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The Development of Language-Specific and Language-Independent Talker Processing

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Abstract

Purpose—In this study, the authors aimed to investigate how differences in language ability relate to differences in processing talker information in the native language and an unfamiliar language by comparing performance for different ages and for groups with impaired language.

Method—Three groups of native English listeners with typical language development (TLD; ages 7–9, ages 10–12, adults) and 2 groups with specific language impairment (SLI; ages 7–9, ages 10–12) participated in the study. Listeners heard pairs of words in both English and German (unfamiliar language) and were asked to determine whether the words were produced by the same or different talkers.

Results—In English, talker discrimination improved with age. In German, performance improved with age for the school-age children but was worse for adult listeners. No differences were found between TLD and SLI children.

Conclusion—These results show that as listeners' language skills develop, there is a trade-off between more general perceptual abilities useful for processing talker information in any language and those that are relevant to their everyday language experiences and, thus, tied to the phonology. The lack of differences between the children with and without language impairments suggests that general auditory processing may be intact in at least some children with SLI.

Keywords

speech perception; talker processing; specific language impairment; development

The speech signal is the realization of an individual talker producing a linguistic target and, thus, gives rise to (at least) two types of information: what is being said and who is saying it. Abundant research has found that these two types of information interact during perception (e.g., Cutler, Andics, & Fang, 2011; Green, Tomiak, & Kuhl, 1997; Mullennix & Pisoni, 1990). Although the development of perceptual processes underlying the linguistic component has been widely explored, there is relatively little work on the development of the perception of talker information. In this article, we seek to gain a fuller understanding of how listeners process talker information and how these skills develop so that we may

understand speech perception, generally. In particular, we investigate the perception of language-specific information that is used when listening to a familiar language and compare this to the perception of general, language-independent information that can be used when listening to an unfamiliar language.

The perception of talker information in the native language begins at the earliest stages of development. Differentiating between the mother's voice and an unfamiliar female voice has been found in fetuses (Kisilevsky et al., 2003), newborns (DeCasper & Fifer, 1980), and infants in their first year of life (Purhonen, Kilpeläinen-Lees, Valkonen-Korhonen, Karhu, & Lehtonen, 2004, 2005), suggesting that talker processing begins with familial relationships (Kreiman & Sidtis, 2011). Infants in their first year can also differentiate between unfamiliar voices (DeCasper & Prescott, 1984; Johnson, Westrek, Nazzi, & Cutler, 2011).

Bartholomeus (1973) found that preschool children ages 4–5 could identify their classmates' voices above chance (approximately 60% accuracy with 18 voices to identify), although this was highly variable across children. Mann, Diamond, and Carey (1979) directly tested the development of talker processing and found improvement in talker identification across ages 6–10, with a small drop during early teens and then a large increase in performance for 14-year-olds. These results show that age, and by inference language development, influences talker processing.

In addition to age, language ability (impaired vs. typical) has also been shown to affect the perception of talker information in language impairment. Perrachione, Del Tufo, and Gabrieli (2011) found that adults with a history of dyslexia (reading impairment) were worse at identifying different talkers than were adults with normal reading ability. As with development, the data from language-impaired populations show that more advanced language skills are associated with more accurate perception of talker information.

These findings hold for listeners processing talker information in their native language. Abundant research on the perception of talker information has found that listeners are more accurate at perceiving talker information in their native language than in an unfamiliar language (Goggin, Thompson, Strube, & Simental, 1991; Goldstein, Knight, Bailis, & Conover, 1981; Hollien, Majewski, & Doherty, 1982; Köster & Schiller, 1997; Perrachione & Wong, 2007; Thompson, 1987; Winters, Levi, & Pisoni, 2008). Listeners learning a second language quickly exhibit nativelike talker processing skills (Schiller & Köster, 1996; Sullivan & Kügler, 2001; Sullivan & Schlichting, 2000), showing that as the second language is learned, talker processing also improves.

This difference in performance between familiar and unfamiliar languages can be attributed to the two different types of talker information that are present in the speech signal: language independent and language specific (Wester, 2012; Winters et al., 2008). Winters et al. showed that listeners can identify and discriminate among talkers when those talkers are speaking different languages; these findings revealed that some markers of talker identity are present regardless of the language being spoken. This language-independent talker information that is available across different languages includes properties such as age, gender, and vocal tract length. In contrast, when listeners make judgments about talker identity or talker differences within a single familiar language, they also have access to

talker information that is tied to linguistic information, such as dialect affiliation or how a particular talker articulates native speech sounds (idiolect). This language-specific talker information is not available when listening to an unfamiliar language or to two different languages where listeners do not have knowledge of the unfamiliar language's phonology. In this study, we investigate the development of these two types of talker information by using an AX discrimination paradigm. Thus, we can simultaneously test the effects of development and language familiarity to gain a clearer understanding of the processes that underlie the perception of talker information. An AX discrimination task was selected to test the development of talker processing because it is one where listeners need not develop a category for the different talkers they hear. Instead, the task can be performed based only on differences or similarities between talkers that are present on a particular trial.

In addition to examining performance by children with typical language development (TLD), we also present preliminary data from children with specific language impairment (SLI). There are both theoretical and clinical reasons for the inclusion of children with SLI. Studies showing impaired perception by children with SLI on nonlinguistic, purely auditory perception tasks (e.g., tone detection; McArthur & Bishop, 2004; Tallal, 1976; Tallal & Piercy, 1973a, 1973b; Wright et al., 1997) have been used in theoretical debates to argue for a more general auditory-processing deficit in children with SLI. This theory can be tested with our study because attention is directed not at the linguistic content of the utterance but at who is talking. Testing the perception of talker information with German words further segregates talker processing from linguistic processing by preventing listeners from accessing linguistic information. Thus, this study will be able to test whether children with SLI show intact perception of talker information in German, where they can rely on only nonlinguistic, language-independent talker information. It will also test their perception of talker information in English, where they have access to both language-specific (here English-specific) and language-independent talker information. Examining differences between TLD and SLI children in two languages may help specify the degree to which an auditory deficit in SLI is general versus specific to language processing.

The clinical motivation for including the children with SLI is that it allows for a comparison with the findings of Perrachione et al. (2011), who examined talker identification by adults with reading impairments. Oral and written language disorders are frequently comorbid (Bishop & Snowling, 2004; Catts, Adlof, Hogan, & Ellis Weismer, 2005; McArthur, Hogben, Edwards, Heath, & Mengler, 2000), and deficits on linguistic auditory perception tasks like those found in children with SLI have also been found in children with reading impairments (McAnally, Hansen, Cornelissen, & Stein, 1997; Mody, Studdert-Kennedy, & Brady, 1997; Serniclaes, Sprenger-Charolles, Carré, & Demonet, 2001; Studdert-Kennedy, 2002; Studdert-Kennedy & Mody, 1995; Vandewalle, Boets, Ghesquière, & Zink, 2012). Despite similarities between these disorders, it remains unclear whether they derive from the same underlying impairment. This study will provide additional data on the relationship between language impairments and talker processing.

Method

Participants

Thirty-eight adult native speakers of American English (ages 18–25) participated in the study. All adults indicated through self-report that they had no history of speech or hearing impairments. Four groups of children participated in the study: 18 older children ages 10–12 ($M = 10;6$ [years; months], $SD = 8$ months) with TLD; 32 younger children ages 7–9 ($M = 8;3$, $SD = 8$ months) with TLD; six older children ages 10–12 ($M = 11;2$, $SD = 10$ months) with SLI; and six younger children ages 7–9 ($M = 8;2$, $SD = 10$ months) with SLI. Children were classified as SLI or TLD based on their performance on the Clinical Evaluation of Language Fundamentals, Fourth Edition (CELF–4; Semel, Wiig, & Secord, 2003) and the Test of Nonverbal Intelligence, Third Edition (TONI–3; Brown, Sherbenou, & Johnsen, 1997). The CELF is a comprehensive test of language skills for individuals ages 5–21 years. Children were given the subtests of the CELF that generate the composite scores of core language, expressive language, and receptive language. The TONI is a test of nonverbal cognition, which uses black and white line drawings to test problem solving and pattern matching. Children in the SLI group performed at least 1.25 SD s below the mean on two or more subtests of the CELF and achieved a score of ≤ 85 on the TONI. Children were classified as TLD if they scored ≤ 85 on the composite measures (core language, expressive language, receptive language) of the CELF and achieved a score of ≤ 85 on the TONI. None of the participants had any knowledge of German (the second language used in the perception task).

Stimuli

Three female bilingual German-L1/English-L2 speakers were recorded producing 360 monosyllabic CVC words in both English and German. Recordings were made in a sound-attenuated IAC booth at the Indiana University Speech Research Laboratory using a SHURE SM98 head-mounted unidirectional (cardioid) condenser microphone with a flat frequency response from 40 to 20000 Hz. Productions were digitized into 16-bit stereo recordings through Tucker-Davis Technologies System II hardware at 22050 Hz and saved directly to a PC. Speakers read each word as it was presented to them on a computer monitor in random order, blocked by language. All sound files were normalized to have a uniform RMS amplitude. The three bilingual speakers used in the current study were highly intelligible and selected from a larger group of bilinguals (Levi, Winters, & Pisoni, 2011; see Table 1). In addition, the three speakers were selected as having relatively different average fundamental frequency across productions.

The 360 English words were rated independently by three individuals (one of whom was the first author) as likely to be known to children ages 6–9 (high frequency), likely to be unknown to these children (low frequency), or possibly known by these children. Out of these words, 133 were rated as high frequency and 115 were rated as low frequency by all three raters. We compared our ratings of familiarity with age of acquisition (AoA) ratings from Cortese and Khanna (2008). For their ratings, lower numbers indicate that the words were acquired earlier. The mean AoA for the high-frequency words was 3.01 (acquired between ages 4–6) and for the low-frequency words was 5.34 (acquired after ages 8–10).

Only three of our high-frequency words were not found in Cortese and Khanna's database (*house, mouse, pill*). Seventeen words from our low-frequency list were not found in the database; 15/17 have a frequency of 1 based on Kuera and Francis (1967) and two (*couth, goon*) are not included. Examples of English and German words are provided in the Appendix.

Monosyllabic CVC words were used to avoid differences in language-specific phonotactic restrictions (e.g., on consonant clusters, stress patterns) and to limit listeners' ability to use prosodic features to distinguish talkers, as would be present in longer utterances. Previous work (Winters et al., 2008) has shown that these short stimuli are indeed sufficient to perceive differences across talkers.

Procedure

All participants performed two separate self-paced talker discrimination experiments in English and German, with the order of presentation counterbalanced across participants. Listeners were informed whether they would be listening to English or a language other than English, but they were not told what the other language would be. Participants heard pairs of distinct words separated by a 750-ms interstimulus interval. Stimuli were presented binaurally over Sennheiser HD-280 circumaural headphones. Participants were asked to determine whether the words were spoken by the same talker or by two different talkers and received feedback in the form of a face with a smile or a frown after each trial. Different lexical items were used in each trial, requiring listeners to process the talker information at an abstract level (e.g., Talker 1 *book*, Talker 2 *room* for Different Talker trials; Talker 1 *cat*, Talker 1 *name* for Same Talker trials). Participants completed two experimental blocks consisting of 24 trials, half of which were same-talker pairs and half were different-talkers pairs. In addition, in the English task, half of the pairs consisted of high-frequency words and half consisted of the pairs of low-frequency words. Prior to the experimental blocks, participants completed a practice block, which was not included in the analysis. No difference in performance was found between the two experimental blocks, and, thus, they were collapsed in the analyses presented below.

For the purposes of analysis, performance for each listener was based on A' , a nonparametric measure of sensitivity that is based on the proportion of hits (P_{HIT}) and false alarms (P_{FA} ; see Equation 1 below; Grier, 1971) rather than on percentage correct. For the purposes of analysis, hits were responses of "different" on different talker trials. A' ranges from 0.0 to 1.0, where 0.5 is chance performance and 1.0 is perfect sensitivity to differences:

$$A' = 0.5 + \frac{(P_{\text{HIT}} - P_{\text{FA}}) \cdot (1 - P_{\text{HIT}} - P_{\text{FA}})}{4 \cdot P_{\text{HIT}} \cdot (1 - P_{\text{FA}})} \quad (1)$$

Results

Talker Discrimination in English

For the TLD children and adults, a one-way analysis of variance (ANOVA) of performance on the English talker discrimination task showed a clear effect of age, $F(2, 85) = 19.47$, $p < .$

001 (see Figure 1). Planned comparisons showed that adults performed better than older TLD children, $t(54) = -2.61, p = .012$, Cohen's $d = 0.75$, who, in turn, performed better than younger TLD children, $t(48) = 2.82, p = .007, d = 0.83$. Even with the small sample size, children with SLI also showed a significant effect of age on talker discrimination in English. Older children with SLI performed better than younger children with SLI, $F(1, 10) = 6.13, p = .032, d = 1.43$. These findings indicate that, across development, the ability to perceive fine acoustic detail that relates to talker differences also improves.

To assess the effect of language ability as a function of oral language impairment, performance was compared across TLD and SLI children. No significant differences were found between TLD and SLI children for the English talker discrimination (older: $p = .69$; younger: $p = .17$), although the number of participants in the SLI group was small.

Paired-samples t tests comparing sensitivity on high-frequency versus low-frequency words revealed no significant differences: younger TLD, $t(31) = 0.64, p = .52$; older TLD, $t(17) = 0.20, p = .84$; adult, $t(37) = 0.58, p = .55$; younger SLI, $t(5) = 1.01, p = .35$; older SLI, $t(5) = 1.18, p = .29$.

Talker Discrimination in German

In German, a one-way ANOVA for the TLD participants also revealed a significant effect of age, $F(2, 85) = 5.63, p = .005$ (see Figure 1). Planned comparisons showed that older TLD children performed better than younger TLD children, $t(48) = 3.19, p < .002, d = 0.94$. Unexpectedly, adults performed significantly worse than the older TLD children, $t(54) = 3.25, p = .002, d = 0.93$, and no differently from younger TLD children ($p = .90$), suggesting that as perceptual skills are honed across development, talker perception is improved for a listener's native language but eventually weakened for an unfamiliar language. A one-way ANOVA examining performance for the children with SLI also revealed that older SLI children performed significantly better than younger SLI children, $F(1, 10) = 6.25, p = .031, d = 1.44$. As in the English discrimination task, no differences were found between SLI and TLD children on the German discrimination tasks (older groups, $p = .65$, younger groups $p = .88$).

A comparison between performance on English and German revealed a significantly higher performance in English than in German for the adult listeners, $t(37) = 9.66, p < .001, d = 1.60$. A small but significant difference in performance was revealed for the younger TLD children, $t(31) = 2.62, p = .013, d = 0.33$. No differences were found for the remaining groups of children (older TLD, $p = .36$; older SLI, $p = .53$; younger SLI, $p = .29$).

Discussion

This study confirmed that processing talker information in the native language improves with age for both the TLD and SLI participants. The pattern of results was different in the unfamiliar language where talker discrimination improved with age in both the SLI and TLD children but where adults actually performed worse than the older group of TLD children.

Our results suggest that there is a change in how listeners weight language-specific and language-independent talker information across development and into adulthood. As children develop, they become more accurate at perceiving acoustic information that helps differentiate talkers generally, showing improvement in both English and German. This suggests that they rely on and use language-independent talker information. This language-independent information is not tied to linguistic information such as how a particular speaker produces a particular phoneme, but instead it provides information about the talker, such as age, gender, and size (e.g., vocal tract length). It is this type of language-independent information that is likely to be useful when processing talker information in unfamiliar languages.

It is interesting that as children develop into adults, they begin to rely on language-specific talker information, at the expense of language-independent talker information. This can be viewed as a shift in how listeners weight the language-independent and language-specific information. This change may reflect a process of attunement to language-specific talker information in the native language. A similar phenomenon, although with a much younger population, is found in the development of linguistic processing. Infants begin as language-general perceivers and are able to distinguish speech sounds that are not present in the ambient linguistic environment (Kuhl et al., 2006; Maye, Weiss, & Aslin, 2008; Maye, Werker, & Gerken, 2002; Werker & Tees, 1984). By the end of their first year, infants have become language-specific perceivers, distinguishing only those sounds that are linguistically relevant in their native language. This change reflects a perceptual attunement to information in the speech signal that is linguistically relevant. Our study shows an analogous attunement to talker information by revealing a simultaneous improvement for processing language-specific talker information along with a decline in performance when processing language-independent talker information.

In a study of talker processing in infants, Johnson et al. (2011) found that infants cannot detect talker differences in an unfamiliar language. On the basis of these findings, they argued that knowledge of phonology, and not of lexical semantics, supports the perception of talker information. Our analysis of high- versus low-frequency words in the English condition also suggests that phonological knowledge supports talker processing in adults. No differences were found in performance for the high- versus low-frequency words, many of which were likely processed as nonwords (e.g., *neap*, *luff*, *doff*). Although these words were low frequency or functionally nonwords, they were produced in English with English phonology. The lack of a difference between highly familiar words that are known and those that are unfamiliar and may not have a semantic representation suggests that phonological properties and not semantic properties play a critical role in the perception of talker information by adults.

No differences in performance were observed between the SLI and TLD children in either English or German talker discrimination tasks. The lack of a difference between TLD and SLI children may seem surprising given that several studies have found that children with SLI perform more poorly than TLD controls in a variety of auditory-processing tasks. That no differences in performance were found in the English and German tasks suggests that children rely on language-independent talker information regardless of the language spoken.

In our data, at an age where language-independent talker information is used, children with SLI also perform well, but it remains unknown whether the shift to using language-specific talker information that occurs in adulthood would be impaired in adults with a history of SLI. The finding that adults with dyslexia (Perrachione et al., 2011) are impaired when performing talker processing tasks in English suggests that they are unable to use language-specific talker information and, thus, may imply that adults with SLI would also have difficulty when processing talker information where reliance on language-specific talker information is important.

Conclusion

The data presented here reveal that talker processing continues to develop across school-age children and into adulthood. Furthermore, although language-specific talker processing improves into adulthood, language-independent talker processing declines, revealing a trade-off between those skills that are relevant and potentially useful in (adult) speech perception and those that do not exist in everyday listening situations. This shift may represent a change in how listeners weight language-independent and language-specific talker information. The lack of differences across SLI and TLD children may provide evidence that more general auditory processing—for tasks and stimuli that are natural—is not impaired in children with SLI, although these results are preliminary.

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Appendix

Table A1

Sample words Used in English and German

English		German		Gloss
Orthography	IPA	Orthography	IPA	
then	en	Ritt	rit	“ride”
chop	tʃap	Napf	napf	“bowl”
run	ran	süß	zy:s	“sweet”
head	hed	hoch	ho:x	“high”

English		German		
Orthography	IPA	Orthography	IPA	Gloss
mode	mouð	tief	ti:f	“deep”
leach	liʃ	Fett	fɛt	“fat”
sage	seɪdʒ	Sack	zak	“sack”
zeal	zil	Zahn	tʰsa:n	“tooth”

Note. IPA = International Phonetic Alphabet.

Figure 1.

Sensitivity (A') and SE for the five participant groups in the English (native language) and German (unfamiliar language) discrimination tasks. TLD = typical language development; SLI = specific language impairment.

Table 1

Intelligibility and F0 information about the speakers used in this study and a larger group of bilingual and monolingual speakers.

Variable	Speaker	Intelligibility (%)	F0 (Hz)
Current study	F3	49.1	222
	F8	54.7	170
	F11	41.2	260
Additional bilingual speakers	F2	37.1	207
	F4	43.8	186
	F5	41.0	208
	F7	33.5	177
	F9	48.4	202
	F10	38.4	222
	F12	54.7	186
Native English speakers	EF1	47.8	183
	EF2	52.7	185
	EF3	56.7	189
	EF6	43.4	194
	EF7	37.8	204

Note. *Intelligibility* refers to the average number of words correctly identified across three signal-to-noise ratios and a clear listening condition (Levi et al., 2011). *F0* is the average fundamental frequency at the vowel midpoint for the 360 English words.