**Individual differences in 7.5-month-olds' novel word segmentation from
maternal and unfamiliar voices**

Manuscript Contributors

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Abstract

Starting in the mother's womb, language learning benefits from maternal speech exposure (DeCasper & Spence, 1986). In addition, maternal speech has been shown to facilitate discrimination of speech from background noise (Barker & Newman, 2004). In line with this boost in learning through the mother's voice, the current study explores whether maternal speech also facilitates infants' word segmentation, familiarizing infants to passages produced either by their own mother or an unfamiliar speaker. The test phase with isolated tokens of familiarized and novel control words revealed that infants were unable to demonstrate successful segmentation regardless of whether the speaker was their own mother or a stranger. However, further exploratory analyses suggested that familiarization impacted infants' listening behavior with successful segmentation from maternal speech. Together, these results demonstrate that a) individual differences in infants' listening behavior are related to their listening times during familiarization, and b) infants benefit from maternal fluent speech.

Keywords: word segmentation; infant-directed speech; maternal input; individual differences

INTRODUCTION

One of the critical milestones of infant language development is the natural ability to segment words from fluent speech. Yet, there seem to be considerable cross-linguistic differences with respect to the age at which infants start to segment words from fluent speech (e.g., Jusczyk & Aslin, 1995; Kuijpers, Coolen, Houston, & Cutler, 2008; Nishibayashi & Nazzi, 2016). In addition, a number of factors have been identified that impact infants' ability to segment words from fluent speech, i.e., word-form familiarity (Altwater-Mackensen & Mani, 2013), extended familiarization at home (Schreiner, Altwater-Mackensen, & Mani, 2016), and exaggerated infant-directed speech (Schreiner & Mani, 2017).

Language learning benefits from even prenatal maternal speech exposure (DeCasper, Lecanuet, Busnel, Granier-Deferre, & Maugeais, 1994; DeCasper & Spence, 1986): Newborns prefer their mother's voice to an unfamiliar one (DeCasper & Fifer, 1980). The mother's voice elicits increased pre-attentional and cognitive processing localized to language-related areas relative to an unfamiliar voice (Beauchemin et al., 2011), highlighting the salience of maternal input in early language acquisition. Similarly, using near-infrared spectroscopy (hereafter, NIRS), studies find that infants exhibited larger cerebral responses to maternal infant-directed speech (henceforth, IDS) and adult-directed speech (henceforth, ADS) compared to IDS and ADS of an unfamiliar speaker, especially in frontal areas from 7- to 9-months of age (Naoi et al., 2012). Earlier still, at 4-months of age, the latency of infants' early brain responses to their mother's voice is reduced relative to an unfamiliar voice, although later cognitive components are reduced in amplitude to maternal input relative to unfamiliar voices (Purhonen, Kilpeläinen-Lees, Valkonen-Korhonen, Karhu, & Lehtonen, 2005). The authors interpret the latter finding as

indexing the ease of formation of a template for familiarized stimuli in the maternal voice relative to unfamiliar voices, leading to reduced demands in processing language stimuli in this more familiar voice. In keeping with this suggestion, research proposes that infants are able to discriminate speech from background noise, given maternal input but not when exposed to an unfamiliar voice (Barker & Newman, 2004). Finally, with regard to recognition of input in maternal speech, in an assessment of 9-month-olds' word recognition in an ERP-task, infants demonstrated a benefit in recognizing previously familiar word-object associations presented in maternal speech relative to an unfamiliar voice (Parise & Csibra, 2012). Similarly, while 6-month-olds show a behavioral preference for their own name regardless of whether it was produced by their own mother or an unfamiliar speaker, hearing their names in the maternal voice elicited greater hemodynamic activity relative to an unfamiliar speaker (Imafuku, Hakuno, Uchida-Ota, Yamamoto, & Minagawa, 2014). Taken together, these findings suggest that maternal speech may boost early language learning, with particular regard to the ease of establishing memory traces of language input provided in the maternal voice leading to improved encoding and recognition of maternal input. However, the studies reviewed above have predominantly tested infants' responses to maternal speech and their recognition of familiar language input in maternal speech, which do not inform us with regards to improved encoding and recognition of linguistic representations initially familiarized in maternal speech. One study does examine the extent to which familiarization with input in maternal speech may boost encoding and later recognition of this input, and finds no benefit of speaker familiarity on word form learning and recognition (van Heugten & Johnson, 2012).

Investigating the effect of cross-gender variation on infants' word segmentation abilities, van Heugten and Johnson (2012) familiarized infants with words embedded in sentences in their mother's voice. Infants were then tested on their recognition of isolated tokens of these familiarized words (relative to novel control words) in their father's voice. Another group of infants were familiarized with passages produced by an unfamiliar female voice and tested on isolated tokens produced by an unfamiliar male voice. Both groups of infants, those exposed to familiar and those exposed to unfamiliar voices, demonstrated a novelty preference regardless of speaker familiarity. Thus, there appeared to be no maternal boost in infants' segmentation of words from fluent speech. The lack of a facilitating effect of maternal voice in word segmentation in this study relative to the work reviewed above is puzzling. On the one hand, the switch in gender between familiarization and test required infants to generalize across gender and speaker characteristics – as opposed to the other work reviewed above – the complexity of which may have overshadowed any potential boost provided by prior familiarity with the speakers' voice. Furthermore, as stated by the authors, this study had an extended familiarization exposure to the passages with 110 to 120s per passage compared to previous studies with familiarization times of 25 to 40s per passage (c.f., Mandel, Jusczyk, & Pisoni, 1995; Seidl, & Johnson, 2006), which may have led to infants being able to segment words from fluent speech equally well in an unfamiliar voice. Finally, we note that a number of the studies reviewed above have used previously familiar words (Barker & Newman, 2004; Jusczyk & Aslin, 1995; van Heugten & Johnson, 2012; Parise & Csibra, 2012; Imafuku, Hakuno, Uchida-Ota, Yamamoto, & Minagawa, 2014), or words that are likely to be familiar to infants – especially given that infants already comprehend a number of words by around 6-months of age

(Bergelson & Swingley, 2012, 2015; Tincoff & Jusczyk, 2012). Thus, infants' prior familiarity with the word-forms may have influenced their listening behavior making generalizations on the effect of maternal voice on infants' novel word segmentation on the basis of these studies difficult.

Against this background, the current study examines the extent to which infants are able to segment words from fluent speech when presented with this speech in their maternal voice compared to an unfamiliar voice. In particular, we presented infants with passages containing critical words in either their mother's voice or an unfamiliar voice and examined their listening times to isolated tokens of these critical words presented again in either their mothers' voice or an unfamiliar voice. Importantly, the words presented were unfamiliar to infants. Furthermore, the voice presenting the words at familiarization and test remained constant, thus infants did not need to generalize their prior experience with the words in one speaker's voice to another speaker's voice. This allows us to test whether there is a boost in encoding and later recognition of unfamiliar word-forms when these are presented in maternal speech as opposed to unfamiliar speech, as has been shown in studies examining language preference, word recognition and infants' brain activity to language input in maternal and unfamiliar speech. We predict that given these additional constraints on our task relative to previous work, we will find infants being more able to segment words from fluent speech when presented with this speech in the familiar voice of their own mother.

This is especially of interest given the population under study, namely, German infants. A number of previous studies highlight the difficulties German-learning infants face in segmenting words from fluent speech relative to American-English-learning infants (Schreiner & Mani, 2017; Schreiner, Altvater-Mackensen &

Mani, 2016). We examine therefore whether we might find increased evidence for German infants' segmentation of words from familiar speech given input in a familiar voice.

METHOD

The current study set out to investigate the effect of familiarity with the speaker's voice on infants' ability to segment words from fluent speech. Infants were familiarized with unfamiliar novel words embedded in sentences presented in either their mother's voice or an unfamiliar voice. They were then tested on their recognition of isolated tokens of these previously familiarized words using their listening times to previously familiarized words and novel control words as an index of segmentation and recognition of words from fluent speech. Half of the infants were exposed to recordings of the highly familiar voice of their own mother whereas the other half listened to an unfamiliar speaker, namely the same recordings presented to infants in the own mother condition.

Participants

Fifty-two 7.5-month-old monolingual German-learning infants made up the final sample of the study. Infants ranged in age from 212 to 250 days with a mean age of 230 days. An additional number of 6 children had to be excluded from the study for reasons of inattentiveness ($n=3$); technical error ($n=2$), and maternal interference ($n=1$). Infants received a t-shirt or a book in return for their participation in the study.

Materials and design

Four monosyllabic pseudowords, *Fend* [fɛnt], *Mieck* [mi:k], *Nohl* [no:l], and *Kulb* [kʊlp], were embedded in passages of German sentences (see Appendix) and

recorded as isolated tokens. For half of the infants, these passages and isolated tokens were recorded by their own mother (hereafter, maternal-voice condition), whereas for the other half, they were presented in an unfamiliar voice (hereafter, unfamiliar-voice condition). Importantly, each infant in the maternal-voice condition was matched with an infant in the unfamiliar-voice condition, with both infants hearing the same recordings. A blinking colorful checkerboard design was used as a visual stimulus during the study.

Procedure

A modified version of the preferential-listening task was employed for the study (cf., Mani & Pätzold, 2016). Infants were seated on their parents' lap or in a car seat for the duration of the study. A monitor located 100cm in front of them displayed the visual stimulus, i.e., the blinking checkerboard. Two loudspeakers located above this monitor presented the auditory stimuli of the study.

Trials in the familiarization and test phase only began when the infants were fixating the monitor in front of them. Infants' attention was oriented back to the screen using an attention-getting stimulus (a chime and a Teletubby) before starting the trial if they happened to be looking away. Once infants were fixating the monitor, an experimenter blind to the experimental condition initiated the trials. Trials began with the blinking checkerboard on-screen and the presentation of the auditory stimulus. The experimenter indicated throughout the experiment whether infants were orienting towards the monitor or away. The auditory stimulus continued so long as the infant continued to fixate the monitor. Trials ended when the infant looked away from the monitor for more than 2s or when the auditory stimulus was completed. The auditory stimulus presented differed across the familiarization and the test phase of the experiment.

During the familiarization phase, in each trial, infants listened to passages of sentences containing one of the four monosyllabic pseudowords (trial length 24s). Infants were presented with passages containing two of the four pseudowords during the familiarization phase across trials. The familiarization phase concluded when infants accumulated a total of 100s of listening time to the familiarization passages or when all 12 familiarization trials had been presented to infants. During the test phase, infants were presented with isolated tokens of the two previously familiarized words and the two other novel control words that had not been part of the familiarization phase (see Table 1). All trials lasted until infants looked away for more than 2s or until the auditory stimulus was completed after 16s.

Infants' looking behavior was assessed online by an experimenter who observed infants' fixations of the monitor via two cameras located above the monitor. The experimenter coded whether infants were fixating the monitor by pressing a corresponding button on the keyboard. Both, parents and experimenter were blind to the experimental phase and condition via headphones to prevent any systematic influence on infants' listening behavior. A difference in infants' listening times to familiarized and novel control tokens is taken as an index of infants' discrimination of the previously familiarized words from the novel control words and, consequently, of their segmentation of these words from the fluent passages presented during familiarization.

Table 1. Schematic procedure of the study.

	Condition	
	Maternal-voice	Unfamiliar voice
Familiarization phase	"The FEND is hiding behind..."	
	"The KULB is climbing over..."	
Test phase	" FEND, FEND, FEND ..."	Familiarized word
	" KULB, KULB, KULB ..."	Familiarized word
	" MIECK, MIECK, MIECK ..."	Control word
	" NOHL, NOHL, NOHL ..."	Control word

RESULTS

First, we examined whether there was a difference in infants' listening times to fluent passages presented in their mother's voice compared to an unfamiliar voice. An independent-samples t-test found no significant differences in infants' listening times during familiarization between the maternal-voice ($M=17.49$; $SD=4.67$) and the unfamiliar-voice condition ($M=17.00$; $SD=5.27$), $t(50)=0.36$, $p=0.722$, $d=0.098$.

To analyze the data from the test phase, we ran a 2x2 mixed-factorial ANOVA with the within-subject factor word recognition (familiarized vs. control) and the between-subject factor condition (maternal-voice vs. unfamiliar voice) and familiarization time as a covariate. There was no significant main effect of condition, $F(1,49)=0.05$, $p=0.832$, $\eta_p^2=0.001$, and no significant interaction between word recognition and condition, $F(1,49)=0.07$, $p=0.792$, $\eta_p^2=0.001$. However, we found a significant main effect of word recognition, $F(1,49)=5.24$, $p=0.026$, $\eta_p^2=0.097$, and a significant interaction between infants' word recognition and their listening time during familiarization, $F(1,49)=5.99$, $p=0.018$, $\eta_p^2=0.109$.

Grouping the babies according to the median familiarization time, planned contrasts revealed that infants with shorter listening times showed a novelty effect, listening significantly longer to novel control words ($M=8.39$; $SD=2.43$) than familiarized words ($M=7.67$; $SD=2.63$), $t(51)=-2.41$, $p=0.020$, $d=-0.334$. Infants with

longer listening times during familiarization showed a familiarity effect, listening significantly longer to trials with the familiarized words ($M=11.71$; $SD=3.45$) than to novel controls ($M=10.87$; $SD=3.84$), $t(51)=2.87$, $p=0.006$, $d=0.398$. Hence, infants' listening behavior in the familiarization phase impacts infants' listening behavior in the test phase (see Figure 1).

Figure 1. Difference scores for infants' listening times (in s) to familiarized and novel control words split by their listening time during familiarization (short vs. long listeners).

Exploratory analyses further investigated the effect of maternal speech on infants' word segmentation abilities using this split on infants' familiarization times to group the babies. In addition to common Frequentist statistics, we also employed Bayesian statistics¹ to aid in interpreting the obtained results. Infants with longer listening times in the familiarization phase listened significantly longer to familiarized, $M=11.28$; $SD=3.25$, compared to novel control words, $M=10.14$; $SD=3.57$, in the maternal condition, $t(51)=3.79$, $p<0.001$, $d=0.525$, $BF_{10}=33.40$. For the unfamiliar-

¹ Using the BayesFactor package for R (Morey & Rouder, 2015), we conducted Bayesian independent samples t-tests (Rouder et al., 2009). For the prior of the effect size, we utilized the default cauchy prior "medium" with the scaling factor of $r=\sqrt{2}/2$.

voice condition, we did not find significant differences in listening times between familiar, $M=12.18$; $SD=3.72$, and novel control words, $M=11.59$; $SD=4.10$, $t(51)=1.96$, $p=0.056$, $d=0.272$, $BF_{10}=1.42$.

Infants with shorter listening times in the familiarization phase listened significantly longer to novel control, $M=9.23$; $SD=2.41$, than familiarized words, $M=8.15$; $SD=2.15$, in the maternal voice condition, $t(51)=-3.59$, $p<0.001$, $d=-0.498$, $BF_{10}=22.61$. There was no difference in infants' listening times to novel control, $M=7.55$; $SD=2.22$, and familiarized words, $M=7.18$; $SD=3.04$, in the unfamiliar voice condition for infants with shorter listening times in the familiarization phase, $t(51)=-1.22$, $p=0.228$, $d=-0.169$, $BF_{10}=0.63$ (see Figure 2).

Figure 2. Infants' difference scores for listening times (in s) to familiarized and novel control words in the maternal-voice and in the unfamiliar-voice condition for short and long listeners during familiarization.

DISCUSSION

The current study set out to further explore the role of talker familiarity on infants' segmentation abilities. In particular, we investigated whether the highly

familiar voice of a mother may improve infants' ability to segment novel pseudo words from fluent speech compared to the voice of an unfamiliar speaker.

Comparing infants' listening times during the familiarization phase revealed that listening times to the familiarization passages did not differ based on whether infants were exposed to the voice of their own mother or an unfamiliar voice. While this finding is surprising, at the very least, this suggests that any differences in infants' listening behavior in the test phase between the maternal- and the unfamiliar-voice condition cannot be attributed to a difference in exposure to the familiarized words.

With regards to the test phase, we highlight two results. First, we find that there was a significant effect of word recognition, such that infants listened longer to familiarized words relative to novel control words, suggesting that infants were able to recognize the words that they had previously been exposed to in fluent speech. This stands in contrast to other studies with German infants (Schreiner & Mani, 2017; Schreiner, Altvater-Mackensen, & Mani, 2016) with similar-aged infants showing no segmentation of words from fluent speech. While this difference might be attributed to the effect of familiarization with speech stimuli produced by the infants' mother, we note that there was no effect of condition, i.e., no difference between infants listening to their own mother relative to an unfamiliar voice. However, as we note below, exploratory analyses do reveal a modulation of infants' behavior by maternal voice which may speak to the finding of successful speech segmentation in this study.

Second, we found that infants' listening behavior at test was influenced by their listening behavior in the familiarization phase, based on an interaction between word recognition (i.e., the difference between listening times to familiarized and control words at test) and familiarization time (the average amount of time infants spent

listening to the familiarization trials). High performers with shorter looking times during familiarization demonstrate a novelty effect – behaving similar to older infants (cf., Schreiner, Altvater-Mackensen, & Mani, under review). Low performers who require longer familiarization show a familiarity effect – similar to younger infants (cf., Jusczyk & Aslin, 1995).

As noted above, there was no difference in listening times at test between infants who listened to their own mother relative to infants who listened to an unfamiliar speaker. This could be taken to suggest that infants in the maternal-voice condition may not have recognized that the speech input presented was from their own mother, as also suggested by the fact that there was no difference in listening times at familiarization between infants listening to their own mother and infants listening to an unfamiliar speaker.

However, some doubt is thrown on this suggestion based on the results of the exploratory analyses, which revealed successful segmentation only in the maternal-voice, but not in the unfamiliar-voice condition. Both high performers with shorter looking times during familiarization and low performers who required longer familiarization showed a difference between familiarized trials and novel control trials, but only in the maternal voice condition and not in the unfamiliar voice condition. Specifically, high performers showed a significant novelty effect in the maternal voice condition and low performers showed a significant familiarity effect in the maternal voice condition, while neither group showed any difference in the unfamiliar voice condition. This suggests that extended familiarity with the mother's voice may be beneficial for infants' early segmentation abilities.

While older infants may have become flexible in recognizing words despite high variability in their surface structure (Singh, Nestor, & Bortfeld, 2010), younger infants

may benefit from low variability, profiting from their increased familiarity with the voice of their mother in finding boundaries between words in continuous speech streams. What remains to be seen is the separate contributions of variability and familiarity in the findings we report, since infants listening to their own mothers' voice have less variability in the stimuli presented relative to the input they are presented with at home, as well as increased familiarity with the physical properties of their mother's speech.

Exploratory as they may be, our findings are also in keeping with neurophysiological findings of infants between 7- to 9-months who show larger responses to their own mother compared to an unfamiliar speaker (Imafuka et al., 2014; Naoi et al., 2012). Taken together, the fact that infants listening to their own mother successfully segmented words from fluent speech, while infants exposed to an unfamiliar speaker did not show similar segmentation abilities suggests that familiarity with the voice of the mother may have an influence on infants' early processing of language stimuli.

Especially given that the population under study, German-learning infants, have difficulties segmenting words from fluent speech at a similar age to that tested in the current study, being presented with language in the infants' mothers' voice may provide additional benefits for German-learning infants' speech segmentation, similar to reported benefits provided by exaggerated infant-directed speech and long-term exposure (Schreiner, Altvater-Mackensen, & Mani, 2016; Schreiner & Mani, 2017), in language processing in young infants. Hence, German infants' relative inability to segment words from fluent German speech streams may be overcome by high familiarity with the speaker of the to-be segmented stream. Further research is needed to explore whether a similar benefit of maternal speech is found in infants of

other language backgrounds that have also been unable to show successful segmentation abilities (cf., Floccia et al., 2016).

In sum, the current study suggests that early language acquisition benefits from maternal input and that given maternal speech, infants appear to be able to segment words from fluent speech at an earlier age than has been reported thus far with German learning infants. While these findings are tentative, given the exploratory nature of the analyses reported, the overall effect of segmentation reported suggests that infants in this study were able to segment words from fluent speech, while previous studies fail to find evidence for segmentation at a similar age. Also of interest is the finding that segmentation was modulated by both the amount of familiarization infants had with the stimuli and their familiarity with the speaker. Overall, these findings suggest that greater familiarity with language and the kinds of stimuli being presented boosts infants' processing of the stimuli and their learning from the language input presented.

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APPENDIX

Auditory stimuli of the familiarization phase of the word segmentation task.

Fend passage

Der Fend hat große, scharfe Zähne.
Im Märchen ist der alte Fend als hinterlistig beschrieben.
Oft hat ein Fend zwölf Kinder.
Im Wald begegnet man dem Fend.
Manchmal ist der Fend am Tag unterwegs.
Der Fend versteckt sich im Gebüsch.

Mieck passage

Der Mieck hat keine scharfen Krallen.
Im Zoo kann ein gesunder Mieck sehr alt werden.
Oft gräbt der Mieck einen Bau.
Die Kinder malen Bilder vom Mieck.
Nie schläft der Mieck draußen im Schnee.
Der Mieck frisst gerne süße Beeren.

Nohl passage

Der Nohl hat ein graues Fell.
In unserem Wald leben ein Nohl und ein Bär.
Ich habe den Nohl kreischen gehört.
In unserem Keller wohnt ein Nohl.
Heute bleibt der Nohl allein zu hause.
Der Nohl hat kleine, kurze Ohren.

Kulb passage

Der Kulb hat einen buschigen Schwanz.
Am Bauch hat der kleine Kulb ein weißes Fell.
Tollwut macht den Kulb sehr zutraulich.
Der Junge sieht einen riesigen Kulb.
Selten geht der Kulb früh ins Bett.
Der Kulb klettert über die Mauer.