Temporal Processing Skills of Children with and without Specific Language Impairment

Le traitement temporel chez les enfants avec et sans trouble spécifique du langage

Simon Grondin
Ginette Dionne
Nathalie Malenfant
Marilyn Plourde
Mariève Cloutier
Catherine Jean

Simon Grondin, PhD
Professor of psychology
Université Laval
Québec, QC Canada

Ginette Dionne, PhD
Professor of psychology
Université Laval
Québec, QC Canada

Nathalie Malenfant,
PhD candidate
École de psychologie
Université Laval
Québec, QC Canada

Marilyn Plourde,
PhD candidate
École de psychologie
Université Laval
Québec, QC Canada

Mariève Cloutier, M.Sc.
Speech-language
pathologist

Catherine Jean, M.Sc.
Speech-language
pathologist
Commission scolaire de la
capitale
Québec, QC Canada

Abstract

This paper compares the temporal processing skills of 6- to 9-year-old children meeting criteria for enrolment in specific language impairment (SLI) special classes to controls. Children were tested on two temporal-order judgment tasks (TOJ) and one interval-production task with 31 finger taps at a rate of 1 tap/s. Nonverbal IQ (NVIQ) was assessed using the Block Design subtest of the WISC-III. In a visual task (V-TOJ), children indicated which of two flashes, left or right, appeared first; and, in a bimodal task (B-TOJ), they indicated which signal, a sound or a light, appeared first. In the production task, groups were compared on mean production interval, the variability of produced intervals and the coefficient of variation. The results indicate a weaker capacity of children with SLI to determine the order of arrival of sensory signals in both TOJ tasks, and more variability (and higher coefficient of variation) of children from the same group in the production task. Furthermore, there were no group differences on NVIQ. Binary logistic regression revealed that performance on the V-TOJ task is sufficient to predict group membership with a 78% accuracy rate.

Abrégé

Cet article compare les compétences pour le traitement temporel des enfants de 6 à 9 ans qui répondent aux critères d'admission dans des classes spéciales pour ceux qui ont un trouble spécifique du langage aux compétences des enfants d'un groupe contrôle. Les enfants ont subi deux épreuves (visuelle et bimodale) de jugement de l'ordre temporel et un test de production d'intervalles temporels à l'aide de frappes digitales à un taux de 1 frappe à la seconde. Le quotient intellectuel non-verbal a été mesuré à partir du sous-test Block Design du WISC-III. Dans le cadre de l'épreuve visuelle, les enfants devaient indiquer lequel de deux signaux visuels, celui de gauche ou celui de droite, est apparu en premier. Pour l'épreuve bimodale, ils devaient indiquer quel signal, le son ou la lumière, est apparu en premier. Pour la tâche de production, on a comparé l'intervalle moyen de production entre les groupes, la variabilité des intervalles produits et le coefficient de variation. Les résultats indiquent une capacité réduite chez les enfants atteints d'un trouble spécifique de langage à déterminer l'ordre d'arrivée des signaux sensoriels pour les deux tâches de jugement de l'ordre temporel et une plus grande variabilité (et un coefficient de variation supérieur) pour le test de production temporelle chez les enfants de ce même groupe. Qui plus est, nous n'avons relevé aucune différence entre les groupes pour le quotient intellectuel non-verbal. Une analyse de régression logistique binaire a montré que les résultats de l'épreuve visuelle étaient suffisants pour prédire l'appartenance à un groupe avec un taux de précision de 78 %.

Key Words: Specific language impairment, temporal processing, temporal order judgement, interval production, nonverbal IQ

Specific language impairment (SLI) is a neurological impairment involving problems with speech and language understanding that cannot be explained by a general cognitive deficit. It is estimated that 3% to 7% of children suffer from this impairment (Leonard, 1998; Tallal, Stark, & Mellits, 1985). These children might also suffer from other problems involving psychosocial adjustment (Cohen, 2001), literacy (Tallal, 2003), fine motor skills and temporal processing (Tallal et al., 1985). Little is known about the etiological factors of SLI. One hypothesis states that the cognitive abilities related to the processing of time, referred to as temporal processing skills, could operate as a causal factor in SLI (see Benasich & Tallal, 2002; Jensen & Neff, 1993; Tallal, 1993; Wright et al., 1997). Speech perception, arguably fundamental to language acquisition, requires that a child be able to segment the stream of speech into meaningful units. This could be a daunting task if we consider that phonemes, the basic acoustic units of speech, occur at the rate of one per few milliseconds in normal speech. Tallal and others (e.g., Benasich & Tallal, 2002; Jensen & Neff, 1993; Leonard, 1998) have hypothesized that the inability to process the rapid succession of acoustic sounds in speech could explain why some children fail to develop appropriate language skills for their general cognitive abilities. They claim that the hypothesized temporal processing deficit of children with SLI impairs the development of phonological awareness.

A series of studies conducted by Tallal and Piercy (1973, 1974, 1975) are at the basis of the hypothesis that SLI and temporal processing are closely linked. In these studies, when children have to identify in what order a pair of auditory stimuli are presented, those with SLI displayed poorer performances, especially when sounds were brief and the intervals between sounds were short. Other studies also supported the hypothesis of a temporal processing deficit in SLI. For instance, in a study using a discriminant analysis of over 160 variables known to be related to speech deficits (sensory, neurodevelopmental, demographic, motor, and speech-related) to classify children according to their SLI status, Tallal et al. (1985) reported that six of these variables were sufficient to accurately classify 98% of participants. All six variables involved temporal processing skills. More recently, a prospective longitudinal study conducted by Benasich and Tallal (2002) has shown that rapid auditory processing abilities measured during infancy accurately identified children at risk of developing a SLI and predicted subsequent language skills[1].

In spite of the evidence reported previously, several researchers have questioned the relevance of temporal processing deficits as a fundamental cause of SLI (Bishop, Carlyon, Deeks, & Bishop, 1999; Mody, Studdert-Kennedy, & Brady, 1997; Studdert-Kennedy, 2002). One reason for questioning this hypothesis is the failure to replicate some of Tallal's previous findings (Bishop et al., 1999; Hanson & Montgomery, 2002; Mody et al., 1997). Moreover, even when temporal processing deficits in children with SLI are reported, it is often the case that not every child in their SLI group presented such a deficit. For instance, in an authoritative study, Bishop and colleagues (1999) have shown that some children with SLI do not exhibit any difficulty to process temporal information, while some children with temporal processing deficits do not have language impairment. They concluded that a temporal processing deficit is neither a sufficient nor a necessary causal factor of SLI. Bishop and colleagues' conclusions are consistent with the hypothesis of Ramus (2003) who contends that in dyslexia, temporal processing problems could be a symptom that affects only a portion of the dyslexic population. In addition, even though a stable link between temporal processing and language skills is observable in the literature (Tallal, 2003), it is not possible to totally reject the hypothesis that the temporal processing deficit is only a secondary manifestation of a linguistic deficit in SLI (Studdert-Kennedy, 2002), or that the link between temporal processing and language skills is due to a third variable. For Ramus (2003), temporal processing problems fall into a more general sensorimotor syndrome. According to Ramus' hypothesis, the sensorimotor syndrome would explain why some dyslexics present a plethora of symptoms, from rapid temporal processing to poor fine motor skills. Some researchers argue that the nonverbal cognitive abilities (Bishop et al., 1999) or the general cognitive processing skills (e.g., Hanson & Montgomery, 2002) might partly explain the relationship between temporal processing and language skills.

Other criticisms can also be addressed to the temporal processing deficit hypothesis. Because the tasks employed to measure temporal processing skills are so different across studies, it is sometimes difficult to clearly identify what aspects of temporal processing are impaired in SLI. If there is a general temporal processing deficit, it should not be restricted to the auditory mode, and should be apparent in other sensory modalities. In their review of the literature concerning the link between dyslexia and temporal processing deficit, Farmer and Klein (1995) identified several studies employing temporal processing tasks with visual or tactile stimuli and reported that temporal processing is not impaired only when auditory signals are used. However, there are only a few studies reporting the performance of children with SLI on temporal processing tasks involving multiple modalities (Tallal et al., 1985). Further, temporal processing deficits in SLI are apparently not restricted to brief or rapidly presented stimuli. For example, some children with SLI show worse performances than children of control groups at producing rhythm during a tapping task involving no brief stimuli (Share, Jorm, Maclean, & Matthews, 1984; Wolff, Michel, Ovrut, & Drake, 1990), a task that is argued to involve some aspects of temporal processing. Indeed, this task requires the explicit measurement of time, a skill closely linked to the use of an internal clock (Ivry & Hazeltine, 1995; Wing & Kristofferson, 1973).

In brief, there are a significant number of studies suggesting that SLI children suffer from a temporal processing deficit. But there are substantial problems with the inferences we can draw from the existing body of data.

This work aims to address two problems in the previous research. In its strict form, the temporal processing hypothesis states that the deficit affects the processing of brief and rapidly presented auditory stimuli, but the extent of this temporal processing deficit of children with SLI is in need of clarification. The present study extends the investigation of the hypothesis to temporal tasks different from those usually reported. In particular, the purpose is to look at the visual temporal processing and bimodal temporal processing (auditory and visual) in children with SLI, and to investigate temporal processing in a context which does not involve only brief or rapidly presented stimuli. This study also seeks to control for the possibility that deficits on these tasks could be due to a more general cognitive deficit.

The present study

The present study employed temporal processing tasks that are usually not used in the study of temporal processing by children with SLI. Two tasks involved a judgement about the order of presentation of stimuli - temporal order judgement (TOJ) - and another one was an interval production task in which the participants produced 1-s intervals by reproducing a rhythm on a keyboard. Although the TOJ tasks were highly similar to the classical temporal processing tasks (e.g., Auditory Repetition Task (ART), Tallal & Piercy, 1973), they were different on two aspects: the involvement of memory skills, and the modalities used for marking sensory events presented during the task.

Most studies relating SLI to temporal processing have used methods similar to the ART, in which judgements are made about the temporal order of consecutive signals, verbal or non-verbal (e.g., Bishop et al., 1999; Tallal & Piercy, 1974). These signals were presented in the auditory mode during a training phase in which the children had to learn the correct response key to every sequence presented (e.g., for two signals, a and b, the possible sequences would be: a-b, b-a, a-a, b-b). During the experimental phases, the level of difficulty increased as the ISI and stimulus duration were decreased. This procedure therefore required some memory skills, as the participants had to maintain the sequence they just heard in memory before they would produce their response. The memory demands of the task were even higher when sequences of more than two stimuli had to be identified, as it was the case in some studies (e.g., Bishop et al., 1999). In order to reduce the memory loading, stimulus sequences in the present study involved only two brief sensory signals. In order to test the hypothesis of a general temporal processing deficit in SLI, the TOJ tasks employed in this study involved the visual modality as well as mixed modalities. In the visual TOJ task (V-TOJ), participants were asked to judge the temporal order of arrival of two visual signals (one presented in each visual hemifield of the participant); in the bimodal TOJ task (B-TOJ), they were asked to determine the order of arrival of signals delivered via a bimodal sequence (a sound and a light).

In addition, children were asked to perform an interval production task. More specifically, this task required them to keep track of a series of brief sounds marking 1- s intervals, and to produce a series of 1-s intervals with finger taps. This task was designed to test the hypothesis that temporal processing deficits are not restricted to rapidly presented stimuli (Bishop et al., 1999; Lincoln, Dickstein, Courchesne, Elmasian, & Tallal, 1992). This task is not often used in the study of SLI, and does not seem to have been explored yet in the context of temporal processing deficits possibly correlated with deficiency in language and literacy, but it is a classical one in the study of time perception (e.g., Ivry & Hazeltine, 1995; Wing & Kristofferson, 1973).

Finally, researchers like Bishop et al. (1999) suggested that nonverbal cognitive abilities could partially explain the relationship between temporal processing and language skills. To provide a control for the possible effect of the nonverbal cognitive skills on the results, the Block Design subtest from the WISC-III (BD) was administered to the participants.

In brief, the main research question of this study is to determine if children with SLI perform more poorly or not than children with no language disability on temporal processing tasks, that is, on visual and bimodal (visual and auditory) time order judgments, and on the production of intervals, a task which involves no stimuli rapidly presented. Another issue in the present study is to provide a control for the possible effect of nonverbal cognitive abilities on the results.

Method

Participants

Forty-two children, in Grades 1 and 2, from four elementary schools in an urban Québec City school board participated in this study. Ages ranged from 6.4 to 9.4 years (M = 7.4 years). Twenty-three children (13 males, M = 7.48, and 10 females, M = 7.51) attending special classes for children with SLI were compared with 19 children (10 males, M = 7.34, and 9 females, M = 7.13) from the same schools on the basis of sex and age (4 months). The SLI diagnosis was established by a speech pathologist on the basis of criteria set in 2000 by the Québec Ministry of Education[2]. Children with known intellectual deficiencies or auditory and visual pathologies were excluded from this study. One female participant from the SLI group had to be excluded from the study because of failure to cooperate and complete the tasks. The final sample included 22 children with SLI and 19 controls.

On average, children with SLI were 7.49 years old (SD = .73) and controls were 7.24 years old (SD = .46). Age did not differ as a function of group membership, $F(1,39) = 1.72, p = .20$. More importantly, groups did not differ on a measure of cognitive abilities, the nonverbal IQ score (NVIQ, see below), $F(1,39) = 2.43, p = .13$, with a mean score of 97 (*SD* = 17) for the children with SLI and 104 (*SD* = 10) for controls.

Apparatus and Stimuli for Temporal Processing Tasks

Two types of sensory signals, auditory and visual, were used in the present study. The 5-ms visual (V) signals consisted of small circular red-light-emitting diodes (LED: Radio-Shack #276-088) placed about 1m from the participant, each subtending a visual angle of about .57 degree. In the V-TOJ task, LEDs were located in the left (L) and right (R) visual hemifields at 48.5 cm from one another. For the B-TOJ task, the LED was placed in front and at about 1m from the participant. The auditory (A) signals were 1-kHz tones with an intensity recorded at about 70 dB SPL, and were delivered from the computer placed in front of the participant. They lasted 5 ms in the B-TOJ task and 15 ms in the production task.

All temporal processing tasks were administered with a Zenith micro-computer. Linked to the computer was a small box with three pushbuttons: the central button was used for producing intervals in the production task, and the left and right buttons were used by the experimenters to indicate the child's responses (1) in the V-TOJ left signal first and right signal first, respectively, and (2) in the B-TOJ task - auditory signal first and visual signal first, respectively.

Nonverbal IQ Testing

Nonverbal cognitive abilities were assessed using the Block Design (BD) subtest of the French adaptation of the Wechsler Intelligence Scale for Children–III (WISC-III; Wechsler, 1991). The Block Design subtest is known to be a reliable and valid predictor of non-verbal intelligence (Sattler, 1992) and is often used as a reliable substitute for non-verbal IQ. Raw scores were converted to scaled scores following standardized procedure and then prorated following Sattler's (1992) procedure to compute a nonverbal IQ (NVIQ) score with a M of 100 and a *SD* of 15.

Procedure

The experiment took place at the school attended by the child. Participants completed the three time processing tasks, followed by the BD subtest. During the TOJ tasks, the room was dimly lit, so the flashes from the diodes were clearly visible. Presentation of the TOJ tasks was counterbalanced: half of participants did the V-TOJ first, and the other half did the B-TOJ first. All participants did the production task between the two TOJ tasks. There was a 1- to 2-minute break between each task. Assessments were completed within one experimental session lasting about 40 minutes. Each child received candy and stickers.

In both TOJ tasks, the child had to indicate which of two sensory signals appeared first. In the V-TOJ, the child was asked to point to the visual source (left or right) and the experimenter recorded the response using the appropriate pushbutton; in the B-TOJ, the child was asked to say if the sound or the light came first, and the experimenter recorded the response with the appropriate pushbutton. Each TOJ task comprised three blocks of trials. The practice block included 8 trials with ISIs of 400 ms or 450 ms between the A-V or V-A stimuli (2 randomized repetitions per condition), and ISIs of 250 ms or 300 ms between the L-R or R-L stimuli (2 randomized repetitions per condition). The two experimental blocks contained 24 randomized trials with four different ISIs for each L-R/R-L and A-V/ V-A sequences, each ISI appearing three times per block (2 sequences X 4 ISI durations X 3 repetitions). In the V-TOJ task, ISIs lasted 40, 120, 200 or 280 ms, whereas in the B-TOJ task, ISIs lasted 60, 180, 300 or 420 ms. The choice of interval parameters was based on pilot testing with children without SLI in order to reach an average accuracy rate of 75% per experimental block. The participants had a 10-s interval for responding and, after the response was recorded by the experimenter, there was a 2.5-s interval before the next trial or a 25-s break before the next block.

In the production task, participants were presented with 10 successive 15-ms sounds at a tempo of one sound every second (1 tap/s target production). At the end of the auditory sequence, the experimenter pressed on the middle pushbutton of the response box reproducing the same tempo with 8 finger taps, until a higher frequency sound was heard, which indicated the end of the task. The participants were then asked to do the same and complete the next sequence until they were told to stop. The child's finger tip was placed on top of the pushbutton before the sequence started. Participants had to produce 30 intervals of 1 s by pressing 31 times on the pushbutton. The session ended with the administration of the WISC-III BD subtest according to the standardized procedure.

Results

This study asked if there is a difference between the performance of children with SLI and a control group in a visual time order judgment task, in a bimodal (visual and auditory) time order judgment task and in an interval production task which involved no stimuli rapidly presented. Possible effects of nonverbal cognitive abilities on the results were controlled.

Group comparisons on TOJ tasks

For each TOJ task, there were seven scores of interest: the overall proportion of correct responses, the proportion of correct responses for each type of sequence condition (A-V and V-A, or L-R and R-L) and the proportion of correct responses for each of the 4 ISIs. A level of significance of .05 was used for all statistical analyses. A matched samples t-test revealed no effect of sequence conditions in both TOJ tasks (A-V vs. V-A: t (40) = .41, p = .68; L-R vs. R-L: t (40) = 1.44, p = 0.16). Sequence condition distinctions were dropped from all subsequent analyses.

Figures 1 and 2 depict the proportion of correct responses for the B-TOJ task and the V-TOJ task, respectively, by group for each ISI. Results generally show much lower proportions of correct responses by children with SLI than by controls. An analysis of variance, according to a 2 (groups) x 4 (ISI) factorial design, with repeated measures on the ISI factor, was conducted for each TOJ task.

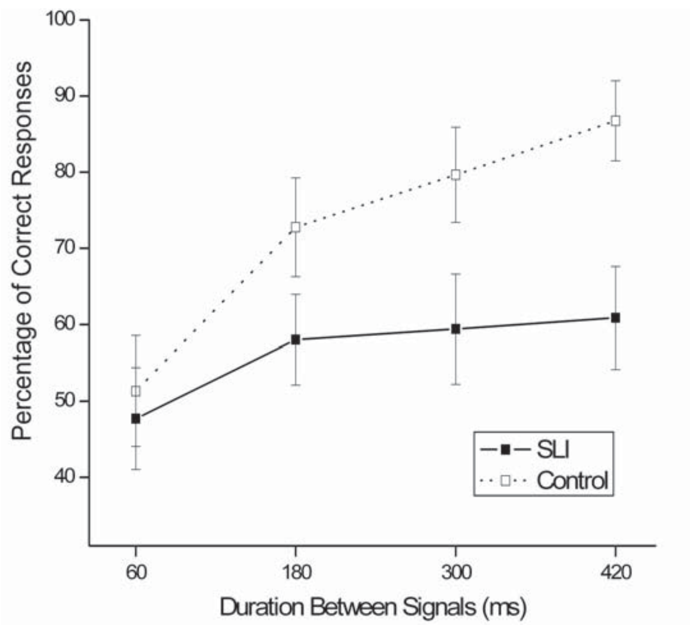

Figure 1. Mean proportion of correct responses as a function of the inter-stimuli intervals in the bimodal temporal order judgment task, for children with specific language impairment (SLI) and controls. Bars represent standard error.

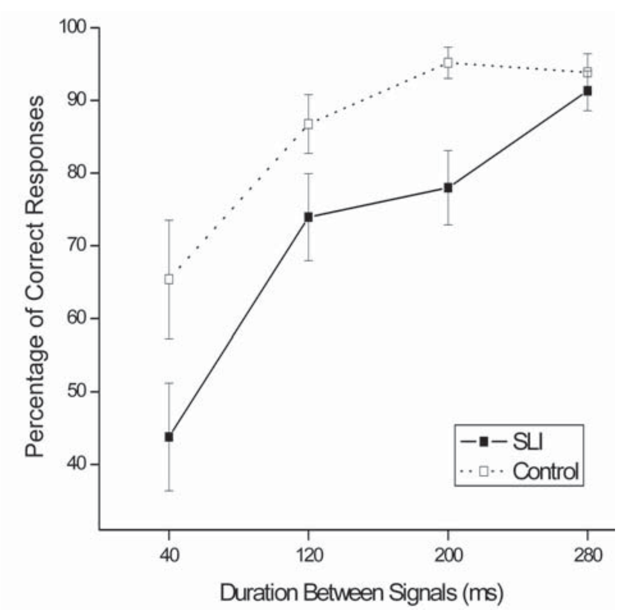

Figure 2. Mean proportion of correct responses as a function of the inter-stimuli intervals in the visual temporal order judgment task, for children with specific language impairment (SLI) and controls. Bars represent standard error.

For the V-TOJ task, the analysis revealed a significant main effect of ISI, $F(3,37) = 30.79$, $p < .001$, with an effect size (η^2) of .714, which means that about 71% of the variance observed on the scores can be accounted for by the experimental manipulation of the ISIs. Note that shorter ISIs are associated with lower proportions of correct responses. Analyses also revealed a main effect of group membership, $F\,(1, 39) = 14.26$, $p < .001$, $\eta^2 = .268$, children with SLI having overall lower proportions of correct responses than controls; and a significant ISI by group effect, $F\,(3, 37) = 6.32$, $p < .001$, $\eta^2 = .339$. ISI comparisons by repeated contrasts revealed that there were significant group differences in the 40 ms, $F\,(1, 39) = 9.51$, $p=.004$, $\eta^2 = .196$, 120 ms, $F\,(1,39) = 4.27$, $p = .046$, $\eta^2 = .099$, and 200 ms, $F\,(1, 39) = 13.86$, $p < .001$, $\eta^2 = .262$, conditions, but not in the 280 ms ISI condition, $F\,(1,39)= .60$, $p = .44$, where both groups showed accuracy above 90%. At 200 ms, however, the proportion of correct responses by children with SLI dropped significantly, $F\,(1, 39)= 22.16$, $p < .001$, $\eta^2=.513$, while children from the control group maintained a level of accuracy similar to that at 280 ms, $F\,(1, 39)= .46$, $p =.51$. Group performances dropped significantly for controls from 200 ms to 120 ms, $F\,(1, 39)= 11.72$, $p = .003$, $\eta^2 = .394$, and from 120 ms to 40 ms, $F\,(1, 39)= 12.07$, $p=.003$, $\eta^2 = .401$. For children with SLI, performances at 200 ms and 120 ms were not significantly different, $F\,(1, 39)= .97$, $p =.34$, but performance worsened from 120 ms to 40 ms ISI, $F\,(1, 39)= 23.84$, $p < .001$, $\eta^2 = .532$.

For the B-TOJ task, the statistical analysis revealed essentially the same results: a significant main effect of group membership, $F\,(3, 37)= 14.07$, $p < .001$, $\eta^2 = .27$, children with SLI having overall lower proportions of correct responses than controls; and a significant main effect of ISI, $F\,(3, 37) = 8.96$, $p < .001$, $\eta^2 = .427$. However, the interaction was not significant. There were no group differences on the shortest ISI, 60 ms, $F\,(1, 39) = .36$, $p =.55$, but significant group differences were found at 180 ms, $F\,(1,39) = 8.0$, $p = 0.007$, $\eta^2 = .174$, 300 ms, $F\,(1, 39)= 9.14$, $p=.004$, $\eta^2 =.194$, and 420 ms, $F\,(1, 39)= 15.54$, $p < .001$, $\eta^2 = .29$. At 60 ms, both groups showed an average correct response level close to 50%, which is equivalent to what would be expected by mere chance. When the ISI increased to 180 ms, both groups showed a significant increase in correct responses, but controls continued to perform significantly better than children with SLI. However, there was no significant improvement in performance with ISIs longer than 180 ms in either group.

Group comparisons on the interval production task

Three dependent variables were derived from the production task: the mean production interval (MPI), the variability of the produced intervals (SDPI), and a coefficient of variation (CV = SDPI/MPI). Table 1 displays Mean and *SD* for each of the three variables. Multivariate analysis of variance indicated an overall group effect, with

Table 1

Mean (in ms) and standard deviation (SD) of the mean produced interval (MPI), variability of the produced intervals (SDPI), and coefficient of variation (CV) in the production task for children with SLI and controls.

	With SLI		Controls			
Interval production	Mean	*SD*	Mean	*SD*	*F*	*df*
Overall					4.05*	3, 37
MPI	845.70	219.40	936.10	147.25	2.05	1, 39
SDPI	210.12	150.37	107.70	52.84	6.48*	1, 39
CV	0.2269	0.1248	0.1172	0.0603	10.36*	1, 39

Note: * $p <$ .05

children with SLI performing more poorly. Overall, intervals produced by children of each group were shorter than the 1-s target, and the groups did not significantly differ on MPI. However, the SDPI was very high (M = 210.1, range from 69.5 to 625.5 ms) for children with SLI, almost twice as high as that of controls, which indicates that children with SLI were much more irregular in their tapping activity than controls. As a result, the CV was much higher for children with SLI which indicates that, even when the MPI difference is taken into account, they still had more difficulty than children from the control group in producing a regular tempo with finger taps.

Correlations between tasks

Performances on TOJ tasks were significantly correlated for the total sample (r =.50, $p <$ .001) and for the SLI group (r = .42, $p <$ .05), but not for the control group (r = .24, p = .33). For the total sample, the correlation between the IP task (CV) and the B-TOJ task was significant (r =.32, $p<$.05), but the correlation between the IP task and V-TOJ was not (r = .20, p = .22). The correlations between each of the TOJ tasks and the IP task, for the SLI and for the control groups, were poor and none were significant. As for nonverbal IQ, the scores for the total sample were significantly correlated with TOJ performances (r = .32 and .37, $p <$ .05), but not with the CV of the IP task (r = .08, p = .64).

Predicting group membership

One critical question regarding the temporal processing skills of children with SLI is whether performance on temporal tasks correctly identifies children with and without SLI. To assess to what extent the three temporal tasks in this study uniquely predicted group membership in this sample, a step-by-step binary logistic regression analysis was conducted, entering as predictors age, sex, NVIQ, overall performances on the V-TOJ and B-TOJ tasks, and the SDPI and CV from the production task. Table 2 presents the results of the logistic regression, with the three variables retained, 1) proportion of correct responses on the V-TOJ task, 2) CV and 3) age, indicating that a model using those three variables accurately classified 85.4 % of children in this sample. Performance on the temporal tasks alone accurately classified 78% of the children (78.9% for the controls vs. 77.3% for the SLI children), indicating that the temporal tasks are sensitive enough to detect deficits that specifically characterise children with SLI.

Table 2

Variables retained to predict group membership in a step-by-step binary logistic regression with age, sex, nonverbal IQ, proportion of correct responses in the visual (V-TOJ) and bimodal (B-TOJ) temporal order judgment tasks, mean produced interval (MPI), variability of the produced intervals (SDPI), and coefficient of variation (CV) in the production task entered in the model.

			Model				
Steps	Variables in equation	Wald	x^2	x^2 change	% correctly classified		
					Control	SLI	Overall
Step 1	V-TOJ	9.22**	16.11**		84.2	68.2	75.6
Step 2	V-TOJ	6.77**	24.26**	8.15*	78.9	77.3	78.0
	CV	5.01*					
Step 3	V-TOJ	6.76**	28.38**	4.13*	84.2	86.4	85.4
	CV	4.47*					
	Age	3.68*					

Note: * $p <$ .05 and ** $p <$ .01

Discussion

The results of the present study strongly suggest that, as a group, children with SLI have much poorer skills than controls to judge the order of sensory signals. This difference applied to both temporal order judgment tasks in this study. Most interestingly, performance on the V-TOJ task was the best overall predictor of group membership in a binary logistic regression. In sum, these results suggest that the deficit for processing temporal information in children with SLI is not specific to the auditory modality. Our results would rather support the hypothesis that there is a central processing mechanism for temporal information, not specific to a given sensory mode. Moreover, they suggest that children with SLI would be less efficient than children without SLI in using this mechanism. Likewise, in their review, Tallal, Merzenich, Miller and Jenkins (1998) suggested that children with SLI: "have a pervasive, pansensory/motor deficit, which impedes their ability to perceive or produce rapidly successive information within a tightly delineated time window of tens of ms" (p. 211).

In the visual temporal order judgment task, there was a clear decline in performance for children with SLI as they reached inter-stimuli intervals of 200 ms whereas the decline was only apparent in children without SLI when intervals decreased to 120 ms. At the 40 ms interval, children with normal language were still able to perform at a better rate than would be expected by chance whereas children with SLI seemed completely unable to process the order of signals. Thus, children with SLI need much more time between visual signals than control children to judge their order of arrival.

The bimodal task in this study was not as powerful as the visual task in distinguishing group membership. Nevertheless, the children with SLI exhibited more difficulty in distinguishing the order of arrival of a sound and a flash. Indeed, even when there was as much as 420 ms between the signals, the mean performance remained very poor (about 60% of correct responses). Heath and Hogben (2004) have suggested that a differential need for practice in clinical groups might explain poorer performance in TOJ tasks by children with dyslexia. Our tasks contained a relatively low amount of trials so this could have meant that we have measured children with SLI at a different place in their learning curves than the children with normal language had reached within the same number of trials. However, the poor performance in B-TOJ cannot be attributed to a low number of trials alone because there was no such problem in the V-TOJ task where a similar number of trials were used. It may be that the children with SLI encounter particular difficulties when they have to judge the temporal order of bi-modal sequences. Therefore, these results point toward a new direction of investigation. Having said this, it should be noted that, in the case of both V-TOJ and B-TOJ, it cannot be excluded that the method adopted is particularly difficult for SLI individuals and using a different method might have led to different results.

Children with SLI also exhibited a marked deficit for another aspect of temporal processing: When asked to replicate regular interval durations by producing a series of finger taps at the rate of 1 tap/s the variability of their produced intervals was much higher than that of children without language impairment. In fact, the CV for children with SLI was twice as high as the CV of controls. Typically, in such production tasks, the observed variability is argued to be issued from two sources. One is the motor process involved in the tapping activity and the other is associated with an inner time-keeping process (Grondin, 1992, 2001; Grondin, Metthé, & Koren, 1994; Ivry & Hazeltine, 1995; Wing & Kristofferson, 1973). Group differences may be due to both processes, motor and temporal. Some children with SLI are known to present significant fine motor skills deficits (Tallal et al., 1985). Although simple taps every second are probably not very demanding on the fine motor coordination of 6- to 9-year-old children, keeping track of time might be. Therefore, one interpretation of the results that cannot be discarded is that the timekeeping process of children with SLI may be impaired. The ability of SLI children to make judgements about the duration of time intervals is certainly another temporal issue deserving further investigation.

The very large variability observed in children with SLI is somewhat surprising if we consider that the processing in this task involved intervals lasting 1 s. This range of duration is much higher than the one usually referred to in the general temporal processing literature, which has emphasised deficits in rapid auditory sequences and/or events. In the present task, it might not be the rapidity of successive events that causes difficulty, but the fact that the sequence is long. It would therefore be the ability to keep track of a long series of events that would be critical and would distinguish children with and without SLI. This interpretation could be consistent with Hanson and Montgomery (2002) who proposed that the language disabilities and temporal processing deficit in SLI could be explained by a general processing deficit or an incapacity for sustaining attention.

The question of the specificity of temporal processes in language acquisition is one that future research needs to address more thoroughly. For instance, in this study, there were no group differences on the nonverbal IQ measure and group differences on the temporal tasks were not explained by nonverbal cognitive abilities as estimated by the BD task. However, the fact that nonverbal IQ was correlated with both TOJ tasks suggests that, although there is a non-temporal specific cognitive component to the performance on TOJ tasks, the covariance between nonverbal IQ and TOJ is not what predicts group membership. In addition, it is not the covariance between V-TOJ and B-TOJ that predicts group membership. Rather, it is the residual variance of both the visual TOJ task and the coefficient of variability that predicts group membership. This could be tentatively interpreted as evidence of the specificity of the temporal pathway to SLI. However, our study does not exclude the possibility that the deficits observed in the SLI group are part of a more general problem affecting only a small part of the experimental group (Hanson & Montgomery, 2002; Ramus, 2003; Roach, Edwards, & Hogben, 2004). According to Roach et al. (2004), more attention needs to be allocated to the variability of the results, which is often more pronounced in the SLI or dyslexic group. Indeed, in the present study, the variability in the experimental group exceeds the variability observed in the control group. However, the deficit on the temporal tasks seems specific enough to the children with SLI to classify them in the correct group at a better than chance level. Having said this, it would be useful, in future studies, to use experimental designs with specific consideration for other cognitive processes like selective attention and working memory, to test further the hypothesis that the temporal processing deficit is part of a more generalized processing problem.

Conclusion

Our study suggests that children in SLI classes exhibit more difficulty than children with normal language in processing the order of arrival of sensory signals. This difficulty is observed when both signals are visual stimuli, or bimodal sequences involving an auditory and a visual signal. Furthermore, children with language impairment showed more difficulty in performing a simple task involving the production of a series of intervals. Overall, our results do not suggest that temporal processing deficits may be a causal factor in SLI, but they do provide tentative new evidence that this language deficit is associated with different forms of temporal processing problems, and that these temporal deficits remain observable even when nonverbal intelligence is taken into account.

Footnotes

[1]Note that a computerized intervention called Fast ForWord was designed to improve the rapid auditory temporal processing skills of children with language learning disabilities (LLD, which is a general term often used in the literature to regroup children with dyslexia and children with SLI). The interventions led to positive results on language comprehension, both in English and in French (Habib et al., 2002; Merzenich et al., 1996; Tallal et al., 1996). However, because the program contains both verbal and nonverbal stimuli, it was not possible to identify specifically which of the training of temporal processing or of linguistic skills was responsible for the improvement. Moreover, several studies where Fast ForWord was compared with different language intervention programs did not support the underlying premise of Fast ForWord, i.e., that acoustically modified speech will improve processing deficits in children's language (Cohen et al., 2005; Pokorni, Worthington & Jamison, 2004; Rouse & Krueger, 2004). In brief, some results obtained with Fast ForWord suggest that children with SLI have a deficit for processing rapid auditory sequences of events, but these results remain debatable.

[2]The Québec Ministry of Education defines SLI as a severe and persistent deficit of language development which restricts social interactions, socialization and academic learning. This deficit must persist above the age of five and the child must experience strongly marked difficulties in language evolution, verbal expression, cognitive-verbal functions, and moderate to severe difficulties in verbal comprehension. This deficit must prevent the child from performing school work usually proposed to children of the same age.

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Correspondence should be addressed to Simon Grondin or Ginette Dionne, École de psychologie, Université Laval, Québec, QC, Canada, G1K 7P4 E-mail: simon.grondin@psy.ulaval.ca or ginette.dionne@psy.ulaval.ca

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