subclinical influence on standardized language test performances, which has been reported elsewhere. Oram et al. (1999) found performance patterns that may have been affected by impulsive responding on a sentence formulation task in children with ADHD who did not have SLI. Cohen et al. (2000) identified that the presence of ADHD, in addition to language impairment, was related to performance on a sentence repetition task.

It is also possible that similarities in language and behaviour in children with SLI and children with ADHD reflect true overlap in certain features of these disorders. Some behaviours commonly associated with ADHD may be subtly evident in children with SLI, even when they do not met full diagnostic criteria for ADHD. Conversely, slight language difficulties may be evident in children with ADHD, even when they do not meet full criteria for SLI. For example, children who grow up with poor language comprehension skills may develop a tendency to disengage their attention or be more easily distracted, even when encountering oral language that is within their capabilities. By the same token, similarities in certain ADHD behaviours and language skills may also reflect subtle and specific, but genuine, language limitations that form part of the ADHD profile (Oram et al., 1999; Westby & Cutler, 1994). These limitations may be less pervasive or severe than the fundamental linguistic impairments seen in children with SLI. Instead, such difficulties may be related to areas of possible dysfunction in ADHD such as executive control (i.e., organization, self-monitoring) or inhibition. That is, the presence of ADHD may disrupt communication in certain, specific ways. For example, poor organization may lead to specific weakness in the production of longer stretches of language such as narrative discourse. Impulsivity may result in pragmatic impairments such as poor turn taking in conversation. In considering our findings, it is important to acknowledge that there may indeed be greater overlap in linguistic and attentional abilities between children with SLI and ADHD than the diagnostic definitions of these disorders may suggest.

Recent work by Hale et al. (2009) raises a different but provocative interpretation of overlap across our groups with SLI and ADHD in some clinical and processing measures. Through investigations of lateralized brain function in individuals with ADHD, Hale and colleagues have amassed empirical support for a dynamic right hemisphere/interhemispheric dysfunction in ADHD. Importantly, the evidence points to right hemisphere (RH) biased processing in ADHD that diminishes left hemisphere (LH) function, putatively resulting in subclinical or state-dependent language impairments. This model points to the possibility that the overlap between ADHD and SLI is reflective of shared underactivation of left hemisphere (LH), language-related functions that has different underlying origins (i.e., abnormal and variable balance of RH/LH use in ADHD versus continuously impaired LH function in SLI). Under this model, we might very well expect to see shared dysfunctions on SLI ''marker'' processes across both disorders, but variability in the degree and expression of language-related impairments in ADHD. The current investigation cannot directly test this model, but its compatibility with our findings highlights the importance of future consideration of this model as it relates to overlap between SLI and ADHD.

5.5. Caveats

An alternative interpretation of group differences in this study is that lowered cognitive ability contributed to the poorer performances of the children with SLI or ADHD relative to the children with TD. All children with SLI and ADHD had a nonverbal IQ of at least 80, and it is unlikely that any of the children with TD had an IQ that was below average, because they had no developmental or school problems and performed within age expectations on language and behaviour measures. Although we made efforts to avoid recruiting children with above average abilities by asking teachers to refer children who were meeting but not exceeding classroom expectations, we did not have access to IQ scores for the TD group to rule out the possibility that some of these children had above average IQ. Therefore, it is possible that the group with TD had higher nonverbal IQ than at least the group with SLI, if not also the group with ADHD, and that this contributed to group differences on the tasks. Low average nonverbal IQ is a frequently observed characteristic of children with SLI and may be related to their language impairment (Plante, 1998). Nonverbal IQ tests like the *WISC-III* Performance scale have some verbal contamination to which children with SLI may be especially vulnerable (Krassowski & Plante, 1997). Also, children with SLI who are not globally impaired in cognition nevertheless perform poorly relative to children without SLI on certain nonverbal tasks (see Leonard, 1998 for a review). Even if the groups in this study did show subtle nonverbal IQ differences, it is possible that controlling for this difference statistically would have the unwanted effect of controlling for a portion of the language disorder. Nonetheless, the association of nonverbal cognitive ability with processing skills in children with SLI and ADHD requires further consideration.

6. Conclusion

We have argued that exploring the uniqueness of processing dysfunctions to SLI by examining the influence of other disorders like ADHD is an important precursor to considering causality and viewing a dysfunction as a marker of SLI. The current investigation has demonstrated the value of this approach. Our results strongly supported the need to further scrutinize accounts of SLI through expanded examination of these processes in ADHD as well as other disorders. At a broader scientific level, future investigations into candidate markers of any disorder need to be subjected to similar considerations. For example, interest has increased in the literature in assessing the predictive accuracy of potential markers of disorders using sensitivity and specificity calculations or likelihood ratios (Conti-Ramsden et al., 2001; Dollaghan & Campbell, 1998). Current findings highlight the need to cast a wider net in making such estimations; specificity analyses (e.g., the probability of children without language impairment being accurately classified as unimpaired) should not be restricted to children who have no developmental or behaviour problems but rather should include all children without language impairment, irrespective of other areas of non-linguistic or behavioural impairment. It is only then that the true promise of proposed phenotypic markers of SLI can be assessed.

Acknowledgments

We gratefully acknowledge the support of Brian Conrod in programming; Dr. Jim Stouffer, Bill Hodgetts and Aravind Namasivayam in calibration of acoustic stimuli; Dr. Carol Miller and her colleagues in sharing the speeded tasks; and Drs. Julie Mendelson and Genevieve McArthur in consultation around ART design. We also thank Drs. Peggy Kirkpatrick and Anne Richards for recruiting children with ADHD from their paediatric practices, and the children, parents, and schools for their participation. This research was supported by the Bamford-Lahey Children's Foundation and the Natural Sciences and Engineering Research Council of Canada.

Appendix A. Continuing education

1. The inclusion of a group of children with ADHD in this study was predominantly motivated by which of the following concerns about the Rapid Temporal Processing (RTP) account of Specific Language Impairment (SLI)?
   a. Some studies have failed to find differences between children with SLI and children with typical language development in RTP.
   b. RTP paradigms place demands on higher level processes in addition to RTP.
   c. Some studies have found that processing impairments are not specific to input that is rapid.
   d. Some authors have argued that RTP impairments are not causally linked to phonological processing problems.
2. Previous research has suggested that children with ADHD have a slowed processing speed (T/F).
3. Analysis of the children's temporal thresholds on the Auditory Repetition Test in the present study revealed impaired RTP in
   a. the groups with ADHD and SLI relative to the group with typical development,
   b. significantly more children with ADHD than children with SLI,
   c. none of children with typical development,
   d. a substantial proportion of children across all three groups.
4. The authors suggested that higher group standard deviations in reaction times in the children with ADHD relative to the other groups may have resulted from:
   a. extreme variability in response speed,
   b. globally slowed processing speed,

c. rapid temporal processing deficits,
d. receptive language impairments.

5. Paradigms are available in which RTP is measured without active responding from children (T/F).

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