Individual Differences in Speed of Auditory Processing and Language in Young Children

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Abstract

Specific language impairment is a developmental language-based learning disorder affecting six to eight percent of children entering kindergarten. The etiology of specific language impairment is currently unknown. One prevalent hypothesis asserts that difficulty in efficiently processing rapidly occurring auditory events such as rapid frequency transitions within the speech stream is underlying the language deficits of children with specific language impairment. Previous research examining temporal auditory processing thresholds in school-age children and infants has elicited evidence in support of this hypothesis. However, temporal auditory processing thresholds have yet to be investigated in toddlers and preschoolers, an important age range for language acquisition. This pilot study tested the feasibility of a new behavioral task created to measure temporal auditory processing thresholds in young children. The results of this pilot study indicate a pattern to warrant further investigation testing the reliability and validity of this task. A sensitive measure of temporal auditory processing thresholds in young children would contribute to the understanding of language acquisition and could have potential implications for the screening of specific language impairment in toddlers and preschoolers.

Keywords: language, auditory perception, rapid auditory processing, specific language impairment, toddlers, preschoolers

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While many skills are necessary for the acquisition of language, most children acquire language with ease. However, for a subset of children, language acquisition can be difficult or delayed. These children are diagnosed as having specific language impairment (SLI), a developmental language-based learning disorder in which deficits in language cannot be explained by hearing impairment, neurological disorder, autism, or unspecified general mental or physical impairment (Leonard & Weber-Fox, 2012). It is estimated that the prevalence of SLI in monolingual English-speaking children entering kindergarten is 6 - 8% (Tomblin et al., 1997). SLI appears to be somewhat heritable as children born into families with a parent or sibling who is affected are three times more likely to be diagnosed with SLI than children born into families with no history of language impairment (Tomblin 1989; Tallal, Ross, & Curtiss, 1989). Additionally, the 70% concordance rate for monozygotic twins is significantly higher than the 46% concordance rate for dizygotic twins (Bishop, North & Donlan, 1995).

To date, the etiology of SLI is unknown. One prevalent hypothesis asserts that an inability to efficiently process and encode rapidly occurring auditory events such as the frequency transitions that typify fluent speech is underlying the language deficits of children with SLI (Tallal & Piercy, 1973; Benasich & Tallal, 2002). Acoustic transitions between phonemes can occur within milliseconds, and therefore, a deficiency in the ability to process rapidly occurring auditory stimuli could potentially lead to speech perception deficits (Leonard, 2000). Deficits in speech perception would in turn have consequences for receptive and expressive language ability (Benasich & Tallal, 2002; Trehub & Henderson, 1996).

There is evidence in support of the hypothesis that differences in basic temporal auditory processing thresholds are underlying the language deficits of children with SLI. Seven to nine year old children with SLI show impaired detection of rapidly occurring tone-pairs as compared to children without a history of language impairment (Tallal & Piercy, 1973). Using a repetition method, children were asked to indicate the order in which acoustic tones were presented within tone-pairs by clicking one of two panels on a computer screen. Four tone-pairs were presented using a 54 Hz tone and 180 Hz tone, each 75 ms in duration. During testing trials, the interstimulus interval (ISI) was varied from 4,062 ms to 8 ms. Children with SLI had significantly lower performance when indicating the order of presented tones than children without language impairment when the presented ISI dropped below 305 ms (Tallal & Piercy, 1973). The observed inability of children with SLI to discriminate tone-pairs with ISIs less than 305 ms is indicative of an inability to efficiently process rapidly occurring acoustic events (Tallal & Piercy, 1973).

Recent investigation indicates that six to ten month old infants with a family history of SLI also have difficulty efficiently processing rapidly presented tone-pairs (Benasich & Tallal, 2002). Infants' auditory processing thresholds were assessed with an operantly conditioned, two-alternative forced-choice task in which infants associated a low-low frequency tone-pair with a toy lighting up and moving to the left of a central fixation point and low-high frequency tone-pair with another toy lighting up and moving to the right of the central fixation point (Benasich & Tallal, 2002). A temporal auditory processing threshold was calculated using infants' looking patterns and direction of gaze (Benasich & Tallal, 2002). During testing trials, ISIs were varied from 500 ms to 8 ms. Infants with a family history of SLI differed significantly in their auditory processing thresholds from infants without a family history of language impairment (Benasich &

Tallal, 2002). Additionally, Benasich and Tallal measured the infants' language and general cognitive abilities at 12, 16, 24, and 36 months of age. Across both groups of infants, individual differences in auditory processing thresholds at 6 to 10 months of age predicted subsequent language ability at 12, 16, 24, and 36 months of age (Benasich & Tallal, 2002). However, no association was found between auditory processing thresholds at 6 to 10 months of age and subsequent general cognition at any of the subsequent time points (Benasich & Tallal, 2002).

While there has been investigation of speed of auditory processing in school age children and during the first year of life, currently, little is known in regards to the temporal auditory processing ability of toddlers and preschoolers. Developmental continuity of individual differences in temporal auditory processing thresholds would be expected, as would an association between individual differences in temporal auditory processing thresholds and language ability during this age range. Investigation into the temporal auditory processing ability of toddlers and preschoolers is of significance because it could elucidate a more comprehensive developmental perspective of individual variability within language acquisition. Additionally, a sensitive measure of individual differences in rapid auditory processing thresholds could have potential implications for the screening of specific language impairment in toddlers and preschoolers. This is an important developmental period because children are rapidly acquiring language, producing a large quantity of new words, and combining words to create longer and more complex sentences. If children are experiencing a delay in language during this period, it would be exigent to intervene as early as possible. However, there are currently very few tools of language assessment for this age range. With further research investigating the relationship between auditory processing thresholds and language, a screening tool for SLI measuring temporal auditory processing thresholds in young children could become a potential reality.

This was a pilot study investigating the feasibility of a new behavioral task created to assess temporal auditory processing thresholds in young children. The task was piloted on a sample of typically developing young children between the ages of 28 and 52 months. Additionally, receptive and expressive language abilities of the children in this sample were measured to assess the validity of the auditory processing task. We hypothesized that there would be individual differences in temporal auditory processing ability, even in typically developing young children. We also predicted that these differences in temporal auditory processing ability would be associated with current receptive and expressive language ability in young children.

Method

Participants

Participants were 19 English speaking children between the ages of 28 and 52 months (mean age = 38.7 months, SD = 6.6 months; 10 males), and were recruited from local parent support groups and from previous study participation at UCSD or SDSU. Exclusion criteria were no previous diagnosis of language delay, no history of hearing dysfunction, no visual or cognitive impairments, and no developmental disorders. One recruited child did have a previously diagnosed language delay, but this information was not openly available until after the child completed the rapid auditory processing task. This child's data was removed from all analyses. Three children did not meet a threshold of completing at least three testing trials per ISI and were excluded from the analyses. Therefore, a total of 15 participants were included in analyses (mean age = 39.2 months, SD = 7.24 months; 6 males). Five participants were not available for the follow-up testing of language measures. Therefore, analyses presented with language measures included a subgroup of 10 participants who completed the temporal auditory processing task and language measures (mean age = 39.0 months, SD = 8.03 months; 3 males). Demographic data were collected by questionnaire completed by the primary caregiver (see Table 1).

	n = 15	n = 10
Mean child age, months (SD)	39.2 (7.24)	39.0 (8.03)
Mean mother's education, years (SD)	16.8 (1.01)	16.8 (1.04)
Mean parents' age, years (SD)	36.3 (3.9)	35.4 (3.08)

Table 1. Demographics data for children who completed the auditory processing task and for children who completed both the auditory processing task and the language measures.

Procedure

The protocol was approved by the UCSD Institutional Review Board, and written informed consent from all caregivers and verbal assent from all children were obtained prior to participation in the study. At the first visit, each child’s caregiver completed a demographics questionnaire providing information on the child’s age, gender, ethnicity, parity, and language text, the mother’s level of education, and the age of parents. Participants read a storybook with the experimenter to become familiarized with the rapid auditory processing task. Participants were then accompanied by the experimenter and caregiver into a sound attenuated room where they completed the rapid auditory processing task.

During a follow-up visit, participants were administered the Peabody Picture Vocabulary Test, Third Edition (PPVT-III; Dunn & Dunn, 1997) and Expressive Vocabulary Test, Second Edition (EVT-2; Williams, 1997). Follow-up visits took place at the residence of the participant and were made 3 to 14 months subsequent to the participant’s initial lab visit.

Measures

Temporal auditory processing task:

The stimuli were two tone-pairs consisting of two 70 ms complex tones, each with a rise and fall time of 20 ms. The tones were the same which were used in Benasich and Tallal's study with infants (Benasich & Tallal, 2002). Tone 1 was 100 Hz in frequency and Tone 2 was 300 Hz in frequency. They were complex tones with a rise and fall time of 20 ms. The tones contained all harmonics with a six decibel roll-off per octave. The first tone-pair consisted of Tone 1 followed by Tone 1. The second tone-pair consisted of Tone 1 followed by Tone 2. The ISI for each tone pair was varied from 10 ms to 150 ms.

Each child was administered a two alternative, forced-choice task using operant conditioning to measure auditory processing thresholds on a touch-screen computer with an Intel Celeron M processor (150 GHz). The child was seated in a booster chair 16 cm from the 40 x 25 cm touch-screen monitor in the center of a sound attenuated room (see Figure 1). The caregiver was seated in a chair behind the child in the rear of the room. The experimenter sat on the floor to the right of the child. A laptop computer was placed to the right of the touch-screen monitor, at an approximate 65 degree angle to the child's right. A space divider was situated directly behind the touch-screen monitor. The session was videotaped from two angles: one camera was placed behind the space divider for a view over the touch-screen monitor facing the child, and one camera was placed to the rear-left of the child for a view of the child's touch responses. Video was later coded for the child's responses to trials, gaze direction, and attentiveness.

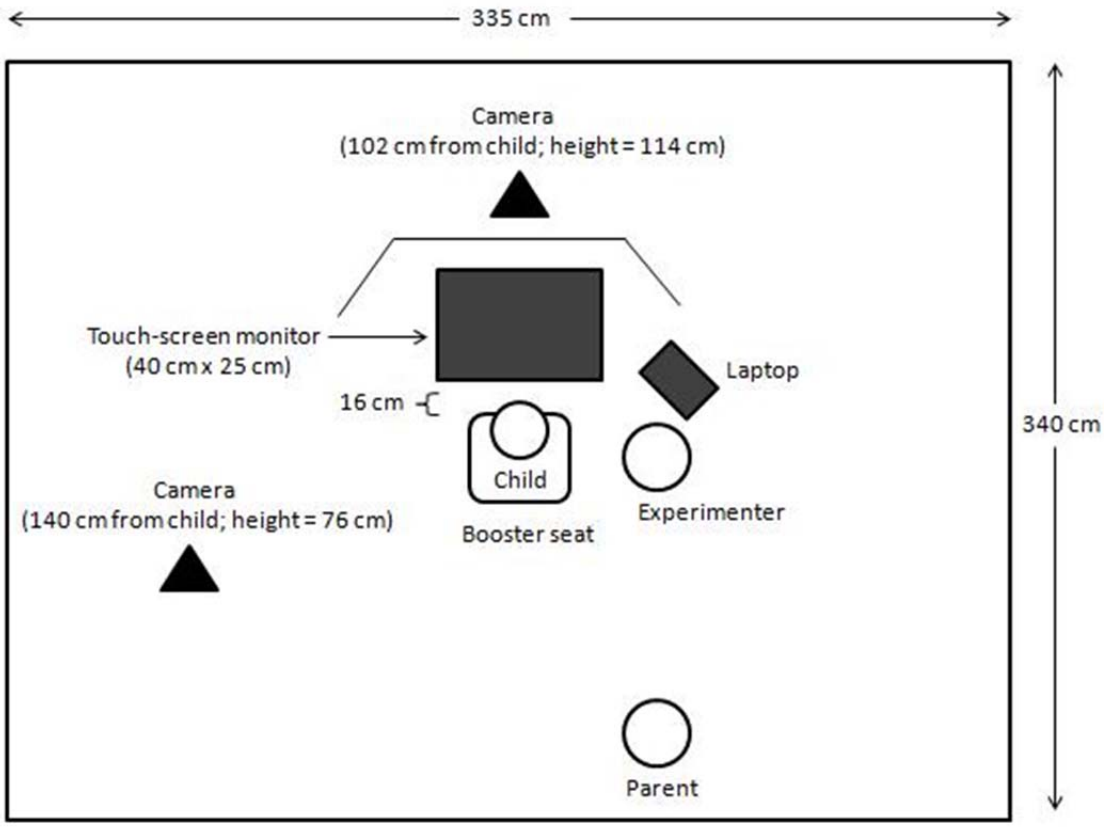

Figure 1. Testing room measurements.

The child was acquainted with a large monkey and a small monkey, each living in respective barrels. The child was told that the monkeys only sing and come out of their barrels when they are hungry, and the child was trained to associate the same-frequency tone pair (Tone 1 – Tone 1) with the large monkey (the large monkey singing) and the different-frequency tone pair (Tone 1 – Tone 2) with the small monkey (the small monkey singing). The child was instructed to touch the barrel of the corresponding monkey when a tone pair was presented and subsequently, the monkey would pop out and get a "treat" (see Figure 2). Additionally, the child received a sticker-sheet before beginning the task. The child received a sticker for each correct response, and after each 10 correct responses (one entire row of collected stickers), a 10 second video reward of a popular children's television show was played for the child on the laptop computer. Thus, a simple touch response was used to assess discrimination of tone pairs with various ISIs. All trials were initiated by the experimenter to ensure the child was oriented towards the touch-screen. If by chance the child was noticeably inattentive during the presentation of auditory stimuli, the experimenter repeated the presented trial. The task was comprised of four phases: orientation, training, criterion, and testing.

Figure 2. Correct response on a 100 Hz– 100 Hz trial and correct response on a 100 Hz– 300 Hz trial.

Orientation consisted of six trials in which the task was explained. During these trials, the visual cue (the large or small monkey) was paired with the onset of the corresponding tone pair. If the child made an incorrect touch response, the experimenter would replay the tone pair and show the child the correct response. The ISI within tone pairs was 150 ms during the orientation trials.

Training consisted of eight trials with an ISI of 150 ms. A visual cue was paired with the onset of the corresponding tone pair during the first four training trials. No visual cues were presented with the tone pairs during the second four training trials. If the child made an incorrect touch response, the experimenter would show the child the correct response and the next trial was presented.

In the criterion phase, no visual cues were presented during four trials with an ISI of 150 ms. If the child made an incorrect touch response, no feedback was given and the next trial was presented. If the child reached a criterion of at least three out of four correct trials, the testing phase would begin. If the child completed fewer than three out of four correct trials, the child reentered the training phase until the criterion was met.

Testing consisted of two blocks of 30 trials. The first 10 trials of each block contained tone pairs with an ISI of 100 ms, the second 10 trials of each block contained tone pairs with an ISI of 70 ms, and the third 10 trials of each block contained tone pairs with an ISI of 10 ms. No visual cues were presented with the tone pairs during testing trials. Same-frequency tone pairs and different-frequency tone pairs were presented in a quasi-random sequence. If the child made an incorrect touch response, no feedback was given and the next trial was presented. If the child completed both blocks of 30 trials, the program was restarted and the child completed additional training and testing trials. The child continued performing the task until compliance ceased to continue and the child was no longer in assent. The task was programmed in Producer by Marybel Robledo using a screen resolution of 1024 x 768.

Language Measures:

The two language measures used were the Peabody Picture Vocabulary Test, Third Edition (PPVT-III; Dunn & Dunn, 1997) and Expressive Vocabulary Test, Second Edition (EVT-2; Williams, 1997). The PPVT-III is a standardized test of listening comprehension assessing receptive vocabulary (standard scores range from 40 to 169) and provides an age-normed score from the age of 2:6 to 90 + years of age. Children’s standard PPVT-III scores were computed for these analyses.

The EVT-2 is a measure of expressive vocabulary and provides an age-normed score for children from 2:6 to 19 + years of age (standard scores range from 20 to 160). Participant’s standard EVT-2 scores were computed for these analyses.

Results

Participants were coded as either attentive or inattentive during rapid auditory processing task trials using video recordings. Inattentiveness was operationally defined as: 1) the child was not looking in the general direction of the touch-screen during presentation of the audio-stimuli 2) the child was talking or making noise during presentation of the audio-stimuli 3) the child was touching the touch-screen monitor during presentation of the audio-stimuli 4) the child was moving the chair or his or her body during presentation of the audio-stimuli. Only attentive trials were used for the following analyses.

A total of 15 children completed the required amount of test trials on the auditory temporal processing task to be included in the analyses. The mean percentage of correct testing trials was 64.3 (SD = 15.01) with a range of 32.4 to 87.7 percent correct (see Table 2). The mean number of testing trials completed was 48 (SD = 14.67) with a range of 24 to 88 trials. The mean PPVT-III standard score for the 10 children who completed the language measures was 122.2 (SD = 14.05) with a range of scores from 102 to 147. The mean EVT-2 standard score for the 10 children who completed the language measures was 123.7 (SD = 13.28) with a range of scores from 103 to 144.

	n = 15	n = 10
Mean training trials (SD)	14.3 (10.00)	15.3 (11.80)
Mean testing trials (SD)	48.2 (14.67)	51.8 (19.13)
Mean % correct 100 ISI (SD)	71.0 (14.24)	73.6 (13.35)
Mean % correct 70 ISI (SD)	62.1 (16.97)	60.6 (18.58)
Mean % correct 10 ISI (SD)	64.6 (16.24)	59.4 (12.59)
Mean testing % correct (SD)	64.3 (15.01)	62.5 (17.05)
Mean PPVT-III (SD)	x	122.2 (14.05)
Mean EVT-2 (SD)	x	123.7 (13.28)

Table 2. Descriptive statistics of children who completed the auditory processing task and of children who completed both the auditory processing task and the language measures.

A pearson product moment correlation was used to test the primary hypothesis that temporal auditory processing ability would be correlated with receptive and expressive vocabulary scores. There was not a significant correlation between percentage of correct testing trials and PPVT-III score ($r_{(8)} = 0.368$, $p = .296$) (see Figure 3), nor was there a significant correlation between percentage of correct testing trials and EVT-2 score ($r_{(8)} = 0.487$, $p = .154$) (see Figure 4).

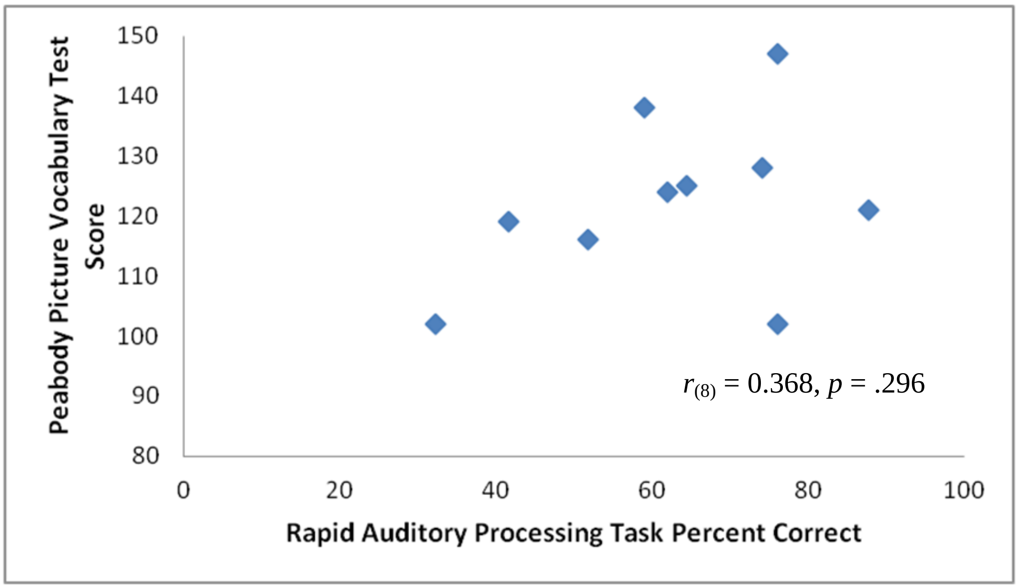

Figure 3. Relationship between percentage of correct testing trials and PPVT-III score.

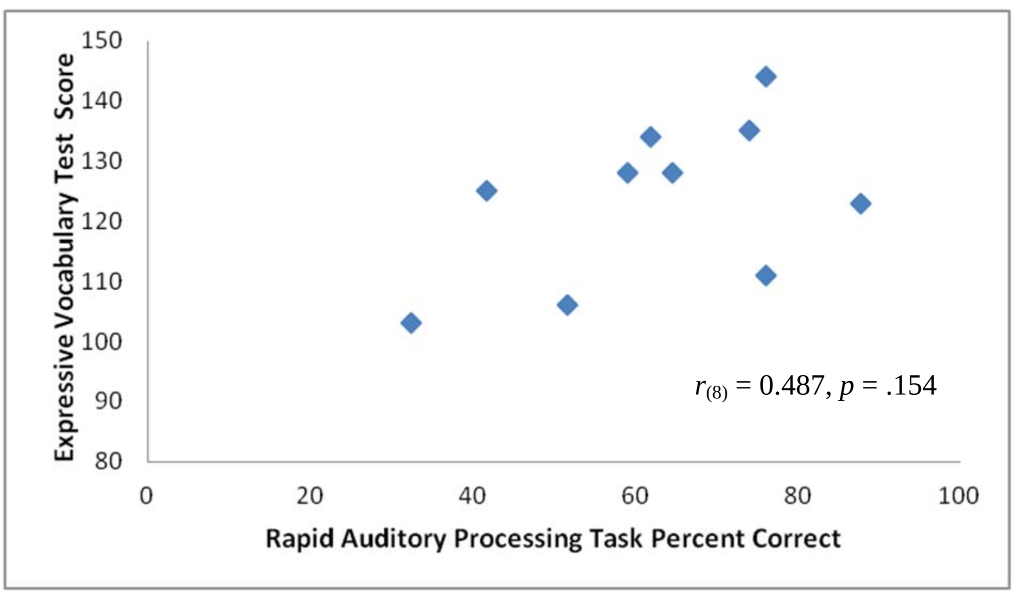

Figure 4. Relationship between percentage of correct testing trials and EVT-2 score.

Secondary findings included significant negative correlations between number of training trials completed to reach criterion and both PPVT score ($r_{(8)} = -0.739$, $p = .015$) and EVT score ($r_{(8)} = -0.887$, $p < .001$). Importantly, age was not correlated with the number of training trials completed to reach criterion. Follow-up *t*-tests were conducted to determine whether children who met the criterion after the first training session (n = 7) would score higher on the PPVT-III and EVT-2 than children who did not meet criterion after the first training session (n = 3). The average number of training trials completed by children who met the criterion after the first training session was 8 trials (SD = 1.8). The average number of training trials completed by children who did not meet the criterion after the first training session was 32 trials (SD = 4.4). Figure 5 shows that children who met the criterion after the first training session had significantly higher PPVT-III scores ($t_{(8)} = 3.34$, $p = .015$) than children who did not meet criterion after the first training session. The average PPVT-III score for children who met criterion after the first training session was 129 (SD = 10.1), whereas the average PPVT-III score for children who did not meet criterion after the first training session was 107 (SD = 8.1). Figure 6 shows that children who met the criterion after the first training session had significantly higher EVT-2 scores ($t_{(8)} = 6.78$, $p < .001$) than those who did not meet the criterion after the first training session. The average EVT-2 score for children who met criterion after the first training session was 131 (SD = 7.2), whereas the average EVT-2 score for children who did not meet criterion after the first training session was 107 (SD = 4.0).

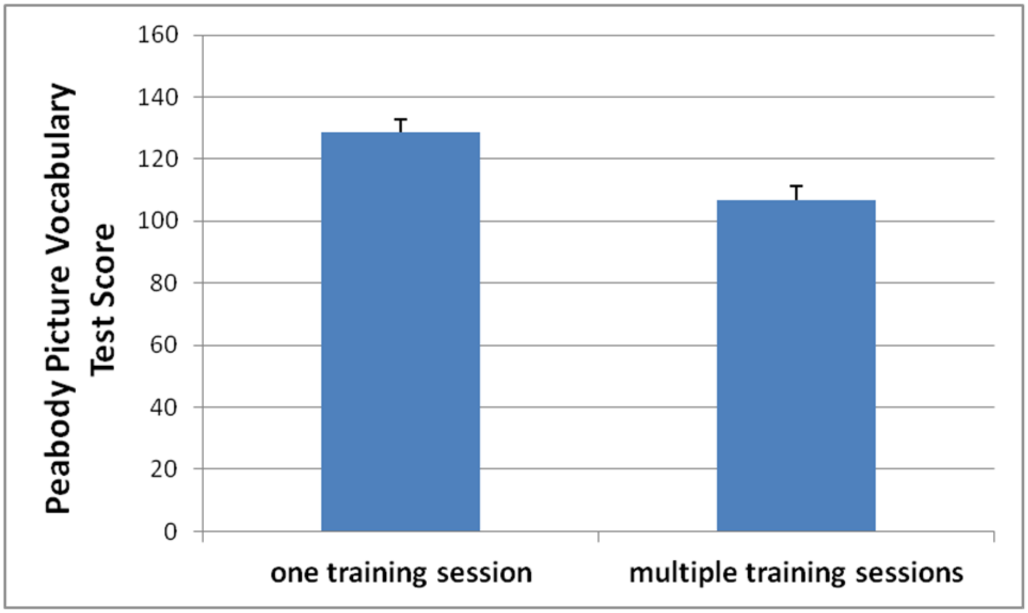

Figure 5. Group differences on receptive vocabulary score.

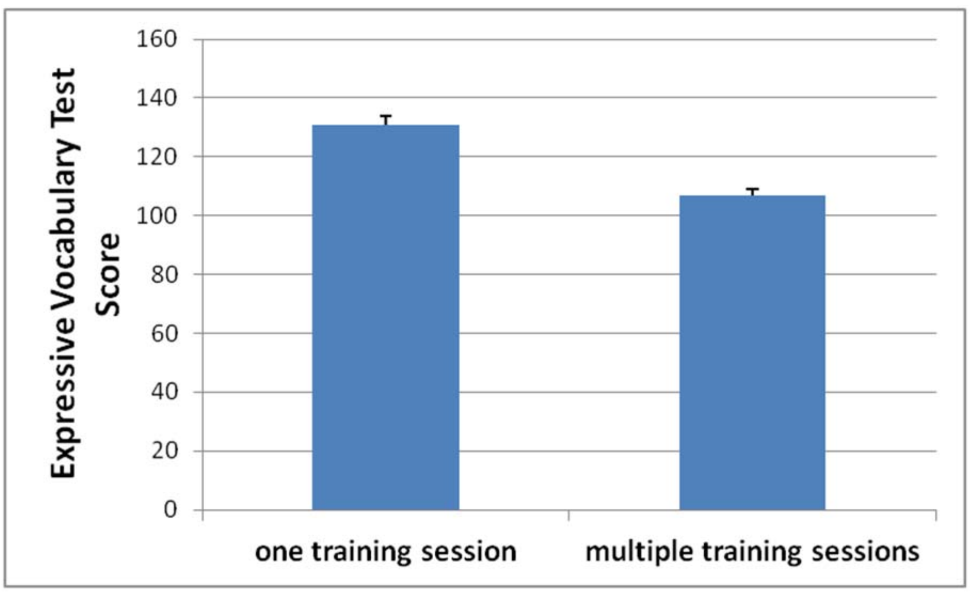

Figure 6. Group differences on expressive vocabulary score.

There was a significant positive correlation between age and number of testing trials completed ($r_{(13)} = 0.664$, $p = 0.007$). However, an association between age and percentage of correct testing trials was not found ($r_{(13)} = 0.407$, $p = 0.132$).

A statistically significant correlation between the number of training trials completed to reach criterion and percentage of correct testing trials was not found. However, there was a trend towards a low-moderate correlation which was approaching significance ($r_{(13)} = -0.495$, $p = .061$).

Discussion

Given these data, it cannot be concluded that this task is a valid measure of temporal auditory processing ability, though it would be feasible to move forward with a larger study. The results do not support the hypothesis that there would be a correlation between temporal auditory processing ability and receptive and expressive vocabulary scores in young children. However, there is a pattern in the results to warrant further investigation, and it is possible that with a larger sample, the low-moderate trends observed in this exploratory pilot study would be replicated with more power. There was a great deal of individual variability in our sample's ability to perform the task with percentage of correct testing trials ranging from 32 to 88 percent. At this point, it cannot be determined whether or not this individual variability can be explained by temporal auditory processing ability or other variables. It should be noted that the variability in task performance is not explained by age. While there was an association between age and number of completed testing trials in which the older children of our sample performed more testing trials than the younger children, task performance was not correlated with age. Therefore, older children may have been more compliant than younger children, but did not differ from younger children in terms of task comprehension or auditory processing ability. Also, there was no relationship between age and the number of training trials completed to reach criterion. It appears that age is not a driving factor of task comprehension or task performance.

One factor which could be driving the observed individual variability is family history of SLI. One of our limitations is that we did not collect this information in our study. Benasich and Tallal (2002) did find differences in auditory processing thresholds between children with and without a family history of SLI. Additionally, it has been previously observed that children who are born into families with a parent or sibling who is affected with SLI are three times more likely to be diagnosed with SLI than children born into families with no history of language impairment (Tomblin 1989; Tallal, Ross, & Curtiss, 1989). Future work should take into account family history of SLI to determine whether this may explain some of the individual differences in temporal auditory processing.

It is also possible, that temporal auditory processing ability is related to language ability in young children, but not as strongly related to the PPVT-III or EVT-2 as to other measures of language ability. Perhaps other measures of language ability besides receptive and expressive vocabulary are more closely associated with temporal auditory processing. Alternatively, it is possible that temporal auditory processing thresholds in this age range are not correlated with current language ability. Perhaps there is not developmental continuity in the relationship between auditory processing and language. Benasich and Tallal (2002) have found that temporal auditory processing ability predicts language outcomes during this period of age. However, perhaps temporal auditory processing ability during this period is not concurrently related to measures of language at this age, although this would not be expected.

While the individual differences we observe in task performance could be representative of individual differences in temporal auditory processing ability, as Benasich and Tallal (2002) found individual differences in temporal auditory processing thresholds in infants across both the group with family history of SLI and the group without family history of SLI, it is also possible that the individual differences in task performance can be explained by other variables. In other words, it is possible that this task is not a valid measure of temporal auditory processing ability. It is possible that the individual differences measured by our task are representative of cognitive ability and task comprehension. We implemented a criterion of correctly associating tone-pairs with their corresponding visual stimuli for at least three out of four trials. While we designed the task as such in order to increase the number of testing trials which could be obtained given the attention span of toddlers and preschoolers, a larger number of criterion trials would be ideal in determining task comprehension. It is possible that children who did not comprehend the task or make the association between the visual and auditory stimuli were able to pass criterion and move onto testing trials. If this were the case, the individual differences seen in task performance could be due to difficulty in comprehension. Alternatively, perhaps some children were able to make the association between the visual and auditory stimuli during training trails and were therefore able to pass criterion but had difficulty remembering the learned association as time passed during testing trials.

Another possible reason for the observed individual differences in task performance could be children’s varying ability to inhibit a touch response either before or after the presentation of the auditory stimulus. Inhibitory control undergoes significant changes developmentally and younger children are not able to inhibit responses as quickly as older children and adults on tasks that require response inhibition (Tamm, Menon, & Reiss, 2002). Individual differences in response inhibition might explain some of the variability we observe in task performance.

Finally, differences in sustained attention and motivation may be resulting in some of the variability between individuals in task performance. Although we attempted to control for inattentiveness by coding for inattentive behaviors during individual trials and removing these trials from the analyses, the operational definitions used for inattentiveness may not embody actual inattentiveness of young children. For example, a child could be sitting still, facing the monitor, and silent but still be inattentive. It is possible that part of the variability in task performance was due to inattentiveness across children in our sample.

The differences in language ability between children who completed one training session and children who completed multiple training sessions to pass the criterion could be explained by multiple factors. It is possible that children with lower language ability had difficulty understanding the verbal instruction given to explain the task due to an inability to process the verbal instruction. It is also possible that children with lower language ability also had more difficulty comprehending the task regardless of being able to hear and process the given verbal instruction. Alternatively, it is possible that the training ISI of 150 ms was too small for children with lower language ability to process and distinguish the tone-pairs. This explanation would be in line with previous research regarding temporal auditory processing thresholds and language ability (Benasich & Tallal, 2002; Tallal & Piercy, 1973).

Moving forward, our results indicate that it would be justifiable to run a larger sample on this task in order to determine the validity of this measure for temporal auditory processing thresholds. Future research utilizing neurophysiological measures such as event related potential components could help to distinguish whether the observed individual differences in young children’s ability to perform this task is due to differences in temporal auditory processing ability. A successful measure for temporal auditory processing thresholds could eventually be used to determine whether there are differences between young children with and without SLI in auditory processing ability. If temporal auditory processing thresholds are indeed related to language ability in young children, a valid and reliable measure for temporal auditory processing thresholds could potentially be used as a screening measure for SLI in toddlers and preschoolers in the future.

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