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Perception of Small Frequency Differences in Children with Auditory Processing Disorder or Specific Language Impairment

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Abstract

Background—Frequency discrimination is often impaired in children developing language atypically. However, findings in the detection of small frequency changes in these children are conflicting. Previous studies on children's auditory perceptual abilities usually involved establishing differential sensitivity thresholds in sample populations who were not tested for auditory deficits. To date, there are no data comparing suprathreshold frequency discrimination ability in children tested for both auditory processing and language skills.

Purpose—This study examined the perception of small frequency differences (Δf) in children with auditory processing disorder (APD) and/or specific language impairment (SLI). The aim was to determine whether children with APD and children with SLI showed differences in their behavioral responses to frequency changes. Results were expected to identify different degrees of impairment and shed some light on the auditory perceptual overlap between pediatric APD and SLI.

Research Design—An experimental group design using a two-alternative forced-choice procedure was used to determine frequency discrimination ability for three magnitudes of Δf from the 1000-Hz base frequency.

Study Sample—Thirty children between 10 years of age and 12 years, 11 months of age: 17 children with APD and/or SLI, and 13 typically developing (TD) peers participated. The clinical groups included four children with APD only, four children with SLI only, and nine children with both APD and SLI.

Data Collection and Analysis—Behavioral data collected using headphone delivery were analyzed using the sensitivity index d′, calculated for three Δf was 2%, 5%, and 15% of the base frequency or 20, 50, and 150 Hz. Correlations between the dependent variable d′ and the

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independent variables measuring auditory processing and language skills were also obtained. A stepwise regression analysis was then performed.

Results—TD children and children with APD and/or SLI differed in the detection of small-tone Δ*f*. In addition, APD or SLI status affected behavioral results differently. Comparisons between auditory processing test scores or language test scores and the sensitivity index d′ showed different strengths of correlation based on the magnitudes of the Δ*f*. Auditory processing scores showed stronger correlation to the sensitivity index d′ for the small Δ*f*, while language scores showed stronger correlation to the sensitivity index d′ for the large Δ*f*.

Conclusion—Although children with APD and/or SLI have difficulty with behavioral frequency discrimination, this difficulty may stem from two different levels: a basic auditory level for children with APD and a higher language processing level for children with SLI; the frequency discrimination performance seemed to be affected by the labeling demands of the same versus different frequency discrimination task for the children with SLI.

Keywords

APD; frequency differences; frequency discrimination; SLI

INTRODUCTION

Auditory perceptual difficulties—such as poor frequency discrimination—that characterize pediatric auditory processing disorder (APD) are often observed in children with language impairments (e.g., Bishop and McArthur, 2005). APD in children refers to the atypical development of auditory skills not attributed to a documented peripheral hearing loss. Symptoms include difficulty in listening in noisy environments, poor sound localization, impaired dichotic listening, and auditory perceptual deficits (ASHA, 2005; AAA, 2010). These auditory deficits affect ~2–3% of school-aged children (Chermak and Musiek, 1997) and may coexist with higher order processing difficulties, such as attention deficit disorder or language impairment (Musiek and Chermak, 2014). Specific language impairment (SLI) is characterized by a difficulty in acquiring language in the absence of a known neurological disorder, or a cognitive, emotional, or sensory deficit (Leonard, 2014; Schwartz, in press). Auditory perception of nonspeech sounds is often examined in children with SLI, because of the assumed comorbidity between APD and SLI (e.g., Bishop and McArthur, 2005; Hill et al, 2005; Ahmmed et al, 2006; Nickisch and Massinger, 2009). There is also a large body of earlier studies that shows that perceptual deficits occur in children with SLI (e.g., Tallal and Piercy, 1973; Spitz et al, 1997). Tallal et al (1993) examined the results across many studies and concluded that children with SLI performed more poorly than typically developing (TD) children when the interstimulus interval between auditory stimuli was short (75 msec) and for stimuli presented at fast rates (generally <1 stimulus per 300 msec). These findings led to the rapid auditory processing model, which proposed that an auditory perceptual deficit is the primary deficit in children with SLI (Tallal et al, 1993). However, since then, other authors have shown that auditory perception abilities vary in children with SLI and that poor auditory skills are not always present in children with language impairment (e.g., Rosen, 2003; McArthur and Bishop, 2005). Overall, these studies' results are difficult to interpret because language-impaired participants are not tested for APD. Our primary goal for the current study was to examine the frequency aspect of perceptual abilities in children with APD and in children with SLI.

Nonverbal auditory perception can be examined in relation to four physical characteristics of sounds: frequency, intensity, phase, and duration. Because of the earlier work of Tallal and her colleagues (e.g., Tallal et al, 1993), earlier studies on auditory perception in atypically developing children emphasized the role of temporal processing. More recent studies have shown that perception of amplitude (e.g., Ahmmed et al, 2006; Corriveau et al, 2007; Richards and Goswami, 2015) or frequency (e.g., Hill et al, 2005) is also impaired in children with language impairment. The detection of frequency differences (Δf) are particularly important for speech intelligibility in children with hearing losses (e.g., Nie et al, 2006) and in the processing of nonspeech sounds in children with normal-hearing acuity (e.g., Kleindienst and Musiek, 2011). However, frequency perception studies in children have primarily focused on Δf thresholds, also called just noticeable difference for frequency (e.g., Moore et al, 2008). Frequency discrimination ability can also be assessed by examining the ability to detect frequency changes that are supra-threshold (i.e., above the just noticeable difference, which in the current experiment was 20, 50, and 150 Hz). Suprathreshold auditory processing is what listeners do every day: integrating and processing several aspects of sounds that are farther apart from their differential sensitivity detection thresholds. In this study, we used the signal detection theory (Green and Swets, 1974) to examine different magnitudes of Δf at supra-threshold levels from small to large Δf.

Frequency Discrimination

The ability to detect the difference in frequency between two nonverbal sounds usually requires participants to indicate whether two sounds are the same or different. In typical young adults, frequency (Δf) thresholds are usually ~1% of the base frequency. That is, with a base frequency of 1000 Hz most adults can detect a 10-Hz difference (e.g., Yost, 2007). However, in adults with language-based deficits, such as dyslexia, Δf thresholds are reportedly elevated with accurate detection occurring above 1% of the base frequency (e.g., Banai and Ahissar, 2004).

In children, there is a greater variability in frequency discrimination results within and across studies even for TD children, with some studies reporting poorer frequency discrimination than adults (e.g., Halliday et al, 2008), and other studies finding Δf thresholds similar in children and adults (Rota-Donahue, 2010). Moore and colleagues studied frequency discrimination abilities in children enrolled in three local schools in the United Kingdom (Moore et al, 2008). They found differences within this group of school children in that “good performers” had Δf thresholds similar to that of adults, at 1% of the base frequency, and “poor performers” had thresholds at 10% or more of the base frequency. The authors also reported that a subgroup of “poor performers” had very variable performance scores, they called that subgroup “noncompliant,” noting that attention might have played a contributing role in the large variance in results of that subgroup.

Divergent findings may be explained in part by the variability in the subject population called “typical,” such as inclusion or exclusion of children with hearing, auditory processing, language, and attentional and cognitive deficits that may or may not be characterized by normative testing. Variations in methods may also account for the discrepant findings. Frequency discrimination performance at threshold can vary in children depending on the psychophysical method that has been selected to test the performance (Sutcliffe and Bishop, 2005). Halliday et al (2008) established Δf thresholds using a method of limits where stimuli were presented in steps to find the minimum threshold. Rota-Donahue (2010) asked children to identify frequency changes in the middle of a continuous tone using a two-alternative, forced-choice procedure. Sutcliffe and Bishop (2005) demonstrated that depending on the method used to establish Δf thresholds, results in TD children could vary by as much as 10% at 1000 Hz.

In the atypically developing pediatric population, findings regarding frequency discrimination are also inconsistent. Some researchers report elevated Δf thresholds in children with SLI (Nickisch and Massinger, 2009), whereas others report that frequency discrimination improves with age in children with SLI and is comparable to that of children in a control group (Hill et al, 2005). Hill and colleagues used a two-alternative, forced-choice procedure and thresholds were obtained using a staircase method. When the children were between 9 and 12 yr of age, Δf thresholds for a 1000-Hz base frequency ranged between 15 and 85 Hz for children with SLI and between 6 and 50 Hz for the children in the control group. The large variance in frequency discrimination results observed in children and the overlap of frequency discrimination performance for children with SLI and TD peers could be due to the presence or absence of APD in participants who were not tested for auditory processing skills. Consequently, in the study of perceptual abilities in children with SLI, it is essential to assess children to determine if they also have APD or other cognitive or developmental deficits.

To date, the question remains open as to whether children who have poor frequency discrimination performance are having difficulty in (a) identifying differences within the auditory signal, (b) interpreting the language instructions required to perform the task (e.g., Moore et al, 2008; Sussman et al, 2015), (c) holding the auditory information in short-term working memory (e.g., Holmes, 2012; Sharma et al, 2014), or (d) some aspect of attention needed to perform the task (e.g., Moore et al, 2008; Sharma et al, 2014).

The Present Study

The overall purpose of this study was to examine the behavioral frequency discrimination in 10- to 12-yr-old children with APD and/or SLI to determine if frequency discrimination difficulties previously reported in atypically developing children was due to auditory-related deficits or language-related deficits, compared with a nonaffected age-matched control group. The first goal of the study was to assess suprathreshold frequency discrimination. Based on reported Δf thresholds in TD children (e.g., Hill et al, 2005; Moore et al, 2008; Rota-Donahue, 2010) and in "poor performers" (Moore et al, 2008), three levels of Δf were chosen: 2%, 5%, and 15% from the 1000-Hz base frequency. The second goal was to measure both auditory and language abilities in all participants.

We hypothesized that children with APD would perform poorly on detection of small Δf, regardless of their language status. In contrast, children with language impairment but without auditory deficits were expected to perform similarly to TD peers (Hill et al, 2005) on our frequency discrimination task.

METHOD

Participants

Thirty children between 10 yr and 12 yr 11 mo participated in the study: 13 TD children (6 males and 7 females) and 17 children (10 males and 7 females) with APD and/or SLI. All participants had normal hearing at 500, 1000, 2000, and 4000 Hz with thresholds ≥ 20 dB HL for both ears. In addition, they were healthy with no known neurological deficits, English was their first language, they had no known attention deficit/hyperactivity disorder or attention deficit disorder and their attentional skills were screened using a questionnaire adapted from the Conners' rating scale (Conners, 2011). Participants had no more than one out of eight signs of attentional problems on that checklist (see Supplemental Appendix S1, supplemental to the online version of this article, for details). All participants also had nonverbal intelligence scores within normal limits, with nonverbal intelligence quotient (IQ) ≥ 85 on the Test of Nonverbal Intelligence 3 (Brown et al, 1997).

The test for auditory processing SCAN-3:C (Keith, 2009), commonly used in clinical practice, was administered to all participants. This included the gap detection screening and four subtests of the SCAN: Auditory Figure Ground (signal-to-noise ratio + 8 dB), Filtered Words, Competing Words, and Competing Sentences. The five main subtests of the Clinical Evaluation of Language Fundamentals (CELF)-4 (Semel et al, 2004) were administered to evaluate language. These included Concepts and Following Directions, Word Classes-Receptive, Recalling Sentences, Formulated Sentences, and Word Classes-Expressive. For inclusion in the TD group, participants performed no more than 1 standard deviation (SD) below the mean on the SCAN and on the CELF. Their composite and core language scores were within 1 SD of the mean for their age. For inclusion in the APD group, children performed more than 1 SD below the mean on the SCAN composite or 1 SD or more below the mean on at least two of the five subtests of the SCAN. Finally, for inclusion in the SLI group, children performed more than 1 SD below the mean on the core language score of the CELF or 1 SD or more below the mean on at least two of the five subtests of the CELF.

Thirteen children were TD and 17 children were not. The groups of atypically developing children were as follows: four children with APD only, four children with SLI only, and nine children with both APD and SLI. A summary of test scores for the TD children and the children with APD and/or SLI is given in Table 1.

Stimuli

The tasks used four pure tones. The duration of each pure tone was 150 msec, with a rise and fall time of 10 msec. The base frequency or standard was 1000 Hz and the other three tones were 1020 Hz (20 Hz or 2% higher than the base frequency), 1050 Hz (50 Hz or 5% higher than the base frequency), and 1150 Hz (150 Hz or 15% higher than the base frequency).

Procedure

The parent/guardian of the child signed a consent form and the child an assent form. The testing session lasted ~2 hr. The session included signing the consent/assent forms, conducting a hearing screening, administering the standardized tests (Test of Nonverbal Intelligence, CELF, and SCAN), and the behavioral frequency discrimination tests. Breaks were given between tests and participants were compensated for their participation. In addition to the standardized tests, children participated in frequency discrimination behavioral task. They were also involved in an event-related potentials and an oddball behavioral task (Rota-Donahue, 2014). Before the start of the frequency discrimination behavioral experiment, children performed a short practice of five runs with feedback to ensure that they had understood the instructions. Stimuli were controlled and presented using E-Prime 2.0 (Psychology Software Tools, Inc., Pittsburgh, PA, 2010).

The tones were presented in pairs, and children were asked if the two tones were the same or different. Participants pressed 1 on the keyboard if the tones were the same, and pressed 2 if the tones were different. This task included 120 pairs of tones: 60 pairs of tones that were the same and 60 pairs of tones that were different. The pairs of tones that were different included 20 pairs with the small frequency change, 20 pairs with the medium frequency change, and 20 pairs with the large frequency change. The tones were presented at 70 dB SPL bilaterally, using TDH 39 headphones, with an ISI of 500 msec.

Data Analysis

Percentages of correct responses or hit rates (HRs) were calculated for each Δf. The HR was based on correctly identifying two tones that were different; it was calculated for each participant for the 60 trials that included different tones. The false alarm (FA)—pressing the different button when two tones were the same— was calculated for the 60 trials with two identical tones. The HR and FA rate were calculated for each of the three Δf. The sensitivity index d′ was determined for each participant using the formula: $d' = z\,(HR) - z\,(FA)$. The maximum value of d′ was 4.65 (because there were no perfect scores recorded, there were no infinite d′ values and no correction formulas were necessary). A d′ value >1 indicated better than chance performance (Macmillan and Creelman, 2005). For each Δf (small, medium, and large), the normality of variance was calculated for the entire sample. The Kolmogorov–Smirnov test of normality showed that the d′ values were normally distributed for each of the three frequency changes.

In addition to describing d′ results for each group of participants, the relationship between performance on the frequency discrimination task and scores on the SCAN and on the CELF were examined using the Pearson correlation coefficients. Furthermore, because a strong relationship was observed, an analysis was conducted to determine if scores on the SCAN or on the CELF could predict frequency discrimination results. A regression model was used to determine if the two predictors, SCAN and CELF, had an effect on the outcome variable, d′. A stepwise regression method was also included to determine the unique variance of one of the predictors on the outcome variable d′.

RESULTS

Table 2 presents a summary of the behavioral data for all groups in all conditions. The TD children detected all levels of Δf significantly better than the clinical groups. Children in the group with both APD and SLI (the BOTH group) performed most poorly. Independent sample t tests comparing the TD and the BOTH groups showed significant differences in the mean d′ for these two groups [$t_{(20)} = 2.53$ for the small Δf, $t_{(20)} = 3.28$ for the medium Δf, and $t_{(20)} = 3.87$ for the large Δf, all significant at the $p < 0.05$ level]. The sensitivity scores for children with APD only or SLI only fell between the performance of the TD and the BOTH groups. Table 2 shows the d′ values for the three Δf for the four groups of participants.

In addition to describing the sensitivity index for each group of participants, the relationship between d′ and scores on the SCAN and on the CELF were calculated. For the SCAN, scores were positively related ($p < 0.05$) to performance on the small and medium Δf (with coefficients $r = 0.43$ for the small Δf and $r = 0.42$ for the medium Δf). Specifically, as scores on the SCAN increased, children were better able to discriminate the small and medium Δf. In contrast, scores on the CELF were more strongly related to performance on the larger Δf ($r = 0.57$ for the medium Δf and $r = 0.72$ for the large Δf, $p < 0.05$). That is, children with high CELF scores showed better performance on the task relative to those with lower CELF scores, especially when Δf was large. Table 3 shows the relationship between the SCAN and the CELF tests with frequency discrimination performances for the three Δf: small, medium, and large.

A stepwise regression analysis was conducted to determine the unique influence of each of the two predictors on the outcome measure; the change in R^2 was calculated when one of the two predictors (either SCAN or CELF) was added to the regression model. Results showed that when the predictor, CELF, was added to the SCAN regression model, the change in R^2 was significant for the big and medium Δf (change statistics at $p < 0.05$). The CELF R^2 change for the small Δf was not significant. The same calculation was done with the predictor SCAN added to the CELF regression model. In that case, the change in R^2 was significant for the small Δf (change statistics at $p < 0.05$), but the other changes (for the medium and large Δf) were not significant.

Figure 1 shows the unique variance of the independent variables CELF and SCAN, which is explained in the outcome measure, d′, when adding one of predictors (CELF or SCAN) to the regression model. In sum, scores on the CELF predicted frequency discrimination abilities for the large Δf and scores on the SCAN predicted frequency discrimination ability for the small Δf.

DISCUSSION

The current study examined children’s performance on a frequency discrimination task to assess auditory processing difficulties in the presence or absence of language impairments. Below, we discuss the findings in relationship to the previous literature.

APD versus SLI

APD or SLI status differentially affected performance on our task of frequency discrimination: the detection of a small change was more difficult for children with lower scores on the SCAN, whereas the detection of larger changes was more difficult for children with lower language scores on the CELF. That is, a large amount of variance (52%) was accounted for by language scores on the CELF, whereas scores on the SCAN showed, at most, a weak relationship with task performance at the large Δf. The opposite effect was obtained for the small Δf. The SCAN scores accounted for more variance (18%) than the CELF (16%), although this difference was small, and the relationship generally weaker. The smallest Δf tested in the current study was 2% of the base frequency, other studies have suggested behavioral thresholds in children with typical development near or below 1% (e.g., Rota-Donahue, 2010). Thus, it is possible that a stronger relationship might have emerged using smaller Δf values.

The finding that the CELF and the SCAN scores showed a different pattern of correlations across the levels of Δf was revealing. This finding suggests a basic level of processing related to the auditory detection of the frequency change, and another higher level of processing that could include verbal encoding, labeling, and retrieval of information for the frequency comparison. Indeed, in terms of auditory perception, the smaller Δf was more difficult to detect than the larger Δf. This was evidenced by all the children showing lower sensitivity to smaller than larger Δf. The finding of a significant correlation between scores on the SCAN and sensitivity at the small Δf and that this correlation was stronger than found for the larger Δf suggests that the SCAN test is capturing something about auditory processing. However, it is important to recognize that the relationship is still moderate, in only accounting for 18% of the variance.

Other studies also suggest that frequency discrimination is related to APD and SLI (e.g., Moore et al, 2010; Miller and Wagstaff, 2011). Miller and Wagstaff (2011) observed that children who generally showed poor performance on tests used to diagnose APD and those used to diagnose SLI showed particularly poor performance on the Frequency Pattern Test (FPT) (Bellis, 2003). Children who generally performed poorly on tests used for APD, but within the normal range on tests of SLI, also showed poor FPT performance (compared to TD controls), but to a lesser extent than those showing both APD and SLI. The FPT requires both frequency resolution and cognitive processing, such as working memory and rehearsal. The Δf between the two tones used in the task was 22%, corresponding to the large Δf in the current study. Thus, the finding that the children with SLI in the Miller and Wagstaff (2011) study showed the poorest performance on the FPT task is consistent with what we have observed.

Moore and colleagues (2010) have argued that poor frequency discrimination is the result of task issues. They observed that children who demonstrated poor performance on tests of nonverbal IQ, memory (digit span and nonword repetition), and reading (words) showed poorer frequency discrimination compared to most 6- to 11-yr-old children. They also found that performance on a questionnaire of listening skills (Children's Auditory Processing Performance Scale) correlated with frequency resolution. These data were collected from a large sample of school-age children (n = 1,463). There was considerable variability in performance on the IQ, memory, and reading tasks in children showing poor frequency discrimination. However, these children's language and auditory processing abilities were not tested. Considering our findings and those of Miller and Wagstaff (2011) the "poor performers" on frequency discrimination from the Moore et al (2008) study are likely to include children with APD only, SLI only and both APD and SLI.

In the current study, lower scores on the CELF were related to poor frequency discrimination ability for the larger Δf. Children with SLI who had the lowest scores on the CELF performed worse on the frequency discrimination tasks, especially at the largest Δf (150-Hz Δf). Thus, a finding of poor performance at the easier Δf suggests poor processing at cognitive rather than purely sensory levels (e.g., ability to follow instructions). Moore et al (2010) argued that poor performance for both easier and more difficult auditory stimuli indicates a deficit, or immaturity, in nonsensory processing, based on derived to isolate auditory processing from task factors measures (subtracting detection thresholds of easy versus difficult stimuli). Our results were consistent with this assessment of cognitive, and thus that difficulty in frequency discrimination in children with SLI may be due to language issues or task-related problems as well as sensory deficits. In contrast, our findings suggest that frequency discrimination in children with APD was more difficult with smaller Δf, indicating an etiology that is sensory in nature.

Brain Basis of APD and SLI

The differential pattern of behavioral performance for children with APD versus SLI might be related to different brain anomalies in these children, such as reported by Boscariol and colleagues (2011). Boscariol et al showed a link between the extent of brain anomalies in children and the severity of the disability. They linked APD and other developmental deficits in language and cognitive skills to an atrophy—or thickening appearance of the cortex—in the perisylvian fissure (Boscariol et al, 2011). In that study, children were also tested for both auditory processing and language ability. In children with APD and/or SLI, this atrophy or polymicrogyria was observed in the regions located around the sylvian fissure (in the left hemisphere they included part of Broca's area, Wernicke's area, and the auditory cortex). Depending on the extent of the atrophy, malformations ranged from mild (in children with subtle developmental delays with normal intelligence) to more severe (in children with cognitive deficits and epilepsy). Our results are consistent with these findings in which there was a significant decrease in performance in children with both APD and SLI. In our clinical groups, frequency discrimination performance of children who exhibited both APD and SLI was the worst. Children who had APD only or SLI only fell between the performance for the TD and the BOTH groups. That is, children with only one disorder (either APD or SLI) performed better on average than children with both APD and SLI, but worse than children in the TD group, suggesting that these disorders have an additive impact.

Limitations

One caveat in framing the current results is the tests used to identify APD and SLI in the sample tested. Children's auditory processing abilities were tested using the SCAN-3:C. This diagnostic tool includes linguistically loaded subtests, which make it difficult to differentiate APD from a language deficit. The SCAN-3:C was used in this study because it represents common, current clinical practices in the United States. Further tests of APD could involve the use of nonverbal tests/subtests, such as the gap-in-noise test (Musiek et al, 2005). Secondly, we used the CELF-4 to identify SLI since this is also a commonly used clinical assessment. The CELF has been criticized for insufficient sensitivity/specificity (Spaulding et al, 2006). However, these are currently some of the best tools available for normative assessment. Importantly, the results from the current study suggest that the SCAN-3:C and the CELF-4 are capturing different aspects of processing.

Clinical Implications

In this study, APD and SLI were as likely to occur together as in isolation. Nine children had both APD and SLI, but only eight children had a single disorder (either APD only or SLI only). This finding confirms the reported comorbidity of pediatric APD and SLI. This study also showed that children with APD and/or SLI performed poorly on a Δf detection tasks, but that their inability to perform the tasks well was related to different types of deficits: one related to auditory perception and the other related to language issues. This finding emphasizes the importance of multilevel testing in children who have difficulty in school, as they might have APD only, SLI only, or both. In addition to a continued need for differential diagnosis, establishing the severity of the impairment is important as it might lead to different treatment plans. The implementation of appropriate remediation plans should include either auditory training or metalinguistic approaches, or both in the case of children with APD and SLI.

Conclusion

The current study confirmed the comorbidity of APD and SLI in children, but also indicated that the disorders are separate. In addition, the study demonstrated that a frequency discrimination task, using a range of Δf, can help to isolate the nature of auditory processing deficits.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Abbreviations

APD	auditory processing disorder
CELF	Clinical Evaluation of Language Fundamentals
FA	false alarm
Δf	frequency differences
FPT	Frequency Pattern Test

HR	hit rate
IQ	intelligence quotient
SLI	specific language impairment
SD	standard deviation
TD	typically developing

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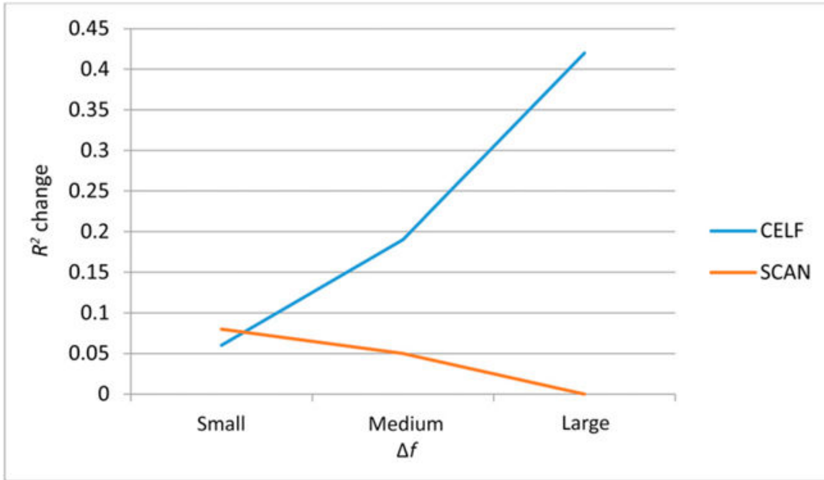

Figure 1.
R^2 change for the three magnitudes of Δ*f*: small, medium, and large, when either the CELF (in blue) or the SCAN (in red) is added to the regression model.

Table 1

Summary of CELF-4 Core and SCAN-3:C Composite Scores for the Four Groups of Participants

Tests	TD		APD		SLI		BOTH	
	M	SD	M	SD	M	SD	M	SD
CELF	114	(14)	105	(7)	86	(7)	74	(17)
SCAN	104	(10)	95	(7)	107	(6)	86	(11)

Table 2

Mean d′ Values, SDs, and Standard Errors (SEs) for the Three Magnitudes of Δf (Small, Medium, and Large) for the Four Groups of Participants

	TD			APD			SLI			BOTH		
Δ*f*	**M**	**SD**	**SE**	**M**	**SD**	**SE**	**M**	**SD**	**SE**	**M**	**SD**	**SE**
Small	1.94	1	(0.28)	1.24	1.07	(0.54)	0.89	1.17	(0.58)	0.9	0.85	(0.28)
Medium	3.1	1.03	(.29)	2.05	1.43	(.72)	1.96	0.68	(.34)	1.6	1.08	(0.36)
Large	3.85	0.79	(0.22)	3.28	1.25	(0.63)	2.63	0.84	(0.42)	2.17	1.25	(0.42)

Table 3

Person Correlation Coefficients (r), Regression Coefficients (R^2), and R^2 Change (R^2C) Values for the Different d′ Values, for the Three Magnitudes of Δf: Small, Medium, and Large, for the CELF and the SCAN Scores

	CELF					SCAN				
Δ*f*	***r***	***p***	R^2	R^2C	***p***	***r***	***p***	R^2	R^2C	***p***
Small	0.39	(0.030)	0.16	0.06	(0.150)	0.43	(0.017)	0.18	0.08	(0.108)
Medium	0.57	(0.001)	0.33	0.19	(0.008)	0.42	(0.021)	0.18	0.05	(0.169)
Large	0.72	(0.000)	0.52	0.42	(0.000)	0.34	(0.063)	0.1	0.00	(0.834)