



## Physiological reactivity of pregnant women to evoked fetal startle

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### ARTICLE INFO

#### Article history:

Received 20 March 2013

Received in revised form 11 July 2013

Accepted 14 July 2013

#### Keywords:

Pregnancy

Psychophysiology

Fetal heart rate

Fetal movement

Maternal–infant interaction

### ABSTRACT

**Objective:** The bidirectional nature of mother–child interaction is widely acknowledged during infancy and childhood. Prevailing models during pregnancy focus on unidirectional influences exerted by the pregnant woman on the developing fetus. Prior work has indicated that the fetus also affects the pregnant woman. Our objective was to determine whether a maternal psychophysiological response to stimulation of the fetus could be isolated.

**Methods:** Using a longitudinal design, an airborne auditory stimulus was used to elicit a fetal heart rate and motor response at 24 ( $n = 47$ ) and 36 weeks ( $n = 45$ ) of gestation. Women were blind to condition (stimulus versus sham). Maternal parameters included cardiac (heart rate) and electrodermal (skin conductance) responses. Multilevel modeling of repeated measures with 5 data points per second was used to examine fetal and maternal responses.

**Results:** As expected, compared to a sham condition, the stimulus generated a fetal motor response at both gestational ages, consistent with a mild fetal startle. Fetal stimulation was associated with significant, transient slowing of maternal heart rate coupled with increased skin conductance within 10 s of the stimulus at both gestational ages. Nulliparous women showed greater electrodermal responsiveness. The magnitude of the fetal motor response significantly corresponded to the maternal skin conductance response at 5, 10, 15, and 30 s following stimulation.

**Conclusion:** Elicited fetal movement exerts an independent influence on the maternal autonomic nervous system. This finding contributes to current models of the dyadic relationship during pregnancy between fetus and pregnant woman.

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### Introduction

Initial developmental research into the maternal–child relationship was guided by the historical philosophical view of the child as a *tabula rasa* and children were primarily regarded as vessels upon which the environment, and most notably their parents, acted. A seminal paper by Bell [1] challenged the existing view of parent–child interaction as a unidirectional phenomenon leading to the now accepted view of the maternal–child relationship as dynamic and transactional. Temporally based associations between parent and offspring have been variously termed synchrony, mutual responsiveness, or attunement [2–5], and are core to understanding the development of regulatory processes within each partner. This research has identified such relations in behavioral domains that include affective and attentional processes, and have also been identified at the psychophysiological level.

There is currently great interest in the manner in which the prenatal period sets the stage for later life [6–9]. Prevailing models focus on the downstream effects of psychological, environmental, and physiological

influences that flow from the pregnant woman to the developing fetus [9–12]. Baseline levels of maternal psychological characteristics related to stress and anxiety [13–16] and products of the hypothalamic–pituitary–adrenal axis [17–19] have been associated with fetal neurobehavior. Perhaps the most convincing evidence of a link between maternal psychological functioning and fetal neurobehavior has been generated from experimental designs in which maternal state is experimentally manipulated and effects on the fetus are observed. Both induced maternal stress [20–25] and relaxation [26,27] have been shown to affect fetal heart rate patterns and/or motor activity.

While such findings are supportive of the role of the maternal context in affecting prenatal development, generally unacknowledged are the potential upstream effects, from fetus to pregnant woman, which may serve as potential regulators of subsequent maternal adaptation to pregnancy and child-rearing. The same neurobehavioral constructs that are central to infant and early childhood have been traditionally applied to fetal development [28,29], although measurement methodology is necessarily different. The prenatal and postnatal environments share little similarity, but the underlying capacities and neurological organization of the developing organism are essentially the same as the fetus adapts from intrauterine function to extrauterine life. It is also clear that the fetus, through its own behavior, plays an active role

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in epigenesis and ontogeny [30,31] as it interfaces with the characteristics of the intrauterine environment.

Previously, in a sample of 137 maternal–fetal pairs assessed longitudinally during the second half of pregnancy, we demonstrated that spontaneous fetal motor activity transiently stimulates maternal sympathetic arousal [32] even though women perceive only a small proportion of fetal movements [33]. This association, which showed little change between the 20th and 38th weeks of gestation, was replicated in an additional sample of women ( $n = 195$ ) from different sociodemographic and ethnic backgrounds [34]. These findings were based on second by second time series analyses of contemporaneous maternal–fetal recordings during undisturbed, baseline periods that were 50 min long. In both reports, spontaneous fetal movements were observed to generate an increase in maternal heart rate and electrodermal activity within 2–3 s at each of the six gestational periods studied. Initially, these analyses were not focused on detecting an effect from fetus to mother. Rather, dual data streams were empirically analyzed  $\pm 100$  s of origin without respect to the originating axis thereby allowing effects to emerge in either direction. From this process, we identified change in the fetus (i.e., in motor activity) to be the impetus for change in the pregnant woman.

However, measurement under baseline conditions does not control for potential joint stimulation of both members of the dyad by uncontrolled sources. Here we use an experimental model in an effort to isolate a maternal response to an elicited fetal movement. Fetuses can detect and respond to sounds external to the uterine environment [35,36], thereby affording us the chance to stimulate the fetus independently of the woman and record any maternal response. The fetal response to the brief application of vibroacoustic or auditory stimulation has been well documented in academic literature as early as the 1930s [37]. Examples of vibroacoustic stimuli applied directly to the maternal abdomen have included those designed for obstetric purposes to stimulate a dormant fetus [38–41], an electronic artificial larynx [42,43], and other devices that emit vibrations [44,45]. In general, fetuses respond to initial applications of vibroacoustic stimuli with transient increases in fetal motor activity and heart rate, consistent with a startle response.

The magnitude of the fetal response tends to be commensurate with the intensity of the stimulus. Thus, airborne auditory signals delivered above and not touching the maternal abdomen tend to elicit a less intense response, but are necessary to a design in which pregnant women must be blind to stimulus presentation. Airborne stimuli shown to elicit a fetal response include electronically generated signals of varying intensity and frequency [46–49], speech sounds [50–52], and music [37,53].

We hypothesized that, as observed with spontaneous movements, elicited fetal movements would generate a transient maternal autonomic response as measured by heart rate, which includes both parasympathetic and sympathetic influences, and electrodermal activity, which is singly innervated by sympathetic processes [54]. Fetal sex and maternal parity were evaluated as potential moderators of either the fetal or maternal response based on the existing data indicating differential responsiveness of male fetuses to stimulation [40] and higher background electrodermal activity in nulliparous as compared to multiparous women [55].

## Methods

### Participants

Participants were 50 volunteer, non-smoking pregnant women with normally progressing, singleton pregnancies and full-term deliveries. All 50 participants attended the first visit; 47 returned for the second visit. Accurate dating of the pregnancy, based on early first trimester pregnancy testing or examination with early ultrasound confirmation was required ( $M$  gestational age at pregnancy detection = 5.0 weeks;  $sd = 1.9$ ). This was the first pregnancy for 52% of participants ( $n = 26$ ). The sample represents a relatively stable population

of well-educated ( $M$  years of education = 16.8 years,  $sd = 1.7$ , mature ( $M$  age = 32.0,  $sd = 4.1$ ), married (90%) women. Most were non-Hispanic white (76%); the remainder was African-American (6%), Hispanic or Asian (18%). Nearly half of the fetuses (42%) were female. Infants had normal birth outcomes ( $M$  birth weight = 3482.1 g,  $M$  gestational age = 39.5 weeks,  $M$  5 minute Apgar score = 8.9).

### Procedure

The experimental procedure was implemented at 24 and 36 weeks of gestation. This followed a 50 minute undisturbed period of maternal–fetal data collection, which is not part of this report. Participants were in a semi-recumbent position. The protocol involved two sets of 3 minute baseline periods that were followed by either a stimulus or sham condition, with order randomly determined (Fig. 1). The stimulus was composed of particulates (i.e., un-popped popcorn kernels) enclosed in a cardboard tube (17.5 cm long  $\times$  6 cm diameter) with metal end plates shaken sharply three times and positioned 4 in. above the maternal abdomen near the fetal head. This created a series of sharp, percussive retorts of 0.52 s duration each (total stimulus duration = 1.6 s). The peak sound level intensity generated by each of the 3 shakes was 89 dB. Pilot data collected previously on 40 maternal–fetal pairs (unpublished) in our laboratory indicated that this device was effective at generating a fetal motor response at 24 and 36 weeks. During the sham condition, the investigator stood in the same location and shook an empty tube in the same manner and at the same distance from the uterus. Women wore gelled eye masks to prevent them from observing the approach of the investigator, and headphones designed to cancel room noise (MSA Headband Earmuff; EN352) coupled with an inputted stream of classical music for further acoustic masking. The protocol was modified if high levels of fetal motor activity were present, suggestive of an active awake fetal state (4F) [56] such that the stimulus or sham was delayed for 3 additional minutes.

### Maternal–fetal data collection

Women were instrumented with a 3-lead electrocardiogram (with thigh ground) to detect R-waves and dual silver–silver chloride electrodes with gelled transducers affixed to the fingertips to measure electrodermal activity. Continuous physiological signals were amplified and digitized at 1000 Hz. Skin conductance was measured by administering a constant 0.5 V root-mean-square 30 Hz AC excitation signal and detecting the current flow. Data quantification proceeded off-line using the PHY General Physiology System and IBI Analysis Systems (James Long Company, Caroga Lake NY). ECG data underwent R-wave detection and manual editing for artifact. Inter-beat intervals were timed (ms) and subsequently converted to heart rate (MHR) in beats per minute (bpm) to be consistent with the fetal heart rate metric. Skin conductance units were scaled from 0 to 25  $\mu$ S and detrended by applying a high-pass filter to the raw signal and amplifying the resultant values [(i.e.,  $\pm 2.5$   $\mu$ S full scale; skin conductance response (SCR)].

Fetal data were collected using a Toitu (MT320) fetal actocardiograph. This monitor detects fetal movement and fetal heart rate through the use of a single wide array transabdominal Doppler transducer. Doppler detects and quantifies motions of the fetal heart using autocorrelation techniques and is the standard method for antepartum fetal heart rate recording. The actograph detects fetal movements by



Fig. 1. Schematic of experimental design involving airborne stimulus and sham conditions. Order of presentation was randomly determined.

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