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Adult listeners can extract age-related cues from child-directed speech

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Abstract

This study investigated adult listeners' ability to detect age-related cues in child-directed speech (CDS). Participants ($N = 186$) listened to two speech recordings directed at children between the ages of 6 and 44 months and guessed which had addressed a younger or an older child. The recordings came from North American English-speaking mothers and listeners were native speakers of Turkish with varying degrees of English knowledge. Participants were randomly assigned to listen either to the original recordings or to the low-pass filtered versions. Accuracy was above chance level across all groups. Participants' English level, age, and the age difference between the addressees significantly predicted accuracy. After controlling for these variables, we found a significant effect of condition. Participants' accuracy tended to be better in the unfiltered condition with the exception of male participants without children. These results suggest that age-related variations in CDS are perceptually available to adult listeners. Furthermore, even though sensitivity to the age-related cues is facilitated by the availability of content-related cues in speech, it does not seem to be solely dependent on these cues, providing further support for the form–function relations in CDS.

Keywords

Child-directed speech; communication; speech register; age estimation; CHILDES

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Public significance statement

This study shows that the age-related changes in child-directed speech can be perceived by adult listeners such that they can make correct judgements about the age of the recipient children. This ability does not depend on listeners' familiarity with the language or having children.

Adult listeners can extract age-related cues from child-directed speech (CDS). Across different species, communicative signals are modified flexibly depending on the characteristics of the communicative partners. A well-known example is the vocalisations produced when addressing infants and young children (e.g., Burnham et al., 2002; Chen et al., 2016; Hirsh-Pasek & Treiman, 1982; Luef & Liebal, 2012; Stern et al., 1983; Trehub et al., 1993; Uther et al., 2007). The acoustic properties of child-directed vocalisations show similarities across human cultures (Moser et al., 2020) and are readily distinguished from vocalisations addressing adults by listeners of varying ages (Bryant & Barrett, 2007; Fernald, 1989; Soley & Sebastian-Galles, 2020; Trehub et al., 1993; Varghese & Nilsen, 2016), suggesting universal form–function links in these signals. While previous studies mainly contrasted adult- and child-directed vocalisations in terms of listeners' ability to identify them, several studies also reveal considerable variation within CDS, depending on the recipient child's age (e.g., Amano et al., 2006; Bernstein-Rantner, 1984; Englund & Behne, 2006; Garnica, 1977; Han et al., 2018; Kitamura & Burnham, 2003; Kitamura et al., 2002; Ko, 2012; Liu et al., 2009; Narayan & McDermott, 2016; Rattanasone et al., 2013; Stern et al., 1983). Here, we examine whether this information is perceptually available to listeners such that they can make more nuanced estimates about the age of the recipients of CDS.

Compared with speech directed to adults, CDS tends to have higher pitch, greater pitch range, pitch variability

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and positive affect, and a slower pace (e.g., Fernald, 1992; Fernald et al., 1989; Fernald & Kuhl, 1987; Kitamura & Burnham, 2003). There is, however, significant variability in these characteristics across infancy and childhood. For instance, studies focusing on pitch have shown a general decrease in pitch height and pitch range in CDS with age across a number of languages including American English, Mandarin, Japanese, Australian English, and Thai (Amano et al., 2006; Garnica, 1977; Han et al., 2018; Kitamura & Burnham, 2003; Kitamura et al., 2002; Niwano & Sugai, 2002; Remick, 1976; Stern et al., 1983). Others have shown that acoustic exaggeration (e.g., vowel hyperarticulation) in CDS decreases as the recipient child's age increases (Englund & Behne, 2006; Liu et al., 2009; Rattanasone et al., 2013). Studies also point to age-related affective changes in CDS (Bornstein et al., 1992; Garnica, 1977; Kitamura & Burnham, 2003; Penman et al., 1983; Sherrod et al., 1978). Specifically, some studies suggest a decrease in affective utterances and an increase in directive utterances as the target child gets older (e.g., Bornstein et al., 1992; Garnica, 1977; Kitamura & Burnham, 2003). Finally, studies also show that both speech rate (number of linguistic units per time) and number of words per utterance tend to increase as the recipient child gets older (Narayan & McDermott, 2016; Phillips, 1973; Sjons et al., 2017).

Together, these studies demonstrate that several changes in CDS take place over the first 5 years of life. It is also important to note that the reported changes are not always observed in a linear fashion across development. For instance, Stern et al. (1983) observed that caregivers use a larger pitch range when their infants were 4 months old compared with when they were newborns, or when they were 1 or 2 years of age. Examining CDS in Australian English, Kitamura and Burnham (2003) found that affective statements peak at the ages of 6 and 12 months, while directive statements peak at 9 months of age. Ko (2012) observed nonlinear changes in the speech rate of American and British English-speaking mothers whose children's ages vary between 15 and 55 months. Similarly, while no difference in acoustic exaggeration in Mandarin CDS was found within the first 18 months of life (Burnham et al., 2015; Cristia & Seidl, 2014; Kalashnikova & Burnham, 2018; Liu et al., 2003), when utterances directed at 7- to 12-month-olds and 5-year-olds were compared, a decrease in acoustic exaggeration was observed (Liu et al., 2009).

These age-related variations are usually linked to different functions CDS might serve at various points in development. Many different functions of CDS have been proposed. CDS is argued to enhance infants' attention (Fernald & Simon, 1984; Werker & McLeod, 1989) and facilitate affective communication between the caregiver and the child (Fernald, 1989, 1992). CDS is also suggested to serve as a pedagogical cue that facilitates infants' and children's learning (Csibra & Gergely, 2006). Others have shown that CDS might help children learn about their social environment by facilitating their acquisition of face–voice pairings (Kaplan et al., 1996) and their identification of suitable social partners (Schachner & Hannon, 2011). CDS might also allow speakers to achieve *social convergence* by modifying their vocalisations when communicating with infants and children (Kalashnikova et al., 2017). Finally, several studies suggest that CDS supports language acquisition by aiding infants distinguish vowel categories (Kuhl et al., 1997; Trainor & Desjardins, 2002), segment the speech stream (Thiessen et al., 2005), learn pairings of words and objects (Graf Estes & Hurley, 2013), and acquire grammar (Christophe et al., 2003). Thus, across development, depending on the newly emerging abilities and the needs of the children, different characteristics of CDS might become more or less salient (e.g., Fernald, 1992; Newport et al., 1977; Snow, 1977). Fernald (1992) suggested, for instance, that CDS is more affective during the first months of life and it becomes linguistically more complex towards the end of the first year. Similarly, Ko (2012) demonstrated that linguistic complexity of CDS differs across development in a non-linear fashion, mimicking target children's linguistic skills.

CDS has characteristics that are shared across various cultures (Broesch & Bryant, 2015; Ferguson, 1977; Fernald, 1989), but the extent to which CDS and adult-directed speech (ADS) differ from one another varies across cultures (Broesch & Bryant, 2018; Farran et al., 2016; Fernald et al., 1989). Despite this variability, listeners can readily distinguish whether the speech they hear addresses a child or an adult and extract intentions from CDS even in unfamiliar languages (Bryant & Barrett, 2007; Fernald, 1989; Golinkoff & Alioto, 1995). By showing that CDS is not only evident, but also readily recognised across cultures, these studies suggest universal links between physical characteristics of CDS and its communicative purpose, supporting the biological significance of this signal (e.g., Bryant & Barrett, 2007). Given the age-related variability observed in CDS across different linguistic groups and contexts, listeners might also be able to extract age-related cues from CDS and make nuanced age-related inferences about the recipients of CDS. Particularly given that these age-related variations are linked to different functions CDS might serve at different ages (e.g., Fernald, 1992), these cues might be perceptually available to listeners, providing further support for the connection between form and function in CDS.

On the contrary, given that extracting age-related cues might be more challenging than simply distinguishing CDS from ADS, these cues might be perceptually more or less available to the listeners depending on their familiarity with the language (e.g., being a native speaker) and with CDS (e.g., having a child or not). As an example, if listeners have to rely on semantic cues in CDS when identifying the recipient child's age, they would have to have some knowledge of that particular language, to be able to do so. Similarly, parents, who are presumably more familiar with CDS, might be more sensitive to certain age-related cues in CDS and make more correct age-related estimates. Some studies also point to differences in terms of both the quantity and quality of CDS produced by mothers and fathers, suggesting that gender may be another potential factor influencing listeners' ability to extract age-related cues in CDS. For instance, analysing adult speech heard by 3- to 20-month-olds, a recent study found that North American children hear about 2–3 times more CDS from females compared with males (Bergelson et al., 2018). A number of studies also point to differences in the acoustic properties of CDS depending on the speaker gender (Fernald et al., 1989; Gergely et al., 2017; Jacobson et al., 1983; Shute & Wheldall, 1999). For instance, one study analysing CDS in five different languages, found that mothers used a larger pitch range when addressing their children compared with when they addressed adults, whereas the pitch range in fathers' CDS and ADS did not differ (Fernald et al., 1989). Jacobson et al. (1983) also showed that regardless of having a child or not, females' CDS had more pitch variability than males' (Jacobson et al., 1983). Gergely et al. (2017), analysing Hungarian, found that while both females and males produced CDS when communicating with their children, males produced less exaggerated vowels when talking to their infants under 18 months of age.

Building on these findings, the present research asks whether listeners can extract age-related cues from CDS and if so, what cues they rely on when making age-related inferences. Specifically, we examine whether listeners can extract age-related cues based solely on acoustic properties of speech, or whether semantic cues are necessary as well. We also ask whether gender and familiarity with CDS play a role in listeners' ability to make correct age-related inferences. To examine listeners' ability to extract age-related cues from CDS, we presented listeners with and without children, with two speech recordings directed at children between the ages of 6 and 44 months. The recordings came from North American English-speaking mothers and listeners were native speakers of Turkish with varying degrees of English knowledge. Half of the participants were randomly assigned to listen to these original recordings and half of them were assigned to listen to low-pass filtered versions. Listeners were asked to guess which recording had addressed a younger or an older child.

Method

Participants

Final sample included data from 186 adults between the ages of 24 and 48 years (96 female, $M_{age}=33.49$ years). Three additional participants were tested but their data were excluded from the analyses because the environment was noisy during testing ($N=2$), or because the participant reported having hearing loss ($N=1$). Ethics approval was obtained from the university review board. Participants were recruited through social media accounts of the laboratory and word of mouth. Some of the participants were parents who came to the laboratory for an infant study. All participants signed an informed consent before participating.

Participants were randomly assigned to the filtered ($M_{age}=34.07$ years, $SD=5.54$) or the unfiltered condition ($M_{age}=32.93$ years, $SD=5.25$). Among the 92 participants in the filtered condition, 48 reported to have children (24 female, $M_{age}=36.23$ years, $SD=4.79$) and 44 reported to have no children (23 female, $M_{age}=31.72$ years, $SD=5.38$). Among the 94 participants in the unfiltered condition, 46 reported to have children (23 female, $M_{age}=35.25$ years, $SD=3.96$) and 48 reported to have no children (26 female, $M_{age}=30.70$ years, $SD=5.41$). Formal music training ranged from 0 to 15 years in the unfiltered condition ($M=0.94$, $SD=2.52$) and from 0 to 15 years in the filtered condition ($M=0.98$, $SD=1.13$). The average of participants' self-reported English proficiency scores (ranging between 0 and 10, 0=*I don't know English at all*, 10=*I speak English like a native speaker*) was 5.33 ($SD=3.01$) in the filtered condition, and 5.12 ($SD=3.03$) in the unfiltered condition. Participant characteristics for each group are summarised in Table 1.

Stimuli. Speech stimuli were selected from the CHILDES database (MacWhinney, 2000). Recordings in North American English were preferred due to the richness of this linguistic group in the database. The selection process was based on a number of criteria: We selected recordings that were taken during free play and had a transcription with information about the age of the child, as well as whether other individuals were present during the recording session. With the aid of these transcriptions, we eliminated recordings of sessions that included other individuals, including the experimenter, father, or other children to make sure that the mother was directing her speech to the infant and not to others in the environment.

Next, the first author listened to the recordings and extracted clips in which the speech continued for at least 3 s before any disruptions had occurred (e.g., the child's vocalisations, the sound of the toys). After the process, 1,749 audio-recordings were retained. Because the quality of the recordings varied quite drastically, two research assistants, who were blind to the purpose of the study, were instructed to listen to the recordings and exclude the recordings with bad quality where the speech was not clearly heard. The assistants agreed to retain a total of 497 recordings. Finally, with the aid of the transcriptions of these recordings, stimuli hinting at the age of the child (e.g., including the words baby or babysitter), including

Table 1. Means and standard deviations of participants' age (in years), reported English level (ranging from 0 to 10), and formal music training (in years) according to Gender, Condition, and Parenthood.

			Age (in years)		English level (range = 0–10)		Formal music training (in years)	
Condition	Parent	Gender	*M*	*SD*	*M*	*SD*	*M*	*SD*
Unfiltered	No	Female (*n* = 26)	30.2	5.04	5.11	3.08	0.68	2.23
		Male (*n* = 22)	31.28	5.87	5.77	3.13	1.45	3.37
	Yes	Female (*n* = 23)	34.47	3.28	4.18	3.12	0.75	1.41
		Male (*N* = 23)	36.04	4.48	5.45	2.73	0.91	2.72
Filtered	No	Female (*N* = 23)	31.76	6	5.26	3.28	1.22	3.18
		Male (*N* = 21)	31.68	4.76	6	2.29	1.33	1.39
	Yes	Female (*N* = 24)	34	4.14	5.14	3.17	1	2.3
		Male (*N* = 24)	38.5	4.4	4.17	3.18	0.42	0.93

SD: standard deviation.

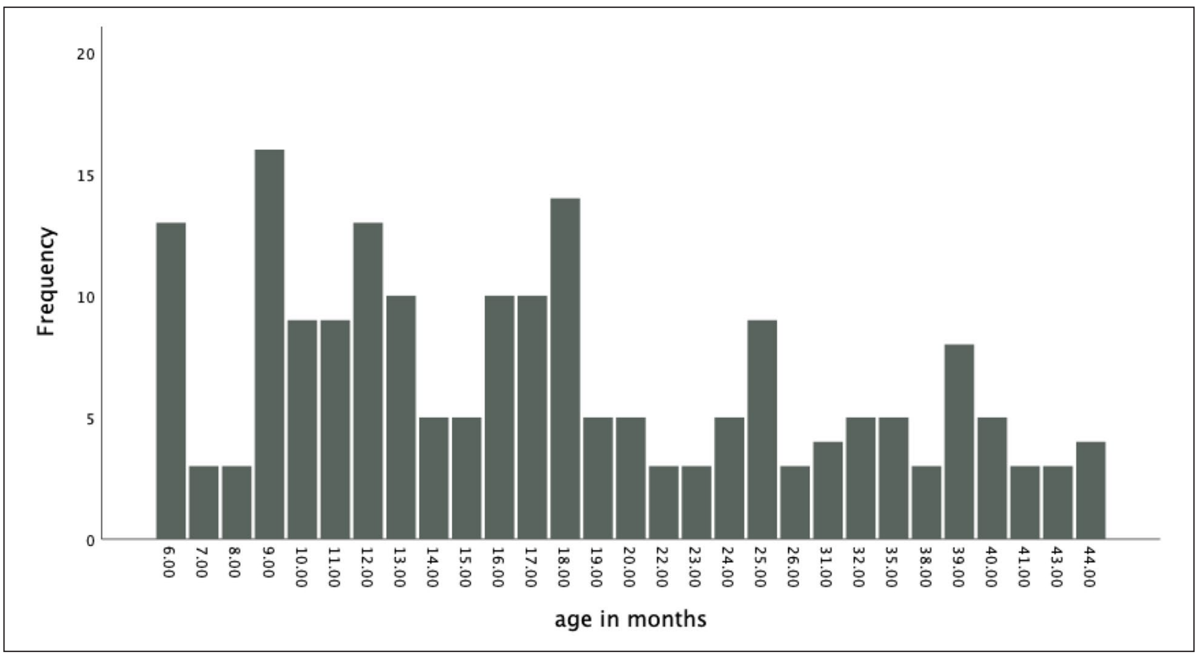

Figure 1. Number of recordings per age group (in months).

the child's name, having less than three words, and stimuli that were clearly not directed to the child (e.g., the mother indicated the date in the beginning of the recording session) were excluded. Finally, we randomly selected five recordings that were directed to the same child in a given age in months, in case there were more than five.

The final stimuli included 193 recordings ranging from 3 to 22 s in duration that originally came from a number of previously published or unpublished studies (Bernstein, 1982; Brent & Siskind, 2001; Demetras, 1989; McCune, 1995; Rollins, 2003; Sachs, 1983; Soderstrom et al., 2008; Weist et al., 2009) and were available on the CHILDES database (MacWhinney, 2000; MacWhinney & Snow, 1990). The recordings came from mothers of 28 children (16 females, 12 males) aged between 6 and 44 months. The number of recordings coming from the same mother ranged between 3 and 19, with an average of 6.89 recordings per mother. The number of clips for each age group (in months) is presented in Figure 1.

There was no relationship between children's ages (in months) and the duration of the audio recordings, $r = -.03$, $p = .72$. For the low-pass filtered condition, all recordings were filtered at 400 Hz (rolloff 24 dB per octave), using Audacity (Cooper & Aslin, 1994). After these processes, both filtered and unfiltered recordings were equalised at 70 dB using Praat (Boersma & Weenink, 2021).

Acoustic analyses. We extracted the minimum pitch, maximum pitch, mean F_0, and the pitch range (maximum F_0—minimum F_0) for each unfiltered recording using Praat (Boersma & Weenink, 2021). The relationship between the recipients' age (6–44 months), and the mean F_0 values, minimum pitch, maximum pitch, and the pitch range (maximum F_0—minimum F_0) were assessed with Pearson's correlations. Results showed that recipients' age was negatively correlated with mean F_0 ($M=263.32$, $SD=65.78$), $r=–36$, $p<.001$), maximum pitch ($M=494.97$, $SD=108.30$), $r=–.20$, $p=.005$), and also with minimum pitch ($M=116.31$, $SD=48.43$), $r=–.20$, $p=.004$). We did not observe any relationship between age and pitch range ($M=378.65$, $SD=112.76$), $r=–.10$, $p=.150$). Thus, mothers tended to use speech with lower mean pitch, lower minimum pitch, and lower maximum pitch when addressing older children.

Native speaker ratings. To confirm that the content-related cues were largely unavailable to the listeners after the filtering process, four native North American English speakers were asked to listen to each audio recording, rate its comprehensibility on a scale from 1 to 7 (1=*Extremely easy to comprehend*, 7=*Extremely difficult to comprehend*), and transcribe orthographically. Two of the native speakers rated the filtered version of the recordings and two of them rated the unfiltered recordings. The raters could listen to each recording as many times as they wanted.

The raters found filtered speech stimuli significantly less comprehensible ($M=6.41$, $SD=0.94$), compared with unfiltered speech stimuli ($M=1.51$, $SD=0.68$) *Welch's* $F(1, 697.78)=6976.26$, $p<.001$, $\eta_p^2=.90$. The percentage of accurate transcriptions was calculated based on the exact accuracy of the phrases. For instance, if the rater could transcribe the entire phrase correctly, that transcription was coded as "correct"; however, if the rater failed to transcribe at least one word accurately, that transcription was coded as "incorrect." In the filtered condition, even though the raters had a chance to re-listen to the stimuli as many times as they wanted, one rater could not transcribe 54% of the recordings at all, and overall, the percentage of the recordings that the rater correctly transcribed was 1%. The second rater could not transcribe 45% of the recordings at all, and overall, the percentage of the recordings that the rater correctly transcribed was 4%. In the unfiltered condition, both raters could transcribe all of the 193 recordings. One rater could transcribe 92% of the recordings correctly, and the other rater could transcribe 93% of the recordings correctly.

Design and procedure

The experiment was designed and run using PsyScope program (Cohen et al., 1993). The experiment took place in a quiet room and participants wore noise-cancelling headphones (SONY, ZX110NC, Tokyo, Japan). Before the testing phase was initiated, participants received instructions on the screen and they received three training trials with identical procedure as the test trials that are described below.

Participants received 40 test trials.[1] On each trial, participants were presented with two recordings and they were asked to indicate which recording was directed to a younger (or an older) child. The question type (i.e., "Which recording was directed to a younger child?" vs. "Which recording was directed to an older child?") was counterbalanced within participants across trials. The recordings were selected and matched randomly by PsyScope from the pool of 193 recordings, with the constraint that the two recordings could not be addressing children of the same age in months. Each recording was heard only once throughout each experimental session. Participants recorded their response by pressing the keys "1" and "2" on the keyboard, indicating the first or the second recording, respectively. After participants had recorded their choice, they also rated their confidence level on a five-point scale with higher scores indicating higher confidence. The experimental session lasted approximately 30 min. At the end of the experiment, participants filled out the demographic questionnaire and were debriefed.

Results

Preliminary analyses on participant characteristics

Three 2 x 2 x 2 ANOVAs with Condition (filtered vs. unfiltered), Parenthood (having at least one child vs. having no children), and Gender (male vs. female) compared participants' self-rated English proficiency level, formal music education in years, and age across these groups. The results revealed that these variables were similar across groups with the following exceptions: age significantly differed across gender ($F(1, 178)=6.16$, $p=.014$, $\eta_p^2=.03$) and depending on whether participants had children or not ($F(1, 178)=40.71$, $p<.001$, $\eta_p^2=.19$). On average, male participants were older ($M=34.36$, $SE=0.51$) compared with female participants ($M=32.61$, $SE=0.492$), and participants who had at least one child were older ($M=35.74$, $SE=0.50$) compared with participants who did not have children ($M=31.23$, $SE=0.50$). We also found a marginal interaction between gender and parenthood ($F(1,178)=3.17$, $p=.077$, $\eta_p^2=.02$): While age did not differ between male ($M=31.48$, $SE=0.734$) and female participants with no children ($M=30.98$, $SE=0.69$), male participants with children were older ($M=37.25$, $SE=0.70$), compared with female participants with children ($M=34.23$, $SE=0.70$). All other effects and interactions were non-significant (all $ps>.15$).

Main analyses

Main analyses were conducted using generalised linear mixed-effects model with binomial distribution and a logit link function. Accuracy (1=*correct* and 0=*incorrect*) was included as target variable and Participant ID was included as random effect. Main variables of interest were Condition

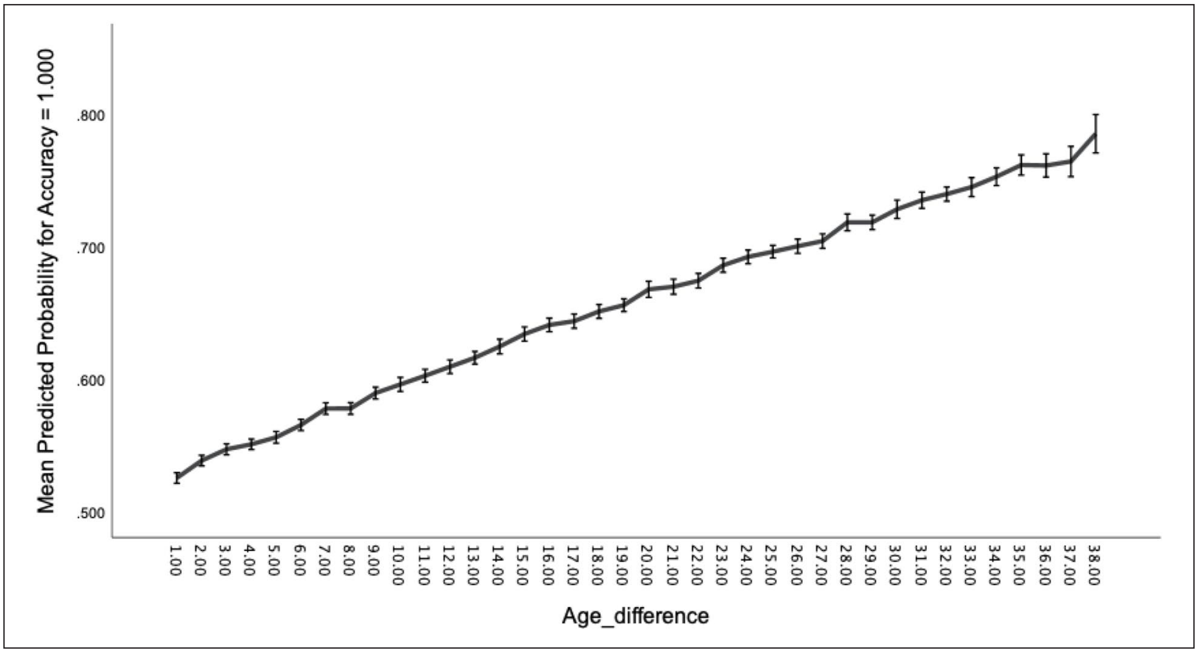

Figure 2. Predicted probability of correct as a function of age difference between the addressed children.
Error bars represent 95% CI.

(filtered vs. unfiltered), Parenthood (having at least one child vs. having no children), and Gender (male vs. female). These and the interactions between them were entered as fixed effects. To control for participants' age and English level, and the age difference between target children, these were included as additional fixed effects. We used Satterthwaite approximation to account for potential unbalanced aspects of the data and robust estimation to handle potential violations of model estimations.

We conducted a preliminary analysis to see whether the task characteristics predicted participants' accuracy. In addition to the variables of interest and the control variables, we included presentation order of the recordings in terms of infants' age (younger–older vs. older–younger) and how the question was formulated (i.e., "Which recording was directed to a younger child?" vs. "Which recording was directed to an older child?") as fixed effects. The results revealed no significant effects of these two task characteristics (*p*s > .15). Therefore, these were removed from the model for subsequent analyses.

Overall, participants were accurate on 62% of the trials and this was significantly different from chance ($t(7424)=21.34$, $p=.000$, $d=.25$). The results of the main analyses revealed significant effects of English level ($F(1, 162)=4.39$, $p=.038$) age ($F(1, 126)=4.89$, $p=.029$), age difference between target children ($F(1, 7414)=113.971$, $p=.000$), and condition ($F(1, 141)=13.69$, $p=.000$) and a significant three-way interaction between Condition, Parenthood, and Gender ($F(1, 176)=4.19$, $p=.042$). Other main effects and interactions were not significant (*p*s > .13) Being older (ß = .011, $SE=0.005$, $p=.029$) as well as having higher English proficiency (ß = .019, $SE=0.009$, $p=.038$) predicted higher accuracy. Furthermore, as the age difference between target children increased, participants were more likely to make correct judgements (ß = .03, $SE=0.003$, $p=.000$) (see Figure 2).

Accuracy was higher in the unfiltered condition ($M=0.65$, $SE=0.009$) compared with the filtered condition ($M=0.60$, $SE=0.008$) (ß = .036, $SE=0.097$, $p=.000$). Follow-up analyses on the three-way interaction between Condition, Parenthood, and Gender (ß = .44, $SE=0.21$, $p=.042$) showed a significant interaction between Parenthood and Condition for male participants: accuracy of male parents was higher ($M=0.68$, $SE=0.016$) in the unfiltered condition compared with the filtered condition ($M=0.61$, $SE=0.019$) (ß = –.33, $SE=0.14$, $p=.024$), whereas for male listeners without children, accuracy was similar across filtered ($M=0.60$, $SE=0.016$) and unfiltered ($M=0.60$, $SE=0.018$) conditions. For female participants no such interaction was observed (ß = .011, $SE=0.16$, $p=.51$). Accuracy percentages for each group are provided in Table 2 (see Figure 3 for predicted probability of correct across groups). Accuracy was above chance level of 50% in all groups (all *p*s < .001).

Additional analyses on reaction times and confidence ratings

Accuracy (1 = *correct* and 0 = *incorrect*) as target variable and participant ID as random effect were submitted to a generalised linear mixed-effects model with

Table 2. Accuracy estimates across groups. Continuous predictors are fixed at the following values: English = 5.2129, Age = 33.5054, Age difference = 13.7921.

					95% Confidence interval	
Condition	Parent	Gender	*M*	*SE*	Lower	Upper
Unfiltered	No	Female	0.659	0.020	0.619	0.696
		Male	0.600	0.018	0.564	0.635
	Yes	Female	0.650	0.018	0.614	0.685
		Male	0.672	0.016	0.640	0.703
Filtered	No	Female	0.602	0.017	0.567	0.636
		Male	0.595	0.016	0.562	0.626
	Yes	Female	0.618	0.017	0.583	0.651
		Male	0.589	0.017	0.556	0.622

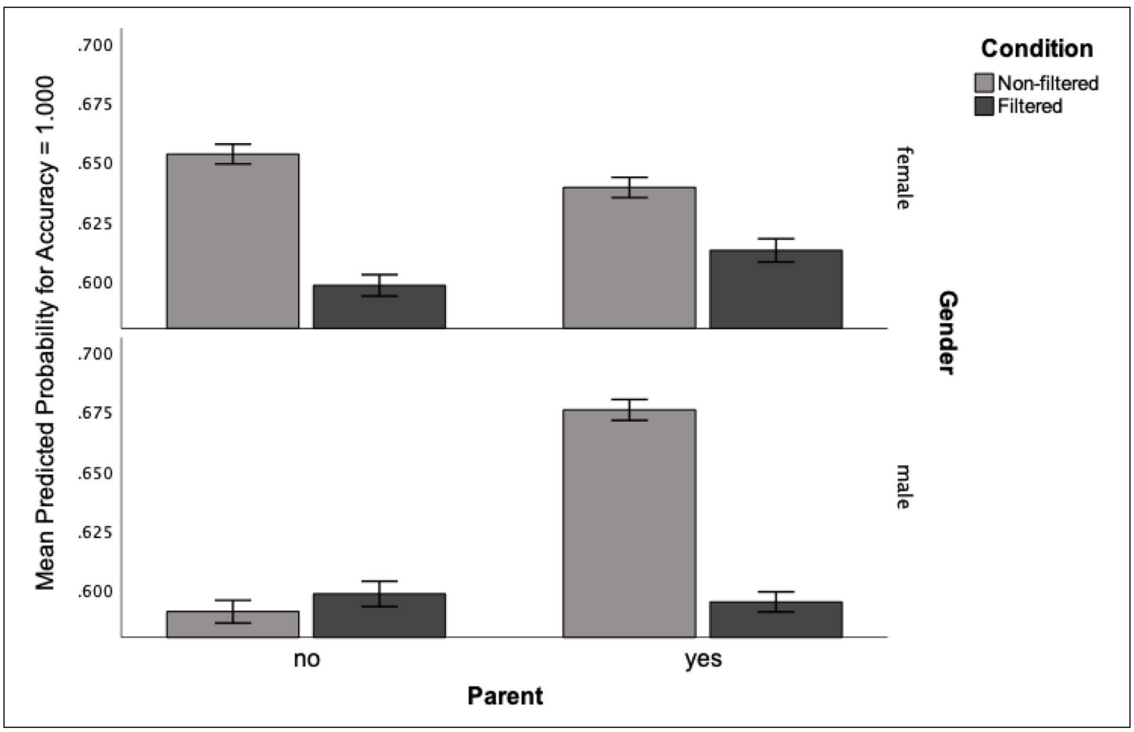

Figure 3. Probability of correct as a function of Condition, Parenthood, and Gender. Continuous predictors are fixed at the following values: Age = 33.51, English = 5.21, Age difference = 13.79.
Error bars represent 95% CI.

binomial distribution and a logit link function. Reaction times and confidence ratings were included as the fixed covariates. The model was specified to use Satterthwaite approximation and robust estimation. The model yielded significant effects of both reaction time ($F(1, 7422) = 7.36$, $p = .007$, ß = –.00, $SE = 0.00$) and confidence ratings ($F(2, 5610) = 50.95$, $p = .000$, ß = .19, $SE = 0.11$). The negative reaction time coefficient suggests that participants were faster when giving correct responses ($M = 2.59$ s, $SD = 2.25$) compared with when giving incorrect responses ($M = 2.73$ s, $SD = 2.55$). The positive confidence rating coefficient suggests that participants gave higher confidence ratings for their correct responses ($M = 3.92$, $SD = 1.10$) compared with their incorrect responses ($M = 3.67$, $SD = 1.15$).

Discussion

This study examined adult listeners' sensitivity to age-related cues in CDS. Specifically, we asked whether listeners can correctly identify which of the two speech recordings they heard was directed at a younger or an older child. We also examined the role of content-related cues, participants' gender, and their experience with CDS (i.e., whether they had children or not) in guiding listeners' age-related judgements.

Listeners could correctly identify which child was younger or older both when they listened to the original recordings and when they listened to the low-pass filtered versions. As expected, performance was better when listeners were presented with original recordings compared with their low-pass filtered versions. Furthermore, listeners' self-reported English proficiency predicted their performance such that participants with higher English proficiency performed better. These findings suggest that content-related cues help to identify the age of the addressee of the speech. However, they do not seem to be necessary: Listeners could still make correct age-related inferences in the low-pass filtered condition, where the content cues were largely unavailable and listeners presumably had to rely on prosodic cues instead. Previous findings suggest that adults not only identify CDS (Golinkoff & Alioto, 1995), but also distinguish different intentions in CDS (Bryant & Barrett, 2007; Fernald, 1989) even in the absence of the semantic and lexical cues. The present findings suggest that listeners' sensitivity extends to age-related variations and this sensitivity, similar to previous findings, does not seem to be solely dependent on the content-related cues in speech. These provide further evidence for the form–function links in CDS by showing that the intended target of the signals can be inferred from the physical properties of the signals.

Results also showed that participants' performance improved with age. This might be because age is confounded with experience. Older individuals presumably have more exposure to CDS compared with younger individuals simply due to having lived longer. In addition, participants' age in the current study varied from 24 to 48. Particularly within this age range, older adults might also be more likely to interact with children compared with younger adults considering lifestyle changes taking place during these years.

We predicted that parenthood and gender might also play a role in sensitivity to age-related cues in CDS. Parents are presumably more familiar with CDS due to both using and being exposed to it more frequently than individuals without children and research suggests that children hear significantly more CDS from females compared with males (Bergelson et al., 2018). Nevertheless, in line with the previous findings suggesting no gender differences in identifying CDS (e.g., Fernald, 1989), overall sensitivity to age-related cues in CDS did not differ across gender in the current study. Furthermore, listeners could also extract age-related cues from CDS similarly, regardless of whether they had children or not. There was, however, a three-way interaction between Gender, Condition, and Parenthood. Specifically, while listeners' accuracy tended to increase when speech was natural compared with when it was low-pass filtered, this trend was not observed among male participants without children. For this group, performance was similar across filtered and unfiltered conditions. This effect is not easily explained and future studies are needed to test the robustness of it.

Listeners' reaction times and confidence ratings also predicted their accuracy. Specifically, faster responses were more likely to be accurate and confidence ratings tended to be higher for accurate responses. These patterns might be interpreted as participants having some level of metacognitive awareness of their performance.

These findings raise a number of interesting questions for future research. One important question that arises from these findings concerns the cue(s) listeners rely on when making age-related inferences based on CDS. Past research suggests that numerous aspects of CDS change with the recipient child's age, including how acoustically exaggerated it is, its pitch-related features (e.g., mean pitch, pitch range), its affect, and its speech rate (Englund & Behne, 2006; Garnica, 1977; Kitamura & Burnham, 2003; Narayan & McDermott, 2016; Phillips, 1973; Stern et al., 1983). Having greater control over their stimuli, previous studies mostly focused on a restricted age range, but they sometimes failed to observe certain age-related changes in CDS within a given age range (e.g., Liu et al., 2003), or these changes were observed in a non-linear fashion (e.g., Ko, 2012; Liu et al., 2009). Given that the recordings used in the current study addressed children from a much wider age range (6–44 months) compared with most previous studies, and that the recordings addressing different aged children often came from different mothers, we did not analyse how different aspects of the stimuli varied with addressees' age. We only analysed basic pitch-related characteristics of the stimuli. While these did not fully align with previous research, we also observed some parallels. Specifically, we did not find any linear relationship between age and pitch range; however, we observed a negative correlation between addressees' age and mean and maximum pitch. Nevertheless, pitch-related features likely vary along with other dimensions such as affect and intention (e.g., Bryant & Barrett, 2007; Kitamura & Burnham, 2003), and a combination of different features have likely contributed to listeners' ability to extract age-related cues from CDS. Future studies, with more controlled stimuli, should examine whether particular features of CDS that change with age facilitate listeners' age-related judgements.

Listeners in the current study were able to correctly identify which of the two recordings they heard, had addressed a younger or older child. A natural extension of this would be to look at whether listeners can make even more nuanced age-related judgements, such as inferring the exact age of the target children. Our results further showed that listeners' performance improved as the age difference between the addressees increased. However, they leave open the question of whether age-relevant cues are easier to detect for a certain age range. Addressing these questions might help better understand the functions child-directed communication serves at different points in development as well as identifying the cues listeners rely on when making age-related judgements.

Across cultures, infants show a robust preference for CDS over ADS (e.g., Frank et al., 2020) and expect speech register to vary depending on the recipient (Soley & Sebastian-Galles, 2020). Together with the current findings, these results raise the possibility that infants and children might also be sensitive to nuanced age-related changes and expect and/or prefer age-appropriate speech to be directed at them. It has been shown, for instance, that a shift in infants' preference from comforting to approving speech takes place between 3 and 6 months of age, and a shift from approving to directive speech takes place between 6 and 9 months of age (Kitamura & Lam, 2009). Future studies could further explore how infants' and children's expectations and preferences change with age regarding different features of CDS.

The current study also has some limitations. First, the speech stimuli used in the current study were not created for the purposes of this study, but came from a number of previously conducted studies. Thus, they were recorded in different environments with different equipment and had different sound quality. In addition, the number of speech stimuli in a given month varied and recordings addressing different aged children sometimes came from different mothers. This considerable variability in the quality of the recordings might have undermined listeners' age-related judgements. As mentioned above, this variability also makes it difficult to conclude which aspects of the stimuli allowed participants to make age-related judgements. Future studies using more controlled stimuli should further explore these issues. Second, we chose to use North American English recordings, because of their richness in CHILDES database. In an attempt to control the use of content-related cues in recordings, we asked listeners to rate their level of English as well as low-pass filtering the stimuli. Nevertheless, none of these eliminates the use of content-related cues completely. Given its prevalence, even participants in our sample who reported no English knowledge, may still have some familiarity with English. Studies using stimuli in unfamiliar languages could help better understand the role of exposure in identifying cues in CDS that vary as a function of age. Such studies, along with studies systematically examining the acoustic correlates of age-based variability in CDS might help us better understand different functions CDS might serve across early years as well as identify universal form-function links in CDS.

Adult listeners' ability to extract age-related cues from CDS provides another case in point where individuals make nuanced inferences about the social characteristics of communicative partners based on speech and provide further evidence about the richness of communication signals as a source of social information.

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Note

1. During 11 experimental sessions, PsyScope quit unexpectedly. Subsequently, one participant completed 35 trials and 10 participants completed 39 trials. The remaining participants completed all 40 trials. All data are included in the analyses.

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