Temporal Resolution in Infancy and Subsequent Language Development

Sandra E. Trehub  
Joanna L. Henderson  
University of Toronto  
Toronto, Ontario

The MacArthur Communicative Development Inventory, a parent-report measure of vocabulary and syntax, was administered to 103 children (M = 23 months) who had participated in a study of temporal resolution when they were 6 months (n = 55) or 12 months (n = 48) of age. Children who performed above the median on the temporal resolution task in infancy were subsequently reported to have larger productive vocabularies, greater numbers of irregular word forms, and longer and more complex sentences than those who had performed below the median. Whether these findings reflect specific links between temporal resolution and language or whether they reflect general developmental factors remains to be determined.

KEY WORDS: auditory, temporal resolution, infants, language, preschool

Children with language impairments are reported to have deficits in sensitivity to subtle speech cues, the identification of consonant-vowel syllables, or the perception of rapid sequences of sounds (Elliott, Hammer, & Scholl, 1990; Frumkin & Rapin, 1980; Sussman, 1983; Tallal & Piercy, 1974; Tallal, Stark, & Mellits, 1985). Moreover, the magnitude of these deficits is related to the degree of language impairment (Elliott, Hammer, & Scholl, 1989; Elliott et al., 1990; Frumkin & Rapin, 1980; Tallal et al., 1985). Some investigators (e.g., Stark & Tallal, 1981; Tallal et al., 1985) relate such deficits to sequencing or speed of processing difficulties in other modalities, postulating underlying problems in the central nervous system (Tallal, Miller, & Fitch, 1993). Others question the notion of a primary disorder of temporal processing, considering the performance deficits to result from the brevity and rapidity of test stimuli (Reed, 1989; Studdert-Kennedy & Mody, 1995) or from labelling as opposed to sensitivity differences (Sussman, 1993). Massaro and Burke (1991), for example, note the absence of empirical support for the popular belief that young children have a slower rate of perceptual processing than do older children or adults. Instead, reported differences in rate of processing may simply reflect differences in sensitivity or discrimination between younger and older children (Massaro & Burke, 1991) or between language-impaired and unimpaired children (Studdert-Kennedy & Mody, 1995). Sensitivity, discrimination, or identification differences would have their greatest impact in the context of tasks involving rapid rates of presentation, highly confusable stimuli, or prior identification of the to-be-compared stimuli.

Regardless of the locus of the problem—rate of processing, discrimination, or identification—it is unclear whether the reported association between auditory processing and language is limited to special cases of impairment or whether it extends to the normal developmental range. In any case, relatively little is known about temporal aspects of auditory processing in infancy and childhood and possible relations to language. Nevertheless, the protracted development of auditory-temporal resolution (Davis & McCroskey, 1980; Irwin, Ball, Kay, Stillman, & Ross, 1985; Jensen & Neff, 1993; Wightman, Allen, Dolan, Kistler, & Jamieson,
1989) offers a unique opportunity for examining relations between individual differences in temporal resolution, on the one hand, and language skills on the other.

Delays in the development of temporal integration and sequencing skills are sometimes considered a cause as well as a correlate of language impairment (e.g., Bernstein & Stark, 1986; Merzenich, Schreiner, Jenkins, & Wang, 1993; Tallal, 1976), but, as noted, sensitivity, discrimination, or identification differences may be implicated (Massaro & Burke, 1991; Studdert-Kennedy & Mody, 1995; Sussman, 1993). The language problems, regardless of their origin, may persist well beyond the apparent auditory difficulties (Bernstein & Stark, 1985). It remains to be determined, however, whether normal variations in auditory pattern processing have comparable correlates in language. The brevity and subtlety of some acoustic cues to consonant discrimination (Jusczyk, 1987; Kewley-Port, Pisoni, & Studdert-Kennedy, 1983) make speech perception and production potentially sensitive to individual differences in auditory processing, especially in early life.

Despite the aforementioned claims of concurrent deficits in auditory processing and language in young children (Elliott et al., 1990; Frumkin & Rapin, 1980; Tallal & Piercy, 1974; Tallal et al., 1985), there have been no attempts to predict language impairment from earlier deficits or to link normal variations in auditory pattern processing to corresponding variations in language acquisition. Nevertheless, variations in infants’ processing of rapidly presented sound sequences have been linked to concurrent variations in the rate of habituation to visual stimuli and to visual recognition memory (Benasich & Tallal, in press). Moreover, successful prediction of childhood cognitive and language status from visual information processing in normally developing infants (Bornstein & Sigman, 1986; Colombo, 1993; McCall & Carriger, 1993; Rose & Feldman, 1995) indicates the potential of predictive approaches. Fortunately, recent advances in the measurement of auditory-temporal acuity in infancy (e.g., Trehub, Schneider, & Henderson, 1995; Werner, Marean, Halpin, Spethner, & Giffenwater, 1992) have made it possible to examine potential relations between early temporal processing and later language.

Temporal acuity is typically indexed by gap detection, which involves ascertaining the minimum interruption, or gap, that leads to the perception of two sounds rather than one. Because adaptation to auditory signals is relatively rapid and more extensive for long- than for short-duration signals (Harris & Dallos, 1979; Westermann & Smith, 1984), reported age-related differences in gap detection (e.g., Irwin et al., 1985; Werner et al., 1993) may simply reflect age-related differences in adaptation (Schneider, Pichora-Fuller, Kowalchuk, & Lamb, 1994; Trehub et al., 1995). Consider the typical signal in gap detection studies—a continuous noise interrupted by a gap. Recovery from adaptation to the original noise must be sufficient to allow listeners to respond to the reintroduction of the noise, thereby indicating detection of the gap. When listeners fail to respond to a gap (i.e., to the reintroduction of the noise), is the issue one of temporal resolution, adaptation, or some combination of these factors?

To minimize adaptation effects, Trehub et al. (1995) used very brief stimuli constructed from Gaussian-enveloped pure tones (following Schneider et al., 1994). Infants listened to repeating 500-Hz tones (with no gap) from a sound source on their left and were reinforced for responding (i.e., turning to the sound source) when a gapped stimulus or interrupted tone with identical overall duration and energy replaced one of the uninterrupted tones. The 6.5-month-olds detected gap durations of 12, 16, 20, and 24 ms, and 40 ms (but not 8 ms); the 12-month-olds succeeded on all gap durations tested: 8, 12, 16, and 20 ms, but overall performance of 6.5- and 12-month-olds did not differ significantly. Moreover, infants and 5-year-old children detected gaps substantially smaller than those reported in previous investigations (Irwin et al., 1985; Werner et al., 1992). In all likelihood, the long-duration signals in previous studies generated dramatic age-related differences that were principally attributable to differences in adaptation as opposed to temporal acuity. By contrast, the very brief tones used by Trehub et al. (1995) resulted in relatively small differences between infants, children, and adults, which may reflect genuine developmental differences in temporal resolution. It is possible, however, that the three populations are roughly equivalent in temporal resolution, the observed differences arising from attentional as opposed to temporal factors. After all, infants are necessarily disadvantaged by their inability to benefit from verbal instructions about what to listen for.

Although Trehub et al. (1995) found better performance at large than at smaller gap durations, as would be expected, there was considerable intersubject variability. The infant participants had received 40 test trials, half with a change (from an uninterrupted to an interrupted tone) and half with no change. Thus, individual d’ scores could be calculated from each infant’s hits (correct responses on change trials) and false alarms (incorrect responses on no-change trials), making it possible to examine, in the present study, whether infant performance differences on the gap-detection task were associated with differences in language ability in the toddler or preschool period.

We assessed the language ability of children from the Trehub et al. (1995) study when they were 16 to 29 months of age (M = 22.9 months, SD = 3.2 months for those originally tested at 6 months of age; M = 22.4 months, SD = 2.5 months for those originally tested at 12 months of age). Admittedly, the age range was substantial, precluding comparisons of absolute performance levels. Instead, we sought to obtain some indication of toddlers’ language status relative to normative data on their age-mates (e.g., percentile scores). Given the speculative nature of the hypothesized association of early temporal processing and later language and the large size of the sample, efficiency was an important consideration. Accordingly, we administered the MacArthur Communicative Development Inventory—Words and Sentences (CDI, Fenson et al., 1993), a parent-report measure of vocabulary and syntax designed for children 16 to 30 months of age. The CDI is cost-effective relative to experimenter-administered language tests or analyses of spontaneous language samples (Dale, 1991). Moreover, scores on the CDI are highly correlated with those on conventional language assessment instruments such as the Bayley Language Subscale, Preschool Language Scale,
Type-Token Ratio, Expressive One Word Picture Vocabulary Test, as well as measures derived from spontaneous language samples (Bates, Bretherton, & Snyder, 1986; Dale, 1991).

The reported relation between auditory processing deficits and language impairment (Elliott et al., 1990; Frumkin & Rapin, 1980; Tallal & Piercy, 1974; Tallal et al., 1985) coupled with the protracted development of auditory-temporal skills (Davis & McCroskey, 1990; Hall & Grosse, 1994; Irwin et al., 1986; Jensen & Neff, 1993; Werner et al., 1992; Wightman et al., 1989) raised the possibility of relations between temporal acuity in infancy and subsequent language acquisition. Accordingly, we hypothesized that temporal resolution in infancy, as measured by gap detection (Trehub et al., 1995), would be related to language skill in the preschool period, as assessed by the MacArthur Communicative Development Inventory (Fenson et al., 1993). Specifically, children who exhibited better temporal resolution than their normally developing age-mates at 6 or 12 months of age were expected to exhibit more mature language in their second or third year of life than those who had not performed as well in infancy.

Method

Participants

There were 160 infants who had completed gap detection tasks, 96 at 6 months of age, 64 at 12 months of age (Trehub et al., 1995). All infants were volunteers from middle-class families in the local community. No child had a family history of hearing impairment, a personal history of ear infections, or known neurological, physical, or developmental impairments. The earlier study established gap detection thresholds for the two infant age groups by means of a between-subjects design. Specifically, each of 6 groups of 16 6-month-olds (total of 96 infants) was tested on a single gap duration: 8, 12, 16, 20, 28, or 40 ms; each of 4 groups of 16 12-month-olds (total of 64 infants) was also tested on a single gap duration: 8, 12, 16, and 20 ms. For the purposes of the present study, each infant in the original sample was assigned to one of two groups designated as high or low temporal resolution on the basis of whether his or her d' score fell above or below the median d' score for infants tested at the same age and on the same gap duration. Five infants who scored exactly at the median were randomly assigned to either the high or low temporal resolution group, with the constraint that three were assigned to one group and two to the other. In principle, an above-median performer on a 20-ms gap might have been a below-median performer on a 12-ms gap. In practice, however, this information was unavailable, precluding an overall rank-ordering of performance for infant participants in the original study. Nevertheless, infants in the above-median group had, on average, better temporal resolution than those in the below-median group.

From the original population of infants in the Trehub et al. (1995) study, 128 were between 16 and 30 months of age at the time of the present study, ages that were appropriate for administration of the CDI-Words and Sentences. We reached 115 of those families several months (in some cases, almost 2 years) after their participation in the original gap-detection study. All families agreed to participate in the language study, but 11 of them failed to return the CDI forms and one family returned an incomplete form. The gap-detection data of these 12 children revealed a typical distribution of scores, indicating that CDI drop-outs did not differ systematically from those who remained in the sample. Because 6-month-olds had performed at chance levels on the 8-ms gap (Trehub et al., 1995), data from these children (n = 8) were excluded from further consideration. The final sample of 95 participants (47 girls, 48 boys) consisted of 47 children with high temporal resolution (i.e., above-median performance) and 48 with low temporal resolution (i.e., below-median performance). Children with high temporal resolution in infancy had a mean age of 22.2 months (SD = 3.0 months) at the time of administration of the CDI; those with low temporal resolution had a mean age of 23.1 months (SD = 2.7 months) at that time. Those originally tested at 6 months of age had a mean age of 22.9 months (SD = 3.2) at the time of CDI testing; those tested at 12 months had a mean age of 22.4 months (SD = 2.5).

Materials

The MacArthur Communicative Development Inventory—Words and Sentences (CDI), a parent-report measure of language, is designed for children 16 to 30 months of age. It assesses productive vocabulary as well as grammatical development. Part I (Words Children Use) includes a 680-item vocabulary checklist divided into 22 semantic categories (e.g., animals, action words). Part II (Sentences and Grammar) has five subsections, three of which are concerned with morphological development and two with sentence forms. The morphology subsection (Word Endings) includes a 25-item checklist of irregular words (e.g., children, went) and a 45-item checklist of overregularizations (e.g., mouses, goed). One of the sentence subsections requests three examples of the child's longest sentences, yielding a very rough estimate of mean length of utterance (MLU). The remaining subsection consists of 37 pairs of sentences that differ in complexity; respondents indicate which sentence sounds most like their child. The inventory takes approximately 20 to 40 minutes to complete, depending upon the child's level of development. The CDI manual provides normative information on productive vocabulary, irregular word use, MLU, and sentence complexity. For productive vocabulary, moreover, there are separate norms for boys and girls.

Procedure

Parents of infants who participated in the original gap detection study were contacted when their child was in the appropriate age range for administering the language inventory. Subsequently, forms (with self-addressed, stamped envelope) from the MacArthur Communicative Development Inventory—Words and Sentences (CDI) were mailed together
TABLE 1. CDI percentile scores (standard deviations in parentheses) as a function of good or poor temporal resolution in infancy.

<table>
<thead>
<tr>
<th>Temporal resolution categories</th>
<th>Good</th>
<th>Poor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Produce Vocabularly</td>
<td>47.1</td>
<td>31.7</td>
</tr>
<tr>
<td>Irregular Words</td>
<td>57.1</td>
<td>42.1</td>
</tr>
<tr>
<td>Sentence Complexity</td>
<td>58.8</td>
<td>39.8</td>
</tr>
</tbody>
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with a letter requesting the completion and return of these forms within a week. No instructions were provided aside from those on the CDI form itself. One follow-up phone call and letter was made to those families who were slow to return the forms.

Results

Percentile scores were determined for each child for productive vocabulary, irregular word use, and sentence complexity, as outlined in Fenson et al. (1993). An MLU deviation score for each child was also calculated by subtracting the expected MLU (following norms provided by Fenson et al., 1993) from the observed MLU (following guidelines of Fenson et al., 1993, and Brown, 1973). Observed MLU was based on the parent's report of three examples of the child's longest sentences, a measure highly correlated with conventional MLU scores (Dale, 1991). Inter-rater reliability, calculated on a randomly selected subset (20%) of the total sample, was .85. In no case did the difference between raters exceed one morpheme. CDI scores for children with high or low temporal resolution (see Table 1) were examined by means of several analyses of variance (ANOVA)s in which sex (male, female), infant age (6, 12 months), and temporal resolution (high, low) were factors.

An ANOVA with vocabulary as the dependent measure indicated a significant main effect of temporal resolution, $F(1, 87) = 7.303, p < .01$, but no effects of sex, $F(1, 87) = 0.257, p > .05$, or of infant age, $F(1, 87) = 0.004, p > .05$, and no significant interactions. On average, children with high temporal resolution in infancy had productive vocabulary scores 15 percentile points higher than those with low temporal resolution (see Table 1). Similarly, an ANOVA with irregular word use as the dependent measure revealed a significant main effect of temporal resolution, $F(1, 87) = 8.130, p < .01$, but no effects of sex, $F(1, 87) = 0.59, p > .05$, or of infant age, $F(1, 87) = 0.002, p > .05$, and no significant interactions. On average, children with high temporal resolution in infancy outscored their toddler peers with low temporal resolution by 15 percentile points on irregular word use (see Table 1).

A further ANOVA revealed significant differences in MLU deviation scores between children with high and low temporal resolution, $F(1, 87) = 8.476, p < .01$, but no effects of sex, $F(1, 87) = 0.1, n.s.$, or of infant age, $F(1, 87) = 0.635, n.s.$ Children with low temporal resolution in infancy (i.e., below-median gap scores) had, on average, 1.2 fewer morphemes than would be expected for their age. By contrast, children with high temporal resolution (above-median gap scores) had MLU scores at expected values (+1 morpheme). There was, however, a significant interaction of sex by infant age group, $F(1, 87) = 6.310, p < .05$. Post hoc comparisons revealed significantly higher MLU deviation scores (i.e., greater differences between observed and expected MLU) for girls originally tested at 12 months compared to those originally tested at 6 months of age ($p < .05$). Although this interaction is difficult to interpret, and likely reflects sampling error, it has no bearing on the relation between infant resolution and subsequent language.

According to Fenson et al. (1993), percentile scores for sentence complexity may be unreliable for children younger than 20 months because of the relatively low frequency of word combinations at that time. Accordingly, the scores of 11 toddlers who were younger than 20 months at the time of CDI administration were excluded from the sentence complexity analysis. The ANOVA for the remaining 84 participants revealed a significant main effect of temporal resolution on sentence complexity, $F(1, 76) = 10.156, p < .01$, but no effects of sex, $F(1, 76) = 0.014, p > .25$, or of infant age group, $F(1, 76) = 1.165, p < .05$, and no significant interactions. Children with high temporal resolution in infancy had sentence complexity scores that were, on average, 19 percentile points higher than children who had low temporal resolution in infancy (see Table 1).

Discussion

Children who exhibited good temporal resolution at 6 or 12 months of age, as reflected in above-median performance on a gap detection task, had, on average, more mature language in the toddler and preschool period, as indicated by parental report, than did children who had poorer temporal resolution (i.e., below-median scores). Specifically, good temporal resolution in infancy was associated with larger productive vocabularies, more irregular word forms, as well as longer and more complex sentences in the toddler or preschool period, as reflected in scores on the MacArthur Communicative Development Inventory. The magnitude of these effects was substantial despite the conservatism of the hypothesis. One would therefore expect even stronger relations between early temporal resolution and subsequent language if infants could be rank-ordered with respect to temporal acuity rather than being assigned to the rough categories of above- or below-median performance in infancy.

The links between early temporal acuity and subsequent language were unaffected by the initial age of assessment (i.e., 6 or 12 months of age). In other words, relations between temporal resolution and language were as robust when the CDI was administered approximately 16 months (on average) after the gap detection task (for 6-month-olds) or when the CDI was administered 10 months after the gap detection task (for 12-month-olds). These findings imply that the temporal acuity measure taps an important and relatively stable characteristic of the developing infant.

Some interpretive caution may be warranted because the child language measures were derived from parental report
rather than direct assessment. Parents may be inclined to provide rich interpretations of their children's linguistic output. For the present findings to be attributable to parental inaccuracy, however, parents would have had to systematically overestimate the linguistic performance of children with high temporal resolution in infancy, or systematically underestimate the performance of those with low temporal resolution. That hardly seems likely. Just as parental reports can be favorably biased, so expert assessments of child language can be biased in the opposite direction because of time constraints and interpersonal difficulties. In any case, the high correlations between the CDI and various experimenter-administered measures (Bates et al., 1988; Dale, 1991) indicate that, at the very least, parental reports and experimenter assessments yield comparable information about relative language abilities. Thus, questions can be raised about the absolute level of language achievement of child participants, but such concerns are irrelevant to the present finding of child language differences on the basis of temporal acuity differences in infancy.

Although the present findings indicate a clear relation between early temporal resolution and subsequent language in the normal range of abilities, they have no bearing on the controversy surrounding temporal processing and language impairment (e.g., Studdert-Kennedy & Mody, 1995; Tallal et al., 1993). In principle, good temporal resolution could enhance the processing of speech in infancy, with potential consequences for early language acquisition. There are no suggestions, however, that the level of temporal resolution exhibited by infants performing below the median of a normally developing sample is insufficient to support normal language acquisition.

It is also unclear whether the findings reflect factors specific to temporal resolution and language. What remains to be determined is whether infants with better temporal resolution than their age-mates are simply more attentive or developmentally advanced, or whether their superior performance is domain-specific. Attentive or developmentally advanced infants may well make more rapid progress in subsequent language acquisition than less attentive or advanced infants. General developmental status in infancy could be assessed by evaluating performance across a wide range of tasks. Although Bensasch and Tallal (in press) suggest that relations among aspects of auditory processing, habituation, and recognition memory in infancy reflect the infant's underlying speed of processing, such findings are also consistent with differences in general developmental status. In any case, it is important to ascertain the durability of linguistic differences among normally developing children who differ in temporal acuity in infancy. From the findings of the present study, such differences remain evident until at least 30 months of age.

Not only does the present investigation confirm an association between early temporal resolution and subsequent language development; it also paves the way for more specific questions. For example, is there some minimal level of temporal resolution in infancy that is required for normal progress in language? Infants with very poor temporal resolution—those who perform substantially below their age-mates (not simply below the median) on temporal acuity tasks but who have normal auditory sensitivity—might be at risk for significant language delay. If so, they could be targeted for appropriate intervention. In the original study of gap detection (Trehub et al., 1995), over 80% of the 6-month-olds detected 20-ms gaps in very brief tones at significantly better than chance levels. One could establish, for example, the ages at which infants who performed at chance levels achieve levels of vocabulary and sentence complexity comparable to those of infants with superior temporal resolution. If the link between early temporal resolution and subsequent language is mediated by general developmental status, as it might well be, then the implications of performance problems on a gap detection task that takes a mere 10 minutes to administer would be profound indeed.

Finally, the observed relations between temporal resolution in infancy and later language are consistent with reported associations between visual information processing in infancy and subsequent cognitive ability (Bornstein & Sigman, 1986; Colombi, 1993; McCall & Carriger, 1993; Rose & Feldman, 1995). An important agenda for future research is to ascertain the broader developmental correlates of auditory-temporal resolution in early life.

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References


