MEASURING HUMAN FETAL RESPONSES TO SOUNDS BY UMBILICAL AND MIDDLE-CEREBRAL ARTERY VELOCITY WAVEFORMS: A PRELIMINARY STUDY

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Abstract

The most common measures of human fetal auditory perception are heart rate and fetal movement using an ultrasound scanner. In this study human fetal responses to two kinds of sounds (white noise and Japanese drumming) were measured by umbilical and middle-cerebral artery velocity waveforms using an ultrasound pulse Doppler unit. The sounds had an effect on umbilical artery velocity waveforms. We will be able to use umbilical artery velocity waveforms as new and sensitive indices of human fetal responses to sounds.

Key Words : Fetus, response to sounds, Umbilical and middle-cerebral artery velocity waveforms, attention

Introduction

According to several reviews (e.g. Kisilevsky, 1995 ; Kisilevsky & Low, 1998; Lecanuet, Granier-Deferre, & Busnel, 1995; Querleu, Renard, Boutteville, & Crepin , 1989), the most common measures of human fetal auditory perception are heart rate (HR) and fetal movement using an ultrasound scanner. In this paper we introduce indices new to developmental psychology, but already widely used in obstetric research (Fleischer, Schulman, Farmakides, Bracero, Blattner, & Randolph , 1985 ; Noordam, Hoekstra, Hop & Wladimiroff , 1994 ; Wladimiroff, 1994) : umbilical artery velocity waveforms (UAVW) and middle-cerebral artery velocity waveforms (MAVW) measured by an ultrasound pulse Doppler unit (see Figure 1). The analysis of UAVM has been a useful,

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non-invasive method of evaluating fetal circulation, especially plancetal circulation (Nyberg, Mahony, & Pretorius, 1990). MAVW also evaluates fetal circulation, especially blood flow in the fetal brain. When the fetus is in severely status, UAVW resistance is increased and MAVW resistance is decreased. These circulation changes are related to fetal catecholamine (CA) levels (Sekizawa, Ishikawa, Sakama, Morimoto, Suzuki, Saito, & Yanaihara, 1995). CA elicts vasoconstrictive and cardiotonic actions. Fetuses stressed pre-natally excrete cortisol and CA. When we can get good results by UAVW and MAVW resistances, we will be able to have new indices of human fetal auditory perception. The main purpose of this study is to evaluate UAVW and MAVW resistances as indices of human fetal responses to sounds.

Fetal auditory responses are thought to mature after about 30 weeks gestation (Kisilevsky, Muir, & Low, 1992 ; Kisilevsky, Pang, & Hains, 2000). But behavioral states are difficult to identify in fetuses less than 36 weeks GA (gestational age, cf. Kisilevsky & Low, 1998, p.12), so fetuses after 37 weeks GA were the participants in this study.

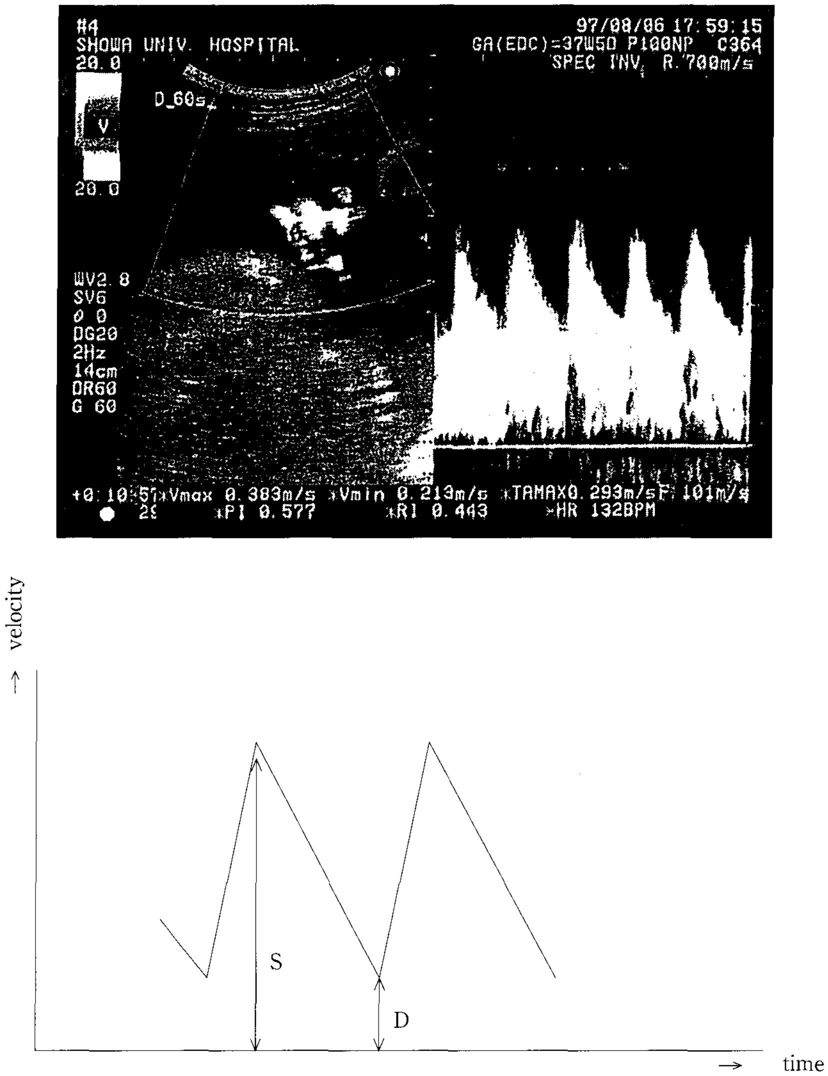
Effective sound stimulus intensity levels for fetuses have been studied, and 105 dB is regarded as the lowest threshold evoking a fetal response (Kisilevsky, Muir, & Low, 1989 ; Lecanuet, Granier-Deferre, & Busnel, 1988 ; Yao, Jakobsson, Nyman, Rabaeus, Till, & Westgren, 1990). Using a hydrophone, Richards, Frentzen, Grehardt, McCann & Abrams (1992) showed that when sounds generated outside the mother pass into the uterine environment, the dB of their constituent frequencies are differentially enhanced/attenuated. But even now 105dB is regarded as the critical threshold (Kisilevsky et al., 2000), so 105dB is used as stimuli in this study.

In our previous studies, we have shown the calming effect of sound on newborns experiencing stress induced by heelstick (Kawakami, Takai-Kawakami, Kurihara, Shimizu, & Yanaihara, 1996 ; Kurihara, Chiba, Shimizu, Yanaihara, Takeda, Kawakami, & Takai-Kawakami, 1996). The presentation of white noise (NOISE) had the strongest calming effect (Kawakami et al., 1996) and the presentation of the sounds of Japanese drums (DRUM) had only a minor effect (Kurihara et al., 1996). We presented the attention hypothesis: NOISE might shift attention of newborns from pain to hearing. The second purpose of this study is to evaluate fetal attentional responses to sounds by analyses of UAVW and MAVW resistances.

Method

1. Participants

Nine healthy volunteer women, between 37 and 39 weeks gestation, participated in the study. However, data for one woman at the MAVW session could not be obtained because major fetal movement precluded measurement. All her data were eliminated from the analysis. We obtained the informed, written consent of all participants. Information regarding socioeconomic status is not recorded in Japanese hospitals. The mean age of the mothers in this study (M = 30.88, SD = 5.74) matched that of pregnant women in Japan. All mothers had no difficulties in these pregnancies and no smoking habit. Although all experiments were performed at Showa University Hospital in Tokyo, the births eventually took place at several hospitals in Tokyo. All infants, 5 males and 3 females, were apparently healthy at the time of birth.



S : Systolic D : Diastolic

RI (resistance index) = (S−D) /S

Figure 1 Results of UAVW for one case.

2. Stimuli and Equipment

NOISE was generated by sound-editing software running on an Apple Macintosh Computer. DRUM was obtained from a compact disk recorded by the Japanese drum group " Ondekoza ". The NOISE used in this study maintained a consistent sound pressure over the frequency range from 0 to 10000 Hz. There is a possibility that the results will be changed when we use NOISE from 0 to 20000 Hz. But we used NOISE from 0 to 10000 Hz in this study, because we used it to be consistent with our previous studies (Kawakami et al., 1996). However, the DRUM sounds showed large sound pressure only at low frequencies, with amplitudes falling almost to 0 dB at frequencies above 2000 Hz.

NOISE and DRUM were recorded on a mini-disk, and were played back on a Sony mini-disk deck (MS-M5). The mini-disk deck was programmed to play a series of sound stimuli of 5 seconds duration followed by a 1 minute pause. The peak sound pressure level in each stimulus, 105 dB using the C scale, was measured by a Rion sound pressure meter (NA-80) and a Rion condenser microphone (UC-30).

Fetal heart rate monitoring was performed with a Corometrics 145 (Atom Inc.). Doppler monitoring was used to obtain a fetal heart rate (FHR) and a rate of uterine contraction (Tucker, 1989).

UAVW and MAVW were obtained by an ultrasound pulse Doppler unit (LOGIQ500MD, GE·Yokokawa Medical Systems Inc.). Figure 1 shows a section of UAVW data with explanations of the indices.

3. Design

There were three sessions (fetal heart rate monitoring, UAVW, and MAVW) and two stimulus conditions (NOISE and DRUM). In each session participants were presented with both stimulus conditions. The design of this study was to find the effect of sound presentation, so we fixed the order of these sessions (fetal HR, UAVW, & MAVW). The order of sessions was fixed and the order of stimulus conditions was counterbalanced, yielding a confounding design requiring a minimum of 8 participants (Iwahara, 1965).

4. Procedure

The sessions lasted 1-2 hours depending on the state of the fetus. At the time of sound presentation, mothers, wearing earplugs and a headphone set (MDR-CD570, Sony), listened to CD music selected by themselves from several kinds of CDs (using a Sony CD deck, CFD-370).

First, the fetal heart rate monitoring session was performed. The mini-disk deck was held approximately 10 cm from the maternal abdomen. For example, 105 dB NOISE was presented three times separated by 1 minute pauses and 105 dB DRUM was presented in the same manner. The order of NOISE and DRUM was counterbalanced across participants. Second, the UAVW session was performed the same way as the fetal heart rate monitoring session. Finally, the MAVW session was performed. All the three sessions (the fetal heart rate monitoring session, the UAVW session, and the MAVW session) were started when the FHR was stable and no fetal movement were detected. It was difficult to get the data of the ultrasound pulse Doppler unit when the fetuses moved too big. So all the fetuses should be in the quiet state (state 1F; Nijhuis, 1995) when the sessions were started.

Results

1. Fetal heart rate monitoring session

Coding of means of basal HR (beat/minute) and presence/absence of HR acceleration was performed by two analyzers independently. HR acceleration was defined by two criteria: over 15 bpm from basal line and lasted more than 15 seconds. The percentage of intercoder agreement was 96.2. A one-way ANOVA with a repeated measures factor for means of basal HR (pre-stimulus, NOISE and DRUM) was performed. There was no significant main effect (F(2, 14) = 0.01). HR acceleration occured in 16.7% of NOISE conditions and 26.1% of DRUM conditions.

2. UAVW session

Ultrasound pulse Doppler waveforms were recorded on a videotape. Monitor frames were stopped every 10 seconds (see Figure 1), and the average of resistance index was calculated. These procedures were independently performed by two analyzers, and the percentage inter-analyzer agreement was 93.0. The resistance index average will be denoted by X.

Figure 2 shows the data for one subject. The x-axis shows the 10 seconds segments. In ultrasound pulse Doppler waveforms changes of resistance index are important. Then sequential differences of X were calculated. If we denote X at time t as Xt, then the next segment (10 seconds later) will be called X(t+1). Figure 3a shows the means of sequential differences ($\bar{d} = 1/(n-1) \sum_{t=2}^{n} |Xt - X(t-1)| \times 1000$)[1] of all subjects in the pre-stimulus, NOISE and DRUM conditions. A one-way ANOVA with a repeated measures factor for $\bar{d}$ (pre-stimulus, NOISE and DRUM) found that the main effect was significant ($F(2, 14) = 7.88$, $p < .01$); inspection of means of sequential differences indicates that DRUM had higher levels than pre-stimulus.

3. MAVW session

Figure 3b shows the means of sequential differences of all subjects in the pre-stimulus, NOISE and DRUM conditions. A one way ANOVA with a repeated measures factor for $\bar{d}$ (pre-stimulus, NOISE and DRUM) found no significant main effect, $F(2, 14) = 1.07$.

To compare the results of UAVW and MAVW sessions, a one way ANOVA with a repeated measures factor for d (UAVW and MAVW) was performed[2]. There was no significant effect ($F(1, 258)=1.45$).

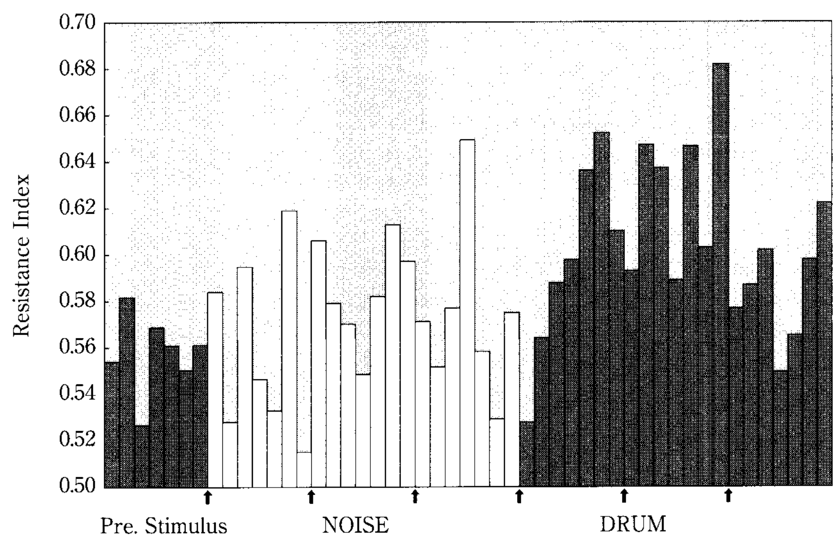


Figure 2 Changes of Resistance Index for one case.
Arrow means the stimulus presentation.

Discussion

Previous research has found that presentation of sounds elicites heart rate acceleration (Lecanuet et al., 1995), and that this trend becomes more clearly evident after 30 to 32 weeks gestation (Kisilevsky, 1995 ; Kisilevsky et al., 1992). Ambient intrauterine sound pressure levels ranged from 72 to 88 dB at 100 Hz, produced by maternal bowel sounds, blood flow, maternal vocalization and external noise (Richards et al., 1992 ; Smith, Satt, Phelan, & Paul, 1990 ; Benzaquen, Gagnon, Hunse, & Foreman , 1990). The intrauterine sound pressure levels ranged from 88.6 to 115.6 dB by 110 dB vibroacoustic stimulation (Eller, Scardo, Dillon, Klein, Atramm, & Newman, 1995), and about 85 dB by 90 dB human voice from 1.2m distance (Richards et al., 1992). From these reports on intrauterine sound, the sound levels which we presented were enough effective to fetuses as much as vibroacoustic stimulation. The small number of participants might cause the results of fetal HR monitoring session.

Cerebral and umbilical vascular resistance responses after vibroacoustic stimulation are significantly lower than those of pre-stimulation in normal fetuses. However, in growth restricted fetuses the responses to sound are different (Loy, Lin, Chien, Kim, & Chiang, 1997), so these responses are related with fetal condition. Our study is the first trial of fetal vascular resistance responses to airborne sounds: NOISE and DRUM. In the UAVW session there were significant differences before and after presentation of two sounds. But in the MAVW sessions there was no significant differences.There was no differences

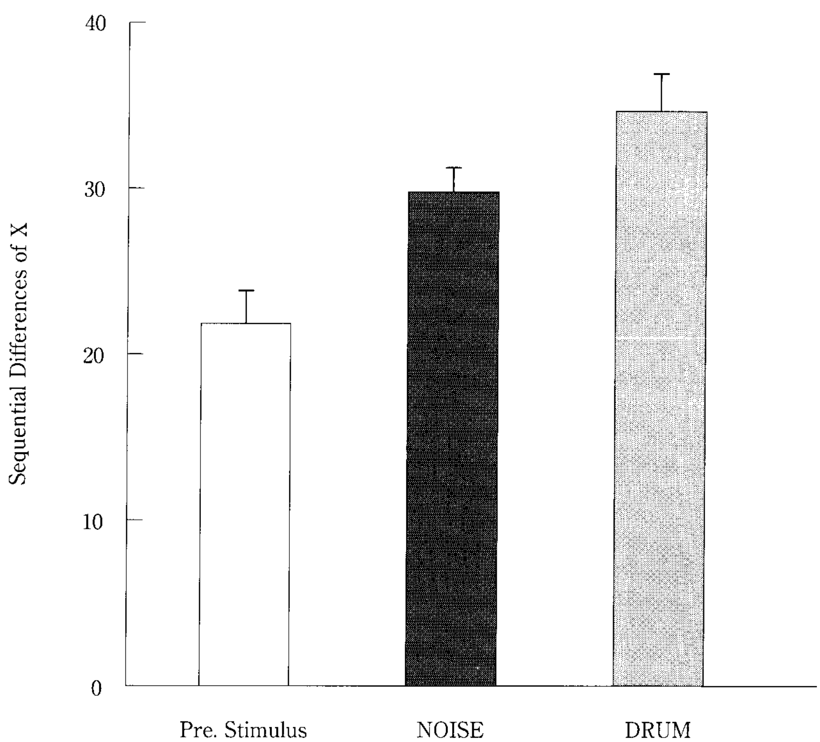


Figure 3a Means of sequential differences in UAVW.
Standard error of the means is indicated by the line above the bar.

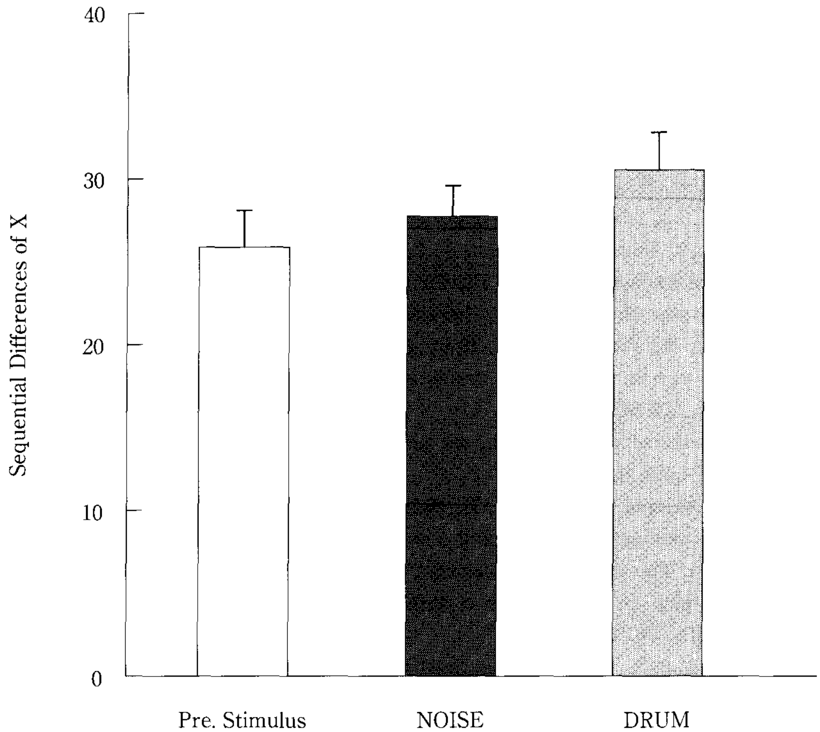


Figure 3b Means of sequential differences in MAVW.
Standard error of the means is indicated by the line above the bar.

in the data of UAVW and MAVW sessions, so we cannot explain these results by habituation. UAVW resistance may be very sensitive index of responses to sound even by small data. The main purpose of this study was to examine the possibility of UAVW and MAVW resistances as indices of responses to sound. We will be able to use UAVW resistance as the measure of resposes to sounds. For the reason of smaller changes in MAVW than UAVW, we might expect greater stability in central nervous system function.

Kisilevsky and Muir (1991) showed that, both before and after birth, noise and vibration elicited greater response than a simple tone. They used pinknoise, vibration and a harmonically simple tone. In our previous studies of newborns, NOISE was effective but DRUM was not (Kawakami et al., 1996 ; Kurihara et al., 1996), a result differing sharply from the outcome of the present study. This discontinuity may be explained by the much greater attenuation of higher frequency sounds as they pass into the intrauterine environment (Querleu et al., 1989 ; Richards et al, 1992). The low frequency sounds of DRUM (Kurihara et al., 1997) may have a greater effect on fetal responses for this reason. Other reasons may lie in the differences in design of the experiments. In our previous studies, stimulus presentation was continued until the end of the experiment, but in this study stimulus presentation was only 5 seconds. Also, in our previous studies, stimuli were presented during especially stressful situation. To more fully understand prenatal to postnatal changes in attentinal response to sound, it will be necessary to carry out further investigations using other experimental designs.

Notes

1 These values are too small, so multiplied by 1000.

2 The data of pre-stimulus were eliminated from the analysis.

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