Fetal rhythm-based language discrimination: a biomagnetometry study

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Using fetal biomagnetometry, this study measured changes in fetal heart rate to assess discrimination of two rhythmically different languages (English and Japanese). Two-minute passages in English and Japanese were read by the same female bilingual speaker. Twenty-four mother–fetus pairs (mean gestational age = 35.5 weeks) participated. Fetal magnetocardiography was recorded while the participants were presented first with passage 1, a passage in English, and then, following an 18 min interval, with passage 2, either a different passage in English (English–English condition: $N = 12$) or in Japanese (English–Japanese condition: $N = 12$). The fetal magnetocardiogram was reconstructed following independent components analysis decomposition. The mean interbeat intervals were calculated for a 30 s baseline interval directly preceding each passage and for the first 30 s of each passage. We then subtracted the mean interbeat interval of the 30 s baseline interval from that of the first 30 s interval, yielding an interbeat interval change value for each passage. A significant interaction between condition and passage indicated that the English–Japanese condition elicited a more robust interbeat interval change for passage 2 (novelty phase) than for passage 1 (familiarity phase), reflecting a faster heart rate during passage 2, whereas the English–English condition did not. This effect indicates that fetuses are sensitive to the change in language from English to Japanese. These findings provide the first evidence for fetal language discrimination as assessed by fetal biomagnetometry and support the hypothesis that rhythm constitutes a prenatally available building block in language acquisition. ***NeuroReport*** **28:561–564** **Copyright © 2017 Wolters Kluwer Health, Inc. All rights reserved.**

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Introduction

Research on early language development suggests that infants can discriminate among languages as early as a few days after birth; neonates can discriminate between their parents' native language and another language [1], and between foreign languages [1,2]. The language pairs that infants can discriminate are argued to belong to different rhythm classes, leading researchers to propose the rhythm-based language discrimination hypothesis, positing that infants initially utilize rhythmic characteristics to discriminate languages [3].

Evidence for rhythm-based language discrimination ability in neonates raises the question of whether this ability is also present prenatally. If so, this may provide the child with one of the very first building blocks in acquiring their native language(s).

Although some components of speech are attenuated in the womb, intonation can be transmitted to the fetal inner ear [4]. There is also some evidence for fetal sensitivity to acoustic characteristics of speech, including recognition of the mother's voice [5], recognition of passages with rhyming speech [6], and discrimination of some speech sounds [7]. Postnatal infants can also distinguish languages on the basis of rhythm when presented with speech sounds that were low-pass filtered [1] to resemble those available to the fetus *in utero*. Although this suggests that rhythm-based language discrimination ability may feasibly be present prebirth, it remains an open question whether fetuses indeed possess this ability *in utero*.

Fetal cognitive processing can be assessed by changes in heart rate. The brain influences heart rate through well-studied neural mechanisms, and there is considerable evidence suggesting heart rate change as an index of cognitive processing, including in fetuses [8]. Kisilevsky *et al.* [9] presented fetuses with two speech recordings to test whether they are sensitive to a change in speech from English (a stress-timed language) to Chinese (often argued to be a syllable-timed language) compared with when they were presented with two English recordings. Fetal heart rate, measured by ultrasound, increased when the language switched from English to Chinese compared with when two English passages were presented in succession. These results were taken to suggest that

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fetuses can distinguish their native language from a foreign language on the basis of their rhythmic properties.

However, the approach used by Kisilevsky and colleagues has some potential limitations. First, the English and Chinese stimuli were recorded by different speakers, raising the question of to what extent the fetal responses may have been because of speaker-related sound differences. Second, the rhythmic contrast between English and Chinese remains controversial, with some claiming that Chinese is not syllable timed, but stress timed like English [10]. Kisilevsky and colleagues do not provide quantitative evidence that their English and Chinese stimuli differ rhythmically, making it difficult to determine to what extent their effects are because of rhythmic differences.

In the current study, we investigate whether fetuses in the third trimester can use rhythmic characteristics to discriminate languages, building upon Kisilevsky and colleagues, but making several modifications to address the above concerns, and introducing a precise measure of fetal heart rate, fetal magnetocardiography (MCG). Unlike the fetal ECG that records electrical currents generated by the fetal heart from electrodes applied to the maternal abdomen, MCG measures the magnetic fields surrounding the electrical current. Unlike ECG, MCG is not distorted by the fetal vernix caseosa or the maternal body. This allows for precise detection of fetal R-waves without loss of signal, necessary for calculating fetal cardiac metrics. In addition, we test two languages whose rhythmic contrast is uncontroversial: English (a stress-timed language) and Japanese (a mora-timed language [11]). We also provide an acoustic analysis to confirm the rhythmic difference between our English and Japanese stimuli. Finally, our English and Japanese stimuli are spoken by the same bilingual speaker to ensure that differences are because of change in language rather than change in speaker.

Participants and methods

Participants

Participants included 24 mother–fetus pairs recruited from the University of Kansas Medical center and the broader Kansas City community. Gestational age ranged from 32 to 39 weeks (mean = 35.5, SD = 1.76) and maternal age ranged from 22 to 41 years (mean = 29.4, SD = 4.25); all mothers were native English speakers. Twelve fetuses were female, 11 were male, and the sex of one fetus was unknown at the time of testing. All participants provided their written informed consent to participate and were compensated for their participation.

Stimuli

The stimuli included three 2 min audio-recorded passages from a children's book: two different passages in English (Make Way for Ducklings by R. McClosky) and one in Japanese (Kamosan Otoori, the Japanese translation of Make Way for Ducklings, by S. Watanabe). They were read by a 28-year-old female bilingual speaker of English and Japanese and recorded in an anechoic chamber using a solid-state digital audio recorder (Marantz PMD671; Marantz Professional, Cumberland, Rhode Island, USA) and a cardioid microphone (Electro-Voice N/D767a; Electro-Voice, Fairport, New York, USA).

To quantify the rhythmic differences between the two languages, we carried out an acoustic analysis of the recorded passages. We measured %V, the proportion of vocalic intervals (i.e. vowels) within a recorded sentence [12], for the first 30 s of each passage, and compared these values across the English and Japanese stimuli. A one-way analysis of variance indicated a significant difference in %V between English (40.8) and Japanese (48.7) [$F(1,14) = 10.323$, $P < 0.007$], confirming that our English and Japanese stimuli are rhythmically different.

Procedure

Participants were tested at the Hoglund Brain Imaging Center, University of Kansas Medical Center. The procedure was approved by the Institutional Review Board at the University of Kansas Medical Center. Participants sat quietly in a reclined support chair in a magnetically shielded room, while the fetal MCG was recorded using an 83-channel fetal biomagnetometer (CTF Systems Inc., Coquitlam, British Columbia, Canada). The stimuli were presented on a speaker outside of the shielded room and delivered through tubing passed through a small opening into the room. The tubing was connected to a plastic cone, positioned ~ 1 cm above the maternal abdomen, over the position of the fetal head, determined by ultrasound. The stimuli were presented at an average of 95 dB; the mother wore a sound-attenuating headset during stimulus presentation.

Following Kisilevsky and colleagues, mother–fetus pairs were exposed to two passages over the two phases of sound presentation. The familiarization phase began with a 2 min silent interval (prepassage silence), followed by a 2 min presentation of the first passage (familiarization passage) and a 16 min silent interval (postpassage silence). The novelty phase then began, starting with a 2 min silent interval (prepassage silence), followed by a 2 min presentation of the second passage (novelty passage), and concluded with a 2 min postpassage silent interval (postpassage silence). Stimuli were presented using presentation (Neurobehavioral Systems Inc., Berkeley, California, USA).

Each maternal–fetal pair was assigned randomly to one of two conditions. In the English–English condition ($N = 12$), the Familiarization passage and the novelty passage were both in English. In the English–Japanese condition ($N = 12$), the familiarization passage was in English and the novelty passage was in Japanese. If the

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fetuses in the English–Japanese condition showed a greater heart rate change during the presentation of the novelty passage (when the language switches from English to Japanese) than those in the English–English condition (when the passage switches from one English passage to another English passage), this would suggest fetal discrimination between the two languages. The speaker of the passages was kept constant across languages. Moreover, as the familiarization and novelty passages are different English passages in the English–English condition, the content of the two passages changes in both conditions. Thus, the effect of language change is disentangled from the speaker and the content of the passages.

Data coding and analysis

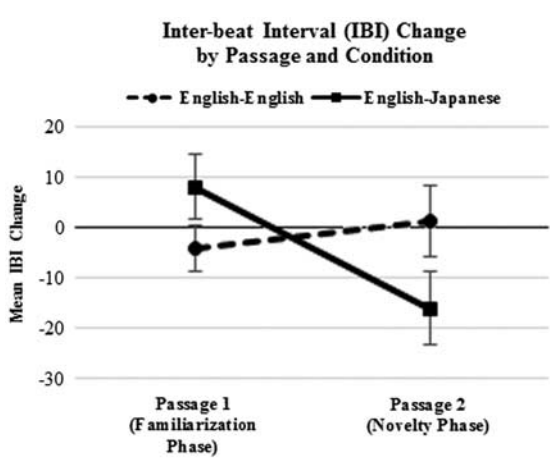
After independent components analysis decomposition of the biomagnetometer recording, the fetal MCG was reconstructed from the MCG-relevant independent components analysis components. We calculated interbeat intervals (IBI) for each fetus and generated mean IBIs for the 30 s interval directly preceding each of the two passages (familiarization and novelty), and for the first 30 s of each passage, using the QRSTool [13] available at *http://www.psychofizz.org*. We derived an IBI-change variable, capturing fetal heart rate change from the prepassage silence to the passage itself, by subtracting the mean IBI of the 30 s interval directly preceding the passage from that of the first 30 s of the passage.

Results

For the English–English condition, the mean IBI-change was −4.1 for the familiarization phase and 1.4 for the novelty phase. For the English–Japanese condition, the mean IBI-change was 8.1 for the familiarization phase and −16.1 for the novelty phase (Fig. 1). Note that negative numbers reflect reduced IBI, or a faster heart rate, during the passage compared with its prepassage silent interval, and positive numbers reflect greater IBI, or reduced heart rate, during the passage compared with its prepassage silent interval.

A mixed analysis of variance with condition (English–English vs. English–Japanese) as a between-participant factor and IBI-change differential (IBI-change for familiarization passage vs. IBI-change for novelty passage) as a within-participant factor yielded nonsignificant effects of condition [$F(1,22)=0.156$, $P=0.696$] and IBI-change differential [$F(1,22)=2.335$, $P=0.141$]. Crucially, there was a significant condition × IBI-change differential interaction [$F(1,22)=5.837$, $P=0.024$]. Post-hoc pairwise comparisons showed that the IBI-change differential was significantly different between two phases for the English–Japanese condition ($P=0.011$), but not for the English–English condition ($P=0.537$). The English–Japanese condition elicited a more robust IBI change for passage 2 (novelty phase) than for passage 1 (familiarity phase), reflecting reduced IBI, or a faster heart rate, during passage 2, whereas the English–English condition did not.

Fig. 1



Mean IBI-change across passage and condition. IBI, interbeat interval.

Discussion

The current study utilized fetal biomagnetometry for the first time to investigate fetal language processing and showed that the fetus is indeed sensitive to a change in language from English to Japanese, two languages with different rhythmic characteristics. This sensitivity is attributable to the rhythmic properties of the languages and is not simply because of a change in the acoustic content of the passages (passages 1 and 2 were different in both conditions) or because of a change in speaker (the speaker was the same across passage and condition). Our findings are in agreement with those of Kisilevsky and colleagues, providing further support for the rhythm-based language discrimination hypothesis and suggesting that cortical tuning to native-language properties begins *in utero* as hypothesized previously largely on the basis of findings from neonates [14]. This prebirth sensitivity may subserve the development of memory traces for language in the auditory cortex, supporting postnatal language learning [15].

Assessments were performed in the third trimester of gestation, after the emergence of specific behavioral patterns linked to fetal state. Around 30–32 weeks' gestation, centrally mediated heart rate patterns along with breathing, body, and eye movements allow for the identification of behavioral state. The coupling and integration of central and autonomic processes represents an important developmental transition to behavioral states that are similar to newborns. These behavioral states are linked to heart rate patterns. Because direct measures of fetal brain function are limited, metrics of heart rate and variability serve as proxies to central control. The heart does not 'hear'; therefore, we attribute the

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differences in heart rate to central auditory processing of the language stimuli [16]. Our novel approach to probing fetal language acquisition by heart rate change may ultimately provide a new tool for studying developmental language impairments.

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Conflicts of interest

There are no conflicts of interest.

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