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ACCELERATION OF THE FETAL HEAD: EFFECT OF DISTANCE FROM VIBRATION SOURCE

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1. INTRODUCTION

Physical trauma complicates approximately one in every twelve pregnancies [1]. Serious retroperitoneal hemorrhage following lower abdominal and pelvic trauma occurs more frequently in pregnant women than in non-pregnant women [2]. Placental separation from the uterus is a complication in nearly half of all life-threatening traumatic injuries [1]. Causes of trauma during pregnancy include falls, direct assaults to the abdomen (battering) and motor vehicle accidents. The fetus is said to be "protected" from direct impact trauma, unless of course the head is engaged and the maternal pelvis suffers a significantly large mechanical shock. However, even the non-vertex fetus has been reported to sustain significant intracranial trauma, even at times with minimal maternal trauma, presumably from the acceleration–deceleration forces [3].

Only very little is known about the effects of long-term, repetitive accelerative forces on the fetus, as might be experienced by pregnant women in the workplace. The majority of work-related, whole-body vibration injuries in men result from the lower level forces directed along the axis of the spine while in the seated position. Long-term exposure leads to increased risk of disorders of the lumbar spine and connected neuro-muscular systems [4]. Low-back pain is the second most common cause of loss of work in industry and is the leading cause of industrial disability payments. The resultant cost to society is estimated as high as 25–95 billion dollars per year[5]. Current standards and guidelines are promulgated to protect workers from over-exposure to whole-body vibration [6, 7]. Currently, regulations do not address fetal exposure limits.

How women react to whole body vibrational forces has received scant attention in spite of the fact that the number and proportion of women of working age who are in the labor force have increased markedly in the last several decades [8]. It would be difficult to deny that the whole body vibration dynamics could be noticeably different in pregnant women because of a changed distribution of body mass, a realignment of the spinal column and hormone-induced ligamental changes [9].

In addition to the route of vibration exposure to the abdominal segment via the extended legs while standing, or through the muscles of the gluteal and posterior femoral regions and ischia of the pelvic bones when sitting, vibration exposure can arise when the vibration source is in physical contact with the abdominal surface. Examples of these conditions would include leaning against a repetitive motion machine and while supporting a vibration hand tool against the torso [10].

In an earlier study [11] of pregnant sheep, it was determined that vibration of the extra-abdominal wall resulted in a frequency-dependent rise in vibration levels at the intra-abdominal wall from 4%–140% of the input level. At the fetal head, a broad, low-level, peak in the frequency response was noted between 6 and 12 Hz. Previous studies of intra-abdominal iso-sound pressure contours had clearly shown frequency and distance related attenuation of vibroacoustic stimuli. The present study was designed to determine

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if accelerative forces measured at the fetal head were dependent on the position of the fetus within the abdominal segment.

2. MATERIALS AND METHODS

Guidelines for the care and use of the animals approved by the Univeristy of Florida were followed. Four pregnant ewes carrying singleton fetuses between 127 and 142 days gestation were anesthetized and ventilated with 2% halothane in oxygen, and underwent a midline abdominal incision and a hysterotomy. The fetal head was delivered and the scalp was incised along the midline. Four stainless steel screws (0–80) were placed in 1 mm holes drilled through the cranium, one on each side of the midline. Next, a stainless steel cube (Entran Devices, Fairfield N.J., model EGA3-MTG) was placed between the screws. A miniature implantable piezoresistive accelerometer (Entran Devices, EGA-125E-10DX) was mounted in the cube so that its direction of sensitivity matched the axis of vibratory stimulation. The cube was fixed to the screws and thereby to the head with methyl methacrylate. Acceleration levels of the fetal head to different frequencies were measured with this accelerometer.

A small incision was made through the right lateral wall of the maternal abdomen midway between the lower border of the rib cage and the crest of the ilium. A second miniature accelerometer (Entran Devices, EGA-125-10DX) was then sutured to the inside of the intra-abdominal wall. As before, its direction of sensitivity also matched the axis of vibratory stimulation. The incision at the fetal head was closed, the head was replaced in the uterus, and the uterine and abdominal incisions were closed. The anesthetized animals remained supine on the surgery table during the experiment.

The actuator head of a shaker (Bruel and Kjaer Instruments, model 4808 Marlborough, MA) was fitted with 4·9 cm^2 circular aluminum disk and an impedance head (Bruel and Kjaer, Model 8001), and placed in line with both the intra-abdominal accelerometer and the head-mounted accelerometer. This instrumentation array provided a method for: (1) introducing vibration into the body; (2) measuring its transfer across the abdominal wall; and (3) assessing acceleration levels at the fetal head.

The shaker was pressed against the flank with moderate constant pressure such that a 3 cm skin depression in the skin occurred in all animals. The system set-up is given in Figure 1 of reference [11]. The acceleration output of the impedance head was used to evaluate acceleration levels at the external surface of the abdomen during the experiment. All accelerometers were calibrated with a calibration exciter (Bruel and Kjaer model 4294). Accelerometer output signals were amplified and conditioned using a Bruel and Kjaer amplifier (model 2634) for the impedance head (external to the abdomen), and Pacific Instruments amplifiers (model 2310, Concord, CA) for the Entran piezoresistive accelerometers (on the intra-abdominal wall and fetal head). The signal voltages from the amplifiers of the accelerometers located on the intra-abdominal wall and fetal head were constantly monitored since they reflected positioning in the critical plane of the accelerometer with respect to the axis of stimulation. The input acceleration levels were held constant at 2·5 m/s^2, r.m.s. for all stimulus frequencies.

The shaker was driven with sine waves generated with a Wavetek (Model 182A) sine-wave generator at frequencies between 3 Hz and 150 Hz. The signals obtained from the accelerometers were monitored on a digital storage oscilloscope to ensure fidelity. Stimulation was performed at frequencies of 3, 4, 5, 6, 7, 8, 9, 10, 12·5, 16, 20, 25, 31·5, 40, 50, 63, 80, 100, 125, and 150 Hz. Spectral analysis was performed with a real time analyzer (Bruel & Kjaer, model 2123) in 1/12 octave bands over a range of 1·45 Hz to 173 Hz. The averaging time was set at one minute. Spectra were obtained with and without stimulation in order to evaluate the noise floor. Analyses were performed on spectra generated for the different frequencies, and at each of the three accelerometer locations (extra-abdominal wall, intra-abdominal wall and the fetal head). Vibration transmissibility was also calculated. Spectra were stored on diskette and plotted on a graphics plotter (Bruel and Kjaer model 2319).

Acceleration responses were measured at the intra-abominal site and fetal site in each of 4 animals at 16 frequencies (range 3–150 Hz) and 3 stimulus source distances (8, 12, 16 cm). Both frequency and accelerator voltage outputs were represented on log scales. Linear regressions were applied to all data in order to calculate slopes and intercepts for individual animal profiles at each site (abdominal wall and fetal head) and stimulus source distance. Repeated measures analysis of variance (ANOVA) was used to compare mean slopes obtained from the two sites. Linear polynomial contrasts were employed within the repeated measures ANOVA model to determine if mean slopes or intersections changes linearly as a function of distance.

3. RESULTS

Acceleration levels at the fetal head were fairly constant as a function of frequency, and did not differ significantly as a function of distance for the vibration source (Figure 1). In 10 of 12 acceleration level response curves spanning the three distances between the abdominal wall and the fetal head, the slopes were negative with respect to the frequency. Acceleration levels at the fetal head were small, always less than 4% of the input acceleration levels (constant at 2·5 m/s^2).

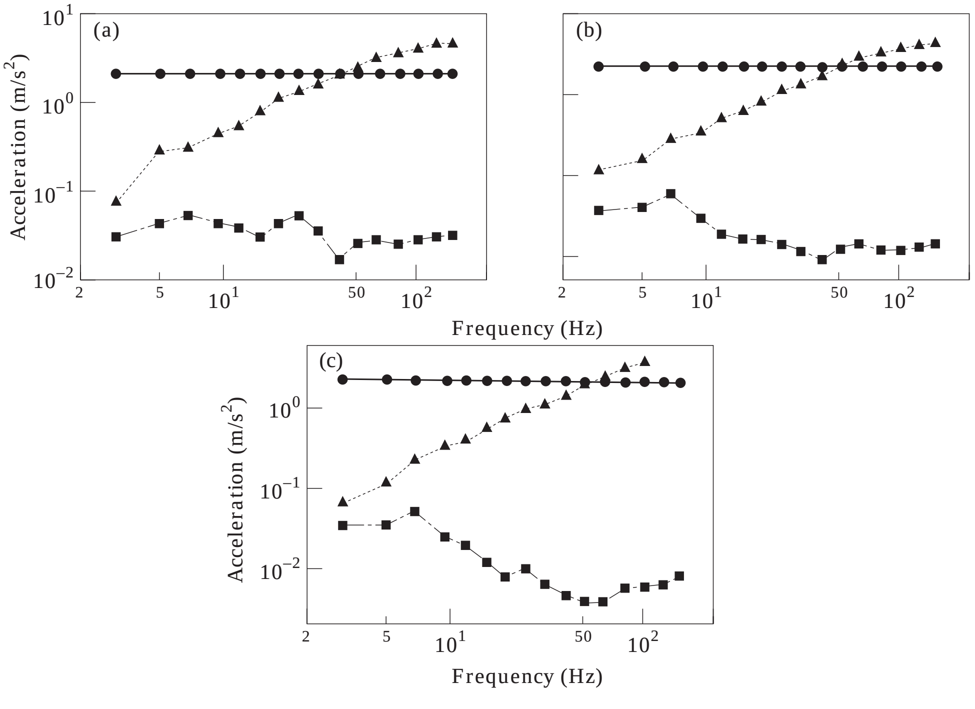

Figure 1. Acceleration levels at the fetal head as a function of (a) 8, (b) 12 and (c) 16 cm distance from the vibration source on the abdominal wall. Key: -●-, input acceleration level measured at the abdominal surface; ···▲···, acceleration levels recorded from the inner surface of the abdominal wall; —■—, acceleration levels recorded from the fetal skull.

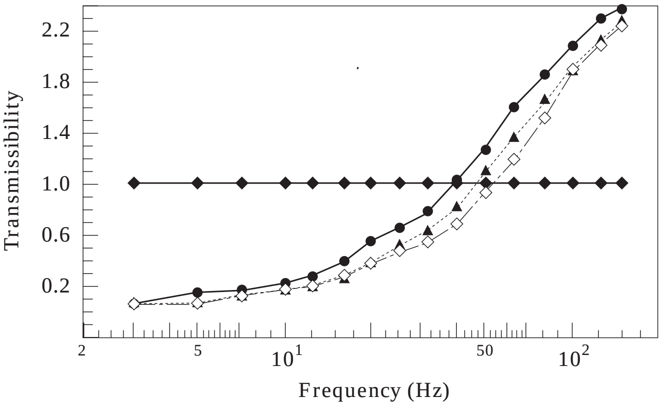

Figure 2. Abdominal wall transmissibility curves showing the effect of increasing distance between vibration source on the abdominal wall and fetal head: ●, 8 cm; ▲, 12 cm; — · ◇ · —, 16 cm. Input levels equal 1.0 at all frequencies

For example, when the head is 8 cm from the abdominal wall, the frequency at which transmissibility into the abdomen exceeds 1·0 is at 40 Hz. As the distance between the head and the abdominal wall increases, the frequency of the intersept increases systematically. The increasing trend in mean intersections as a function of distance was statistically significant ($p = 0{\cdot}033$).

Repositioning of the fetal head further from the abdominal wall did not alter the acceleration levels recorded at the intra-abdominal site. Unlike acceleration levels of the fetal head, as frequency increased so did the acceleration levels recorded at the intra-abdominal site ($p = 0{\cdot}039$). Interestingly, the output of the intra-abdominal wall accelerometer exceeded the input level at all frequencies from 40–80 Hz (Figure 2). A close inspection of transmissibility curves (Figure 2) as a function of distance revealed subtle shifts in the frequency at which intra-abdominal levels exceed input levels.

4. DISCUSSION

The present study confirms earlier findings by Peters *et al*. [11] of a large attenuation for accelerative forces transmitted across the wall of the abdomen. The low vibration levels at the fetal head developed during low frequency displacement of the abdominal wall contrast with the high sound pressure levels at the fetal head found during both sinusoidal vibration [12] and complex vibroacoustic stimulation [13]. During vibration exposures there was a broad peak in spectral levels between 5–15 Hz, implying a small resonance of the fetal head [14], but there was only a suggestion of this phenomenon in the present accelerometry experiments.

Thus, in contrast to the rich and varied sounds to which the fetus is exposed prenatally, external vibratory energy appears to be dramatically attenuated. One must remember, however, that vibrations in the present study were limited in frequency range (3–150 Hz) and were applied to soft tissue of the abdominal wall. For continuous vibrations, health effects are more likely to be noted at the resonant frequencies of the segment or organ in question [15]. The small size of the fetus within the large abdominal segment may not necessarily mean that its resonance will increase in frequency as would be expected by a free-living 2–3 kg cat, for example [16].

In earlier experiments with sound stimulation, intra-abdominal SPL was negatively correlated with distance between hydrophone and the vibrator at low-to-mid frequencies (100–2000 Hz) [17]. Complicated interactions between distance and frequency can be seen in isosound pressure contours published in this article [17]. In the present study while there was a general trend downward in the magnitude of acceleration of the fetal head as frequency increased, the failure to establish a relationship with distance may have been due to extremely low acceleration levels in general. A higher acceleration input with attachment of a shaker over a larger abdominal wall area may have produced a significant distance effect.

In an air medium, the tension of the wall of an enclosure (as within a snare drum) might be expected to effect the SPL and frequency inside the drum during a drum roll. In the abdominal segment filled with fluid and solid media, no interaction was found between fetal head acceleration and the acceleration of the abdomen. The rise in acceleration levels of the wall as input frequency increased, as noted by Peters *et al*. [11] was confirmed. The slopes of the increase, which in all cases led to a resonance (i.e., defined as a vibration of the wall greater than the input vibration) above 40 Hz, were unchanged as the fetal head was moved from 4 to 8 to 16 cm from the wall. However, the frequency at which these resonances appeared was increased during these maneuvers. That is, there was a shift to the right of the point where wall acceleration exceeded input acceleration level. Whether or not this unexpected and unexplained phenomenon had its basis in some heretofore unrecognized problem in the protocol remains to be determined. Slight increases in vibrator static forces [18] lead to increased transmissibility at higher frequencies. The axis of stimulator may also have an effect, at least for low frequencies. Finally, any biomechanical changes in the abdominal wall occurring over time in the anesthetized animal or the build up of rumenal gas may have been factors.

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