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FOETAL CARDIAC RESPONSE TO AUDITORY STIMULATION

by

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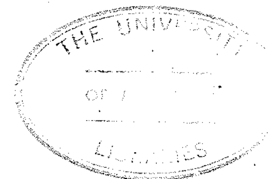

ABSTRACT

Previous research in foetal audiometry has suggested that sound produces heart rate acceleration. To test this, two pure tones of different frequencies and intensities were delivered to 12 foetuses. Each foetus was observed for one session, with one exception, who was seen twice. Peak heart rate and heart rate variability were compared during stimulation and non-stimulation periods, and during the first and second half of the session. Results indicated that there was no cardiac response to the sound, but that there was a change in cardiac response related to the duration of the session. This was discussed in the context of the maternal-foetal relationship, and the pre-experimental state of the foetus.

To the late Michael Bruser, M.D., F.A.C.O.G.,
Researcher-practitioner in the field of
obstetrics and gynaecology, who liked to
have his babies born alive.

Thank you.

"And surely we are all out of computation of our age, and every man is some months elder than he bethinks him."

Sir Thomas Browne
Religio Medici, 1642

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TABLE OF CONTENTS

	Page
DEDICATION	ii
ACKNOWLEDGEMENTS	iii
LIST OF TABLES	v
LIST OF FIGURES	vi
LITERATURE REVIEW	5
METHOD	13
Subjects	13
Apparatus	13
Procedure	14
RESULTS	23
Cardiac Responsivity to Sound	23
The Question of State	35
Effect of Maternal State on Foetal Reactivity	38
Individual Differences	40
DISCUSSION	53
Cardiac Responsivity to Sound	53
The Question of State	55
Effect of Maternal State on Cardiac Activity	56
Individual Differences	58
CONCLUSIONS	59
REFERENCES	60

LIST OF TABLES

Table		Page
1.	Experimental Design	18
2.	Mean Pulse and Range of E.M.'s Heart Rate Compared with Foetal Scores and Ratings	39

LIST OF FIGURES

Figure		Page
1.	Moving mean graph of mean peak foetal heart rate of all foetuses during stimulation and non-stimulation periods	25
2.	Moving mean graph of mean peak foetal heart rate of all foetuses during period 1 and period 2.	27
3.	Moving mean graph of mean peak foetal heart rate of the six H-L foetuses during stimulation and non-stimulation periods	29
4.	Moving mean graph of mean peak foetal heart rate of the six L-H foetuses during stimulation and non-stimulation periods	30
5.	Moving mean graph of mean peak foetal heart rate of the six H-L foetuses during period 1 and period 2	32
6.	Moving mean graph of mean peak foetal heart rate of the six L-H foetuses during period 1 and period 2	33
7.	Moving mean graph of mean peak foetal heart rate of the six S.F. foetuses during stimulation and non-stimulation periods . .	34
8.	Moving mean graph of mean peak foetal heart rate of the six S.S. foetuses during stimulation and non-stimulation periods . .	36
9-20.	Moving mean graphs of mean peak foetal heart rate during stimulation and non-stimulation periods	41-52
	Fig. 9. Foetus No. 1, S.F. group, L-H condition.	41
	Fig. 10. Foetus No. 2, S.F. group, L-H condition.	42

Figure | Page

9-20 cont'd

Fig. 11. Foetus No. 3, S.S. group, L-H condition. 43

Fig. 12. Foetus No. 4, S.F. group, H-L condition. 44

Fig. 13. Foetus No. 5, S.S. group, L-H condition. 45

Fig. 14. Foetus No. 6, S.S. group, L-H condition. 46

Fig. 15. Foetus No. 7, S.F. group, H-L condition. 47

Fig. 16. Foetus No. 8, S.F. group, L-H condition. 48

Fig. 17. Foetus No. 9, S.F. group, H-L condition. 49

Fig. 18. Foetus No. 10, S.S. group, H-L condition. 50

Fig. 19. Foetus No. 11, S.S. group, H-L condition. 51

Fig. 20. Foetus No. 12, S.S. group, H-L condition. 52

In recent years much research has centred around the early months of human development. Among the important reasons for studying the young organism is the possibility for discovering behavioral tendencies which may affect later personality structure. For example, individual differences in response to stimulation may influence cognitive processes and ability to handle stress (Escalona, 1968). Also, there is a growing interest in identifying the age when responses to specific stimuli develop, so that diagnostic norms may be established (Bench, 1972).

Because the behavioral repertoire of the neonate and young infant is limited, physiological measures have been utilized. Heart rate in particular has been studied by many researchers because of its sensitivity to varying conditions and accessibility for precise recording (Eichorn, 1970).

While neonatal response to sound has been demonstrated by measuring heart rate (Bridger, 1961; Bartoshuk, 1962a; Peiper, 1963; Brackbill, 1971), foetal response has been traditionally studied by measuring gross body movements (Ray, 1932; Sontag and Wallace, 1934, 1935; Richards, Newberry and Fallgatten, 1938; Spelt, 1948). However, recent medical studies by Murphy and Smyth (1962) and Johansson, Wedenberg, and Westin (1964) indicate that it is now possible to assess foetal cardiac response to sound.

The long-standing problem of accurate measurement of foetal cardiac activity appears to be soluble due to the development of apparatus for the continuous recording of foetal heart rate. Previous measurements have involved non-continuous samplings of heart rate. Since the heart rate of the foetus is very variable (Eichorn, 1970), this is an inaccurate measure for change occasioned by auditory stimulation.

Bench (1972) has criticized the previously cited research in foetal audiometry for omitting necessary controls. For example, neither interspersed non-stimulation trials nor non-stimulation periods have been used to ascertain whether observed changes in heart rate could be accounted for by normal variability. Bench has also stressed the necessity for further research into the conditions under which the reported acceleration in heart rate might occur. For example, very little is known about foetal thresholds of cardiac response to sound, and individual differences in magnitude of response. The effect of pre-stimulation behavior on post-stimulation response has not been studied nor has response to stimuli of varying intensity.

It is probable that the foetus in utero has the neurophysiological capacity to react to an auditory stimulus for several weeks before birth. The auditory system is structurally mature by about the 27th-28th week of gestation (Hooker, 1943) and tests on prematures born at this time have shown a heart rate acceleration to auditory stimulation (Peiper, 1963). The existence of a structurally

mature system in utero does not imply that the system functions in utero as it will function postnatally. Bench (1972) regards the foetus as an inhibited organism with some aspects of its activity, e.g., vision, blocked until after birth. He questioned the function of the auditory system in utero and suggested that the prenatal maturity of the acoustic nerve might serve as a means of providing developmentally necessary stimulation to the growing foetus. The uterus, however, has been regarded as providing an environment which ensures maximum insulation from external stimulation to the growing foetus. Research has not even established that external and/or internal sound reaches the foetal auditory system.

The present study was conducted in response to Bench's criticisms and to augment the work of researchers in the field of early human development. The present methodology is innovative for this area of foetology, and is intended to provide a base for further research in foetal cardiac response.

This study was chiefly concerned with developing a means of measuring foetal cardiac activity, and demonstrating whether cardiac activity is affected by external sound. In addition the study was concerned with demonstrating the effect on foetal cardiac activity of pre-experimental state and duration of the experimental session.

There are some foetal studies and several neonatal studies related to the assessment of foetal cardiac sensitivity to sound. These will be reviewed in terms of past and present trends in the research in early development.

LITERATURE REVIEW

In the 1930's and 1940's, researchers in foetal and neonatal development were attempting to demonstrate that learning could occur at these early stages. For example, Spelt (1948), using a classical conditioning paradigm, claimed to have shown foetal capacity to form learned associations. Marquis (1931) reported similar findings with neonates. These two psychological studies are frequently cited as representing the beginning of the experimental-manipulative approach with young human subjects.

In the past three decades, there have been few psychologically oriented studies of the foetus in utero. Research on foetology has been concerned primarily with developing the methodology to assess the physical well-being of the growing organism, e.g., through foetal heart rate monitoring (Douglas, 1973).

There has been a growing awareness of the need for interdisciplinary research by medical and psychological investigators in order to learn more about the psychological aspects of uterine development (Bench, 1972). While neonatal and infant mortality have decreased, increasing numbers of growing children have exhibited various learning

problems of unknown etiology; accordingly, the establishment of prenatal psychological norms is of importance for diagnostic as well as for predictive purposes.

Psychological aspects of neonatal life have been studied along two general directions. Along the first direction, many researchers have continued to explore capacity for learning. For example, Lipsitt and his associates (Lipsitt and Kaye, 1964; Lipsitt, Kaye and Bosack, 1966; Siqueland and Lipsitt, 1966) have used both classical and instrumental conditioning paradigms to demonstrate very early ability to learn to discriminate. Along the second direction, researchers have studied the nature of the stimuli to which the neonate can respond, and the various behaviors in its repertoire. A growing body of data has accumulated from this research which indicates that the newborn is highly sensitive to its environment. The use of different modes of stimulation, e.g., sounds, lights, odors, has demonstrated differential responding to stimulation of all the sensory modalities. Reese and Lipsitt (1970) provided a review of the research.

Several approaches and techniques are being developed in order to assess neonatal cardiac response to auditory stimulation. Among these techniques may be several of value to the assessment of foetal cardiac response to sound.

A beginning has been made in assessing the neonatal threshold of response to sound. An accelerative heart rate

response is usually found at an intensity of 70 decibels (dB) or more (Bartoshuk, 1962a; Graham, Clifton and Hatton, 1968). However, Steinschneider, Lipton and Richmond (1966) have suggested that the threshold for sound for some individuals may be as low as 40 dB, but may not be necessarily reflected in heart rate. Such a stimulus would probably be below threshold for the foetus, due to the acoustic barriers afforded by the maternal abdominal wall, the uterus, and the placenta. While the attenuation occurring as external sound travels through these barriers is not known, there is an indication that attenuation increases as birth approaches (Bench, Anderson and Hoare, 1970). Murphy and Smyth (1962) used a pure sine wave tone of 100 dB to obtain a cardiac reaction in foetuses. This is the lowest intensity reported that claims to have produced foetal cardiac response but the study is open to question on grounds that will be discussed later.

The frequency of the pure tones used in foetal research has ranged from 120 cycles per second (Hz) (Bernard and Sontag, 1947) to 4000 Hz (Johansson, Wedenberg and Westin, 1964). Some investigation has been done on the effect of varying combinations of frequency and intensity levels in neonatal research (e.g., Bartoshuk, 1962b), but the area remains to be more fully explored. While reaction to sound cannot exclude the effect of some vibration through the tactile modality, reaction through this modality alone

might be excluded by using frequencies above 1500 Hz (Knudsen, 1928).

Many neonatal researchers have been developing methods to investigate individual differences in cardiac response to sound. For example, Bridger (1961) found that some subjects responded to stimuli more often than others. Lipton, Steinschneider, and Richmond (1963) found differences in ability to discriminate between stimuli of varying levels of intensity. Lipton and Steinschneider (1964) found that the latency of an accelerative response and the time required to return to a pre-stimulus level of responding differed among subjects. In contrast to neonatal research, research of foetal audiometry has not emphasized individual differences except for the study by Welford et al (1967), previously cited.

The effect of pre-stimulus state, or arousal level, on post-stimulus cardiac response has been noted by many neonatal investigators (e.g., Bridger and Reiser, 1959; Lipton, Steinschneider and Richmond, 1961; Lamper, 1971). This effect is predicted by the law of initial value (LIV), formulated by Wilder (1950),which holds that low autonomic excitation preceding a stimulus is associated with high autonomic reactivity upon stimulus presentation and vice versa. Response to a stimulus can be confused with the operation of LIV. Several techniques for controlling LIV effects have been utilized, such as having sessions after

feeding, swaddling, using intense stimuli so that cardiac response will occur regardless of state (Woodcock, 1971). The operation of LIV at the foetal stage has not been explored.

The control of foetal arousal level presents special problems, since not only are the techniques used in neonatal research of no value, it is not known to what extent the arousal level of the foetus is dependent on that of the mother at any given time. Studies on the relationship between the mother and the foetus show confusing findings: Schmeidler (1941) reported that a period of physical activity on the part of the mother resulted in a subsequent decrease in foetal motor activity for about thirty minutes. While there is evidence that maternal and foetal rest periods coincide, in the later stage of gestation, the foetus may become more active even when the mother is resting (Peiper, 1963). Welford et al (1967) found a correlation between foetal activity and foetal heart rate but no correlation between foetal and maternal heart rate measures when the mother was in a semi-reclining position. Sontag (1941) suggested that foetal activity and foetal heart rate both might be influenced by long-term maternal stress through the release of adrenalin into the bloodstream. The control of maternal state during the experimental session is the most feasible method of assessing foetal response to external stimulation until more is learned about maternal-foetal interaction and how this affects foetal heart rate.

Foetal state has been described in terms of heart rate excitation (Goodlin and Schmidt, 1972). A change in foetal state during an experimental session could occur simultaneously with a possible cardiac response to sound. Murphy and Smyth (1962) and Johansson et al (1964) both reported an acceleration in heart rate to sound, but the former found this occurred at an average of 30 seconds after stimulus onset, the latter within a few seconds. Bernard and Sontag (1947) found a maximal response after 11 seconds. None of these studies included an assessment of pre-experimental foetal state, nor were measurements of heart rate or heart rate variability during stimulation trials compared with similar measurements in non-stimulation trials. Results of these studies are therefore open to question. Was there a real change in heart rate due to an external stimulus, or could the apparent change be explained by a change in state or the operation of LIV?

An area of interest in the research on neonates of importance for this study is that of response to stimuli of varying levels of intensity. For example, Steinschneider et al (1966) reported an increase in duration and a decrease in latency of an accelerative cardiac response as intensity levels of stimulation increased. This area has not been studied in foetal audiometry and there is no information on whether such differential responding exists at the foetal stage.

Researchers in foetal audiometry have used a single

sound stimulus in their studies, and claimed to have shown an acceleration in heart rate. The use of two stimuli, e.g., two pure tones of different intensities and frequencies, both comparable to the stimuli previously reported as resulting in a measurable response, could serve as a means of assessing the capacity for differential responding.

For some years the continuous recording of heart rate in neonatal research has been made possible by an electrocardiogram (EKG) machine or an electrocardiograph channel of a polygraph. These machines trace a continuous record of the electric current produced by contraction of the heart muscle. The normal tracing shows upward and downward deflections. The largest upward deflection is called the "R-wave." The "R-R cycle" is the time duration between any two given beats measured from one R-wave to the next. The cardiotachometer channel of the polygraph automatically transforms this time duration into a beat-per-minute (bpm) heart rate (Woodcock, 1971).

It is only in the past few years that a foetal monitoring device (cardiotocograph) for continuous recording of foetal heart rate has been available. Such a unit has been used primarily as a clinical tool during pregnancy and labor in cases where there is concern about normal delivery. While not the main purpose of this study, the use of the unit as a research tool was nevertheless assessed. It was hoped that through improving and adding to procedures previously used in foetal research, the data

obtained would augment existing information with regard to what may be one of the most basic determinants of developmental change and growth--the activation patterns of the organism (Escalona, 1968).

The chief purpose of this study was to determine whether a foetal cardiac reaction to auditory stimulation occurred. Two pure tones of different frequency and intensity were delivered by a loudspeaker located at the maternal abdominal wall. A foetal monitoring unit recorded heart rate continuously. The study also determined whether differential responsivity to the stimuli could be demonstrated; whether individual differences in response could be measured; whether pre-session foetal state affected responding during the session; and whether maternal state affected the heart rate of the foetus.

METHOD

Subjects

Twelve expectant mothers (E.M.'s) were selected from the patient population of the high risk prenatal program of St. Boniface General Hospital. Mothers and/or foetuses in the high risk program had a medical problem which could endanger normal labor and birth. The gestational age of the foetuses ranged from 30 to 40 weeks.

Apparatus

The foetal monitoring unit used was a Hewlitt-Packard Model 8025 A, operated at a paper speed of 2 cm/min. This unit generates an ultrasonic beam at an approximate frequency of 2MHz. This beam is generated through a piezo-electric crystal and detects a reflected beam utilizing a crystal receiver. The major reflection is from the myocardium, and the beam is Doppler shifted, i.e., frequency modulated by the myocardial movement. It is then demodulated and used as the input to the cardiotocograph. The incoming signal is first electronically filtered and has basic pattern recognition and logical schema applied to it. An output of one pulse for each heartbeat is then received by the rate computing circuitry. The pulse-train representative of heartbeat versus time gives an instantaneous heart rate, modified only by comparison with the preceding and the directly fol-

lowing heartbeat of the heartbeat in question. The comparison does not change the rate, but accepts or rejects that it is a valid heartbeat. The continuous recording represents an almost instantaneous conversion of heartbeat into a beat per minute rate.

The stimulus delivery system consisted of a Heathkit audio-generator, Type 1G-72, and one Jana horn loaded loudspeaker, Model JJ10706, with a bell diamater of 5 inches. Stimulus duration and inter-stimulus interval (ISI) were controlled by two Hunter timers, Types 100 c, 111 c. A Brüel and Kjaer, Type 2203, sound level meter was used to calibrate the audio equipment, and to measure the ambient noise level of the experimental room throughout the study. The meter measures sound pressure level (S.P.L.) in decibels (dB) re. dynes/cm^2. A set of Superex earphones, Model 69A-24-19 connected to a Phillips 220 tape recorder playing a musical tape masked the stimuli for the E.M.'s.

Procedure

All sessions took place at approximately 2 p.m., in accordance with hospital routine. Temperature, ambient noise level (69 $\pm$ 2dB), and lighting in the experimental room were constant for all sessions. S.P.L. was measured on the axis of the speaker, $\frac{1}{4}$ inch from the rim of the bell.

There was some question as to whether the stimulation could travel through the abdominal wall of the E.M. and reach the foetus. The two levels of stimulation used in this study

were similar to those used by researchers previously cited. These levels were chosen in order to compare present findings with previous reports and also to avoid possible harmful effects of higher intensities.

Before beginning the study, therefore, additional measurements of S.P.L. were made in order to test out sound transmission through various media. The loudspeaker was placed directly on the abdominal wall of non-pregnant female volunteers and the sound level meter was held ¼ inch from their back, in a position opposite to the speaker. The sound level meter was also used to determine whether sound could travel through such objects as bedding and boneless steak. In all cases, using the same stimulus levels as used in the study, S.P.L. equalled the ambient noise level (69 $\pm$ 2dB) of the experimental room.

The following procedures, suggested by Bench (1972) and the medical staff of the hospital, were used to provide controls omitted in previous studies:

1. Isolation of the E.M. from the stimuli delivered to the subject (foetus):

   This required the use of frequencies above 1500 Hz to avoid a reaction to vibration through the tactile modality, a directional loudspeaker to provide high intensity sound only at the abdominal wall, and isolating earphones to provide continuous masking music.

2. Acquaintance of E.M. with experimental conditions:

   This was aimed at assisting E.M. to relax, as was the music.

3. Posture of the E.M.:

   This was determined by E.M.'s comfort and optimum position for reception of the incoming signal.

4. Temporal equivalence of stimulation periods and non-stimulation periods:

   This was obtained through the use of a counter-balanced design, allowing for half the foetuses to have stimulation during the first part of the session, and half the foetuses to have it in the second part. Also, control trials were interspersed with stimulation trials in the stimulation period.

There was a pre-experimental session of 10-20 minutes during which the E.M. was acquainted with equipment and procedures. The purpose of the study, to investigate the effect of sound on cardiac response, had been discussed previously with the E.M. She was shown how the equipment operated and was encouraged to request further information if any aspect of the procedures was not understood. Spontaneous comment was also encouraged with the goal of enabling the E.M. to be relaxed and co-operative. She was asked to go to sleep if possible. Earphones were placed on her head and masking music adjusted to a comfortable vol-

ume. The monitoring unit began to operate, and an assessment was made of the level of heart rate excitation of the foetus. Measurements of E.M.'s pulse were taken at random intervals during the session. The loudspeaker was placed on the maternal body wall, in a position near the foetal head.

One-half of the foetuses were randomly assigned to the Stimulation First group, one-half to the Stimulation Second group. Table 1 illustrates the experimental design of the study. For both groups, tones were repeated with the duration of each tone set at 10 seconds to allow for the possibility of slow conduction and long response latency. The interstimulus interval (ISI) was 60 seconds to avoid presenting a tone during a response to a previous tone (Graham, Clifton and Hatton, 1968). The foetal monitoring nurse recorded the onset and offset of each tone on the print-out sheet of the monitoring unit.

Stimulation First Group

For half of the foetuses a pure tone of 2500 Hz was delivered at 100 $\pm$ 2dB for 15 trials. A tone of 3000 Hz at 109 $\pm$ 2dB followed for 5 trials. There were three interspersed control trials of 70 seconds, during which no stimulation was given. The other half of the group was given stimulation under the same conditions, except that the tones were reversed in order and number. This was called the stimulation period. A control period consisting of the equivalent of 23 control trials followed, lasting the same

Table 1

Experimental Design

Period	Stimulation First Group		Stimulation Second Group	
	High-Low (H-L) Foetuses (3)	Low-High (L-H) Foetuses (3)	High-Low (H-L) Foetuses (3)	Low-High (L-H) Foetuses (3)
1.	15 trials, 3000 Hz 109 $\pm$ 2dB 5 trials, 2500 Hz 100 $\pm$ 2dB 3 interspersed trials, no stimulation	15 trials, 2500 Hz 109 $\pm$ 2dB 5 trials, 3000 Hz 100 $\pm$ 2dB 3 interspersed trials, no stimulation	23 trials, no stimulation	23 trials, no stimulation
2.	23 trials, no stimulation	23 trials, no stimulation	15 trials, 3000 Hz 109 $\pm$ 2dB 5 trials, 2500 Hz 100 $\pm$ 2dB 3 interspersed trials, no stimulation	15 trials, 2500 Hz 100 $\pm$ 2dB 5 trials, 3000 Hz 109 $\pm$ 2dB 3 interspersed trials, no stimulation

length of time as the stimulation period. This was designated as the non-stimulation period.

Stimulation Second Group

Procedures for this group were the same as for the Stimulation First (S.F.) group except that the non-stimulation period preceded the stimulation period.

At the end of the experimental session, comment was requested from the E.M. as to her physical state, e.g., relaxed, tense, able to sleep. This was recorded along with observations made by investigators as to her behavior during the session, e.g., restless, sleeping.

Limitations of the equipment as well as the goals of the study were the basis for the analyses chosen. The monitoring unit at present does not record data for the precise measurement of second-by-second heart rate fluctuations. Also, the unit does not filter out"noise" due to random movements of the foetus and in such cases continuity of recording is interrupted. No mechanism was available for automatic recording of onset and offset of stimuli, making some measurement error unavoidable. An analysis of tonic heart rate seemed most feasible, in order to make use of the data available and to minimize the effect of measurement error. The tonic h. r. is measured when the inter-stimulus interval (ISI) is longer than 45 seconds. Cardiac activity during this interval is included in the analysis (Johnson and Lubin, 1972).

Each trial, 70 seconds in length, was divided into five segments: 15 seconds of non-stimulation, 10 seconds during which a tone was or was not presented, and three consecutive 15-second segments of non-stimulation. The final 15-second segment of non-stimulation of a trial was immediately followed by the initial 15-second segment of non-stimulation for the next trial, producing the 60-second ISI. The single highest and lowest recorded heart rate in each segment were graphed and used subsequently for data analysis.

In instances where the quality of recording was poor and heart rate could not be accurately read, the rates of the preceding segment or trial were used to obtain values. This avoided excluding entire individual records, parts of which contained more easily read data.

To obtain a measure of average variability the method used by Welford et al (1967) was adapted. In this adaptation, the highest heart rate in each of the five segments of a trial was identified and a mean calculated for each trial. The same procedure was followed for the lowest heart rate. The difference between the mean of the highest and of the lowest rates was found for each trial. The mean of all the difference scores was then used as a single measure of heart rate variability for each subject.

Scores from the trials in which no stimulation was given were not included in the analysis of the stimulation period, and the equivalent segments of data were excluded from the non-stimulation period. In this way, each period

included data from 20 trials.

Since research previously cited would predict an acceleration of heart rate during stimulation, an analysis was required which could compare a rise in heart rate across trials in the period of stimulation to that of non-stimulation. The previously computed mean for each trial of the highest heart rate in each of the trial's five segments was used as a score representing average peak heart rate for that trial. Average peak heart rates for the trials of the stimulation period were averaged and compared to the mean of the average peak heart rates for the trials of the non-stimulation period.

The t-test for paired observations (two-tailed) was used for all statistical analyses of foetal cardiac response (Hays, 1963). For each subject in this study, the paired observations consisted of the average score of all the trials in one period under study and the average score of all the trials in the other period. There were therefore 12 paired observations available for the various analyses. To determine the relation between maternal and foetal cardiac behavior, a comparison of the highest maternal pulse and foetal mean peak heart rate during the session was made. Pearson's product-moment correlation coefficient was used for this analysis (Hays, 1963).

As a way of illustrating peak foetal heart rate across trials, a moving mean measure was used. The purpose

of the moving mean was to smooth the data to make more apparent the effect of the independent variables. This measure consists of computing average scores for overlapping blocks of trials, e.g., the means of the first three trials were averaged, then the means of trials 2, 3 and 4, and so on. When graphed, each data point represented three trials or 210 seconds: the first data point represented seconds 1 to 210, the next data point consisted of seconds 71 to 280, and so on. A moving mean was computed for each subject for the two periods. Each period included data from 20 trials, and excluded data from the three control trials in the stimulation period and the corresponding trials in the non-stimulation period.

RESULTS

Cardiac Responsivity to Sound

Throughout each experimental session continuous foetal cardiac recordings were made. Particular attention was paid to the recording during the presentation of the stimulus and for several seconds thereafter. In cases where the heart rate fluctuated greatly prior to the introduction of the stimulus, it was not possible to identify a heart rate change which could definitely be attributed to the sound. But even when pre-stimulation heart rate was steadier, an immediate reaction to sound still could not be observed: accelerations occurred after stimulation trials which seemed similar to those occurring spontaneously in non-stimulation trials. What was observable were changes in the patterns of cardiac activity. The major problem of analysis, therefore, was to determine whether changes in pattern during stimulation periods differed significantly from pattern changes in non-stimulation periods.

To determine whether stimulation affected heart rate variability, mean variability scores obtained by the Stimulation First (S.F.) group in the first period and mean variability scores obtained by the Stimulation Second (S.S.) group in the second period, representing stimulation for both, were compared with their respective mean scores in

the non-stimulation period. The mean difference was .69 bpm. This was not significant at a .05 level of probability, using the t-test for paired observations.

To assess whether stimulation affected peak heart rate, mean peak foetal heart rate (f.h.r.) scores obtained by S.F. and S.S. groups in the stimulation period were compared with corresponding scores in the non-stimulation period. The mean difference was .33 bpm. The t-test for paired observations was used, with non-significant results at a .05 level. These data are illustrated in Figure 1 in which a moving mean analysis shows a different pattern of mean peak f.h.r. for the period of stimulation compared with non-stimulation. Across subjects under all conditions, the stimulation pattern shows a slight decrease in mean peak f.h.r. followed by an increase. The non-stimulation pattern across all subjects showed less fluctuation.

To determine the effect of trials on heart rate variability, mean variability scores of S.F. and S.S. groups in period 1 were compared with corresponding scores in period 2. The mean difference was 1.41 bpm, with greater variability in the second period. This was not significant at a .05 level of probability, using the t-test for paired observations. However, there was an indication of a trend towards greater variability in the second period.

To assess the effect of trials on peak heart rate, mean peak f.h.r. scores of S.F. and S.S. groups in period 1

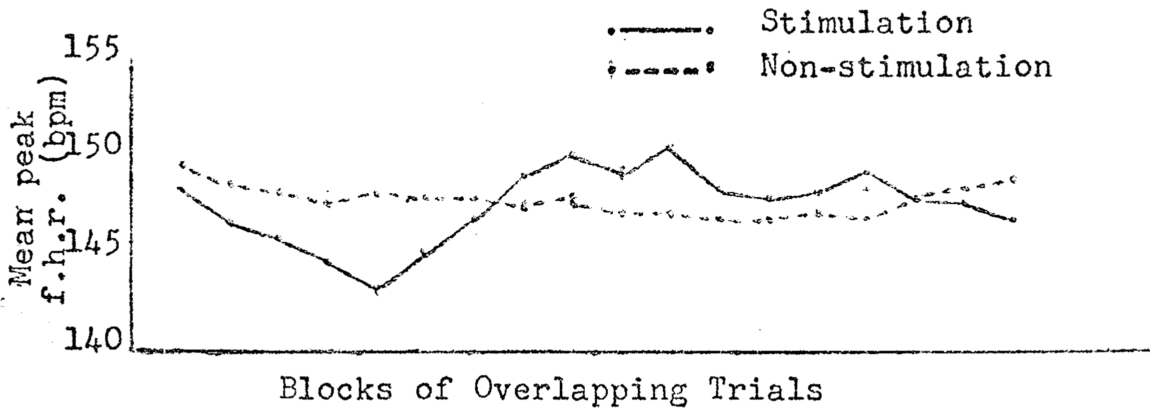

Fig. 1. Moving mean graph of mean peak foetal heart rate of all foetuses during stimulation and non-stimulation periods.

were compared with mean peak f.h.r. scores in period 2. Mean peak f.h.r. was higher by 2.7 bpm in the first period. Using the t-test for paired observations, results were not significant at a .05 level, but again there was an indication of a trend towards a decrease in peak heart rate across trials. These data are illustrated in Figure 2 which shows mean peak f.h.r. across trials for all subjects during the first and second periods of the session. Mean peak f.h.r. was higher in period 1, and there is an indication of greater fluctuation in the second period.

An assessment was made of the effect of the two orders of stimulus presentation on heart rate variability. The mean variability scores during stimulation of foetuses in the 15 trials high, 5 trials low stimulation (H-L) condition and the scores of foetuses in the 15 trials low, 5 trials high stimulation (L-H) condition were each compared with corresponding scores in the non-stimulation period collapsed across S.F. and S.S. groups. The mean difference between the two periods was 1 bpm for H-L foetuses and .4 bpm for L-H foetuses. Neither difference was significant at a .05 level of probability, using the t-test for paired observations.

The effect of the two orders of stimulus presentation on peak heart rate was also assessed. The mean peak f.h.r. scores for H-L foetuses and for L-H foetuses during the stimulation period were each compared with correspond-

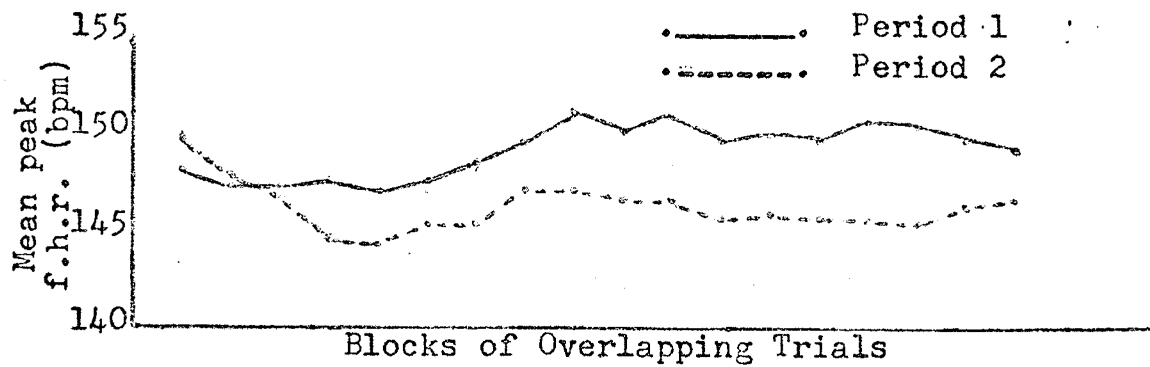

Fig. 2. Moving mean graph of mean peak foetal heart rate of all foetuses during period 1 and period 2.

ing scores in the non-stimulation period collapsed across S.F. and S.S. groups. The mean difference between the two periods was .54 bpm for H-L foetuses and 1.3 bpm for the L-H foetuses, both non-significant at a .05 level of probability, using the t-test for paired observations.

Figure 3 and Figure 4 show moving means for mean peak f.h.r. during stimulation and non-stimulation periods for H-L and L-H foetuses. The patterns for both groups show a decrease followed by an increase in mean peak f.h.r. in the stimulation periods, with a more regular pattern in the non-stimulation periods.

The effect of trials on mean peak foetal heart rate and mean variability scores for H-L and L-H foetuses was assessed by comparing for each group mean peak f.h.r. scores for trials in period 1 to trials in period 2 and by comparing for each group mean variability scores for trials in period 1 to trials in period 2. The H-L foetuses showed a mean difference in mean peak f.h.r. of .4 bpm and a mean difference in mean variability of .10 bpm between the two periods. Neither difference was significant at a .05 level of probability, using the t-test for paired observations. The L-H foetuses had significantly higher mean variability in the second period at a .05 probability level, with a mean difference of 2.93 bpm, t = 2.12. The L-H foetuses also had significantly lower mean peak f.h.r. in the second period, with a mean difference of 4.8 bpm, t = 2.72, with probability at a .05 level, using the t-test for paired observations.

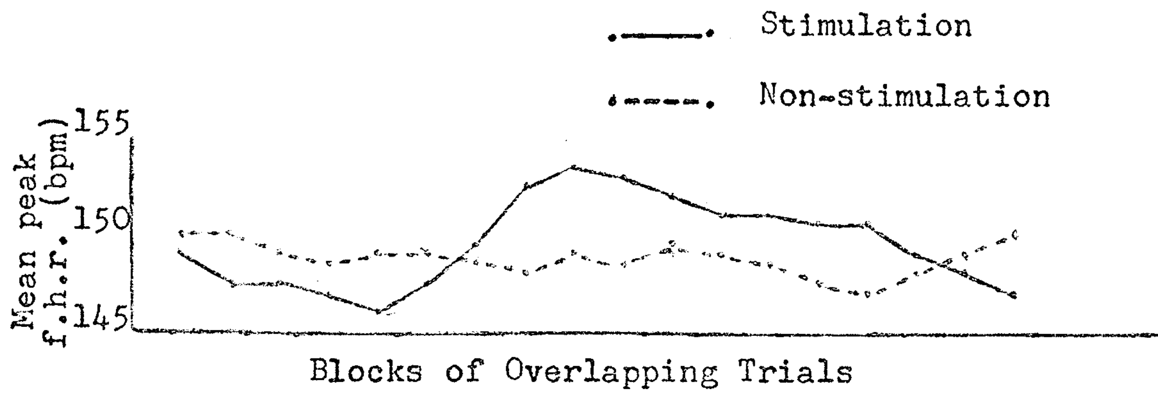

Fig. 3. Moving mean graph of mean peak foetal heart rate of the six H-L foetuses during stimulation and non-stimulation periods.

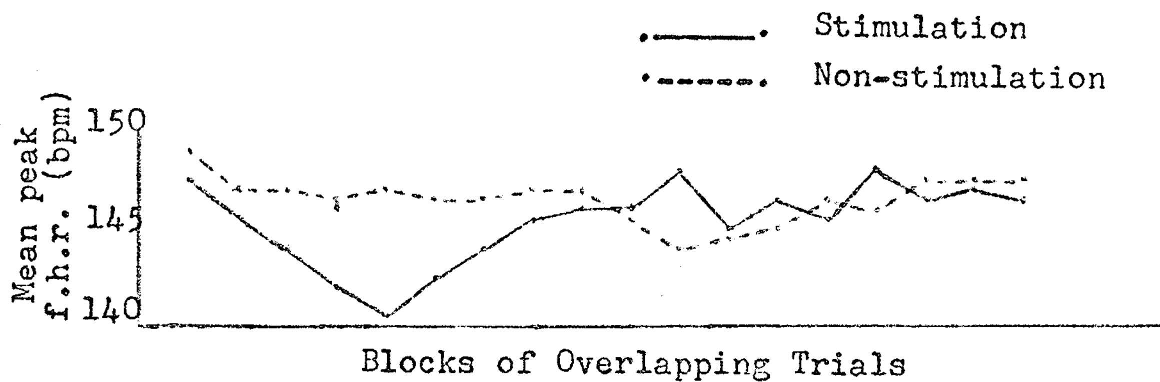

Fig. 4. Moving mean graph of mean peak foetal heart rate of the six L-H foetuses during stimulation and non-stimulation periods.

Figures 5 and 6 show moving means for mean peak f.h.r. of H-L and L-H foetuses in period 1 and period 2. Differential responding of the L-H group in the two periods is apparent (Figure 6). The mean peak f.h.r. was higher in period 1, and the range of cardiac activity was greater in period 2. A decrease followed by an increase in mean peak f.h.r. appears in period 2. This pattern also appears in both periods of the H-L foetuses (Figure 5).

Moving means were used to illustrate ongoing cardiac behavior at the end of the first period and the beginning of the second period. Figure 7 depicts mean peak f.h.r. of the S.F. group during stimulation (period 1) and non-stimulation (period 2). Figure 8 depicts mean peak f.h.r. of the S.S. group during non-stimulation (period 1) and stimulation (period 2).

To assess a possible difference in responding to high stimulation levels compared to low stimulation levels, the mean peak f.h.r. score for trials 11 to 15 and for trials 16 to 20 was calculated for each foetus. A comparison was made between mean peak f.h.r. in the high trials and in the low trials for all subjects. The mean difference was 2 bpm. This was not significant at the .05 level of probability, using the t-test for paired observations.

To determine the effect of stimulation on the three non-stimulation control trials within the stimulation period, mean peak f.h.r. scores in these trials were averaged and compared with averaged scores for corresponding trials

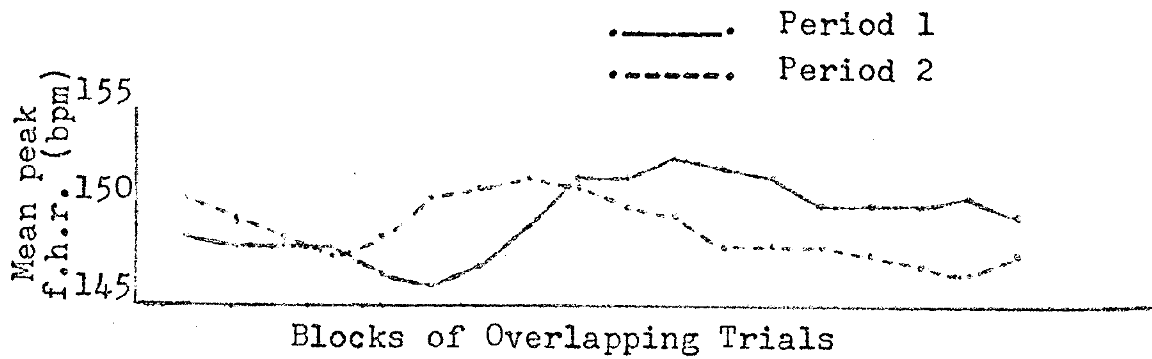

Fig. 5. Moving mean graph of mean peak foetal heart rate of the six H-L foetuses during period 1 and period 2.

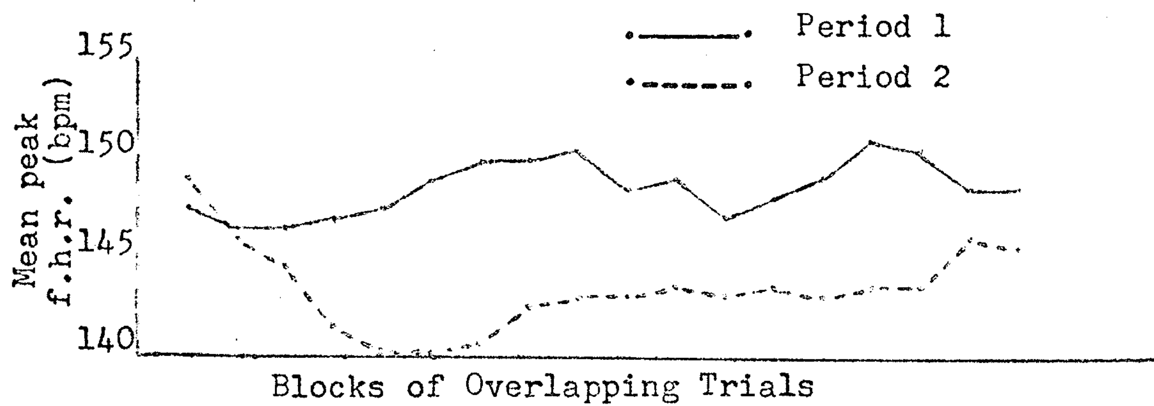

Fig. 6. Moving mean graph of mean peak foetal heart rate of the six L-H foetuses during period 1 and period 2.

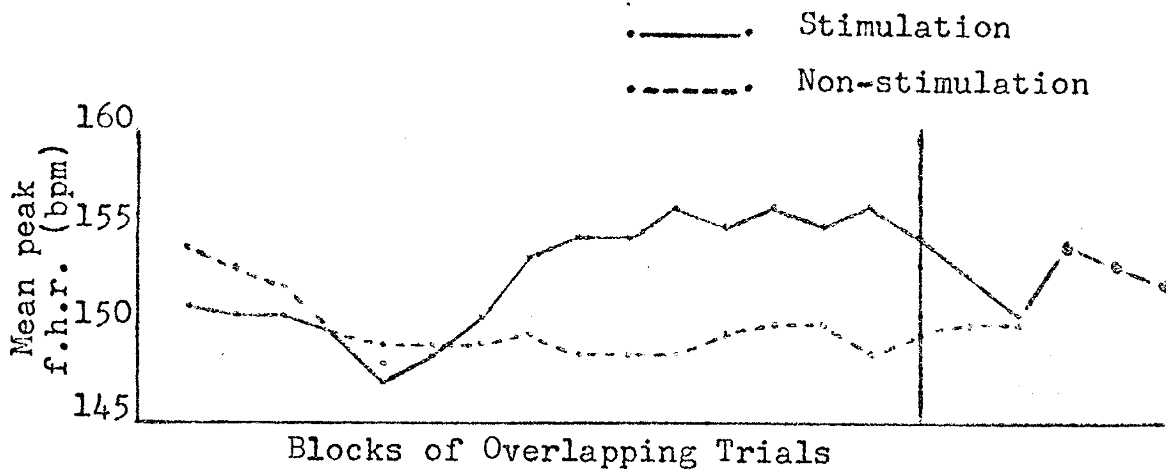

Fig. 7. Moving mean graph of mean peak foetal heart rate of the six S.F. foetuses during stimulation and non-stimulation periods. The vertical line at the right of the graph cuts off the last three data points in the stimulation period (period 1), followed by the first three data points in the non-stimulation period (period 2). See text.

in the non-stimulation period for each foetus. There was a mean difference of .16 bpm, non-significant at a .05 level of probability, using the t-test for paired observations.

When the last three data points in the first period of time are compared with the first three data points in the second time period in each group, the graphs indicate differences in ongoing behavior. The six subjects who received stimulation first (Figure 7) showed an average tendency towards a slight increase followed by a decrease in mean peak f.h.r. when the period of non-stimulation began. The six subjects who received stimulation in the second period (Figure 8) showed an average tendency to decrease when the period of stimulation began.

The Question of State

Human foetal arousal levels (state) have been defined by observing continuous foetal heart rate recordings and grouping the recordings according to patterning of heart rate.

Foetal heart rate usually ranges between 125 to 155 bpm, but can drop below 80 bpm and rise to over 190 bpm for brief periods. The patterns of variation differ markedly between foetuses. The individual foetus can have a pattern of limited change on heart rate (stabile), considerable change (labile), or both, in a given period of time. Average change usually ranges from about 5 to 15 bpm in a 15 minute sampling (Welford et al, 1967). Foetal arousal levels

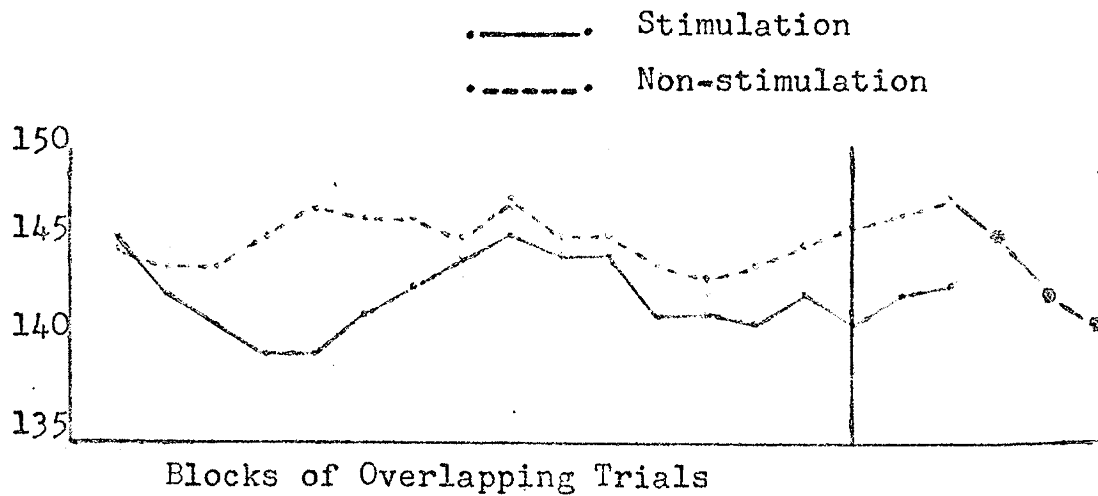

Fig. 8. Moving mean graph of mean peak foetal heart rate of the six S.S. foetuses during stimulation and non-stimulation periods. The vertical line at the right of the graph cuts off the last three data points in the non-stimulation period (period 1), followed by the first three data points in the stimulation period (period 2).

have been classified broadly as being reactive or non-reactive. Reactive levels show changes in baseline heart rate of over 8 bpm occurring without known stimulation. Non-reactive levels show a pattern which is characterized by a flat, unchanging baseline, and is usually considered "ominous" (Goodlin and Schmidt, 1972). In this study, all foetuses showed reactive patterns and all were judged within normal ranges for both heart rate and heart rate variability.

An assessment was made in the pre-experimental period of the state of the foetus, which was determined by observing heart rate patterning. Three categories were used: stabile, heart rate steady, with few fluctuations; moderate, some change in heart rate, with several fluctuations in pattern; labile, continuous change in heart rate with frequent fluctuations. Of the twelve foetuses, five were rated as stabile, three as moderate, four as labile.

In order to compare pre-experimental state with responding during the stimulation period, mean peak f.h.r. scores during stimulation were grouped and averaged according to the pre-experimental ratings, as were the mean variability scores. Across foetuses, the mean peak f.h.r. during stimulation was 147.51 bpm. The five stabile foetuses had an average peak heart rate of 135.57 bpm, the moderate foetuses averaged 146 bpm, while the labile foetuses had a mean peak heart rate of 154.7 bpm. This would indicate that pre-experimental state was reflected in mean peak f.h.r. during the session.

Mean variability for the stabile subjects in the stimulation period was 12.46; for the moderate subjects it was 15.07 bpm, and for the labile subjects 13.88 bpm, while the group mean was 13.58 bpm. In this small sample, the subjects designated as in a moderate state of pre-experimental excitation showed the greatest amount of mean variability. However, group differences are not very large, and pre-experimental state may not be related to mean variability.

Effect of Maternal State on Foetal Reactivity

All E.M.'s were requested to report on their state during the session (e.g., tense, relaxed) and whether they were aware of the sound. The E.M.'s appeared to be sleeping or resting quietly throughout most of the session. Ten E.M.'s reported that they had been relaxed when not sleeping and were unable to hear the auditory stimulus. Two E.M.'s heard it very infrequently and faintly; therefore, it seems likely that the behavior of the E.M.'s was not related to the presence or absence of the stimulation. The E.M. who did not sleep, read during the pre-experimental session, and rested with eyes closed during the experimental session. She described herself as very tense and uncomfortable.

Table 2 lists the range of maternal heart rate, the mean of the sample pulses taken for each E.M., and a summary of foetal scores. There appeared to be little consistent relation between maternal measures and foetal meas-

Table 2

MEAN PULSE AND RANGE OF E.M.'S HEART RATE COMPARED WITH FOETAL SCORES AND RATINGS

E.M.			Foetus				
No.	Mean Pulse	Range	Rating	Mean Acceleration		Mean Variability	
				Stimulation	Non-stimulation	Stimulation	Non-stimulation
1	86	82-96	Labile	153.1	152.7	10	16
2	96.4	92-104	Moderate	146.0	142.2	13.7	14
3	85.7	64-100	Stabile	143.4	145.	15.6	11.6
4	97	92-100	Moderate	148.4	147.3	15.	13.7
5	79	72-100	Labile	149.4	160.8	14.5	14.3
6	86	80- 92	Stabile	122.5	127.6	15.5	9.7
7	93	92- 96	Stabile	149.7	153.8	11.8	11.2
8	83	80- 92	Labile	159.3	152.9	13.7	15.
9	83	80- 84	Labile	156.9	150.3	17.3	15.9
10	72.6	68- 76	Stabile	155.1	147.4	13.5	9.9
11	74.3	72- 78	Stabile	142.7	147.	5.9	9.3
12	76	72- 80	Moderate	143.6	147.1	16.5	14.

ures. As a way of comparing the cardiac behavior of the E.M.'s and foetuses, the highest pulse of the E.M. and the mean peak f.h.r. of the foetus during the session were compared. The Pearson product-moment correlation was -.21 and was not significant at a probability level of .05.

Individual Differences

A purpose of this study was to develop measures which would be useful for future research requiring measurement of foetal cardiac activity. Figures 9 to 20 illustrate responding for individual foetuses. It is apparent that the moving mean measure, based on mean peak f.h.r., is sensitive to the diversity of cardiac behavior patterns both within and among individual foetuses.

The mean variability measure was adopted from the measure used by Welford et al (1967). Their study is one of the few which attempted to assess the stability of cardiac behavior of the individual foetus over several weeks. In this study the measure was used to compare responding of groups of subjects in different conditions. However, the measure is sensitive to individual differences in cardiac behavior, as indicated in Table 2.

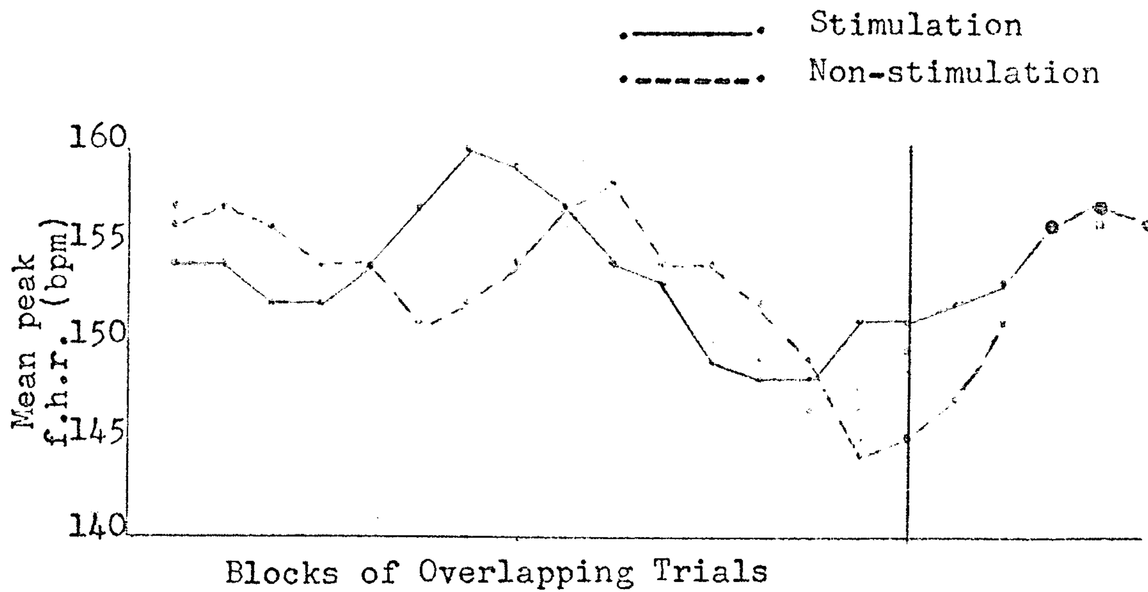

Fig. 9. Moving mean graph of mean peak foetal heart rate of foetus No. 1, S.F. group, L-H condition, during stimulation and non-stimulation periods. The vertical line at the right of the graph cuts off the last three data points in the first period, followed by the first three data points in the second period.

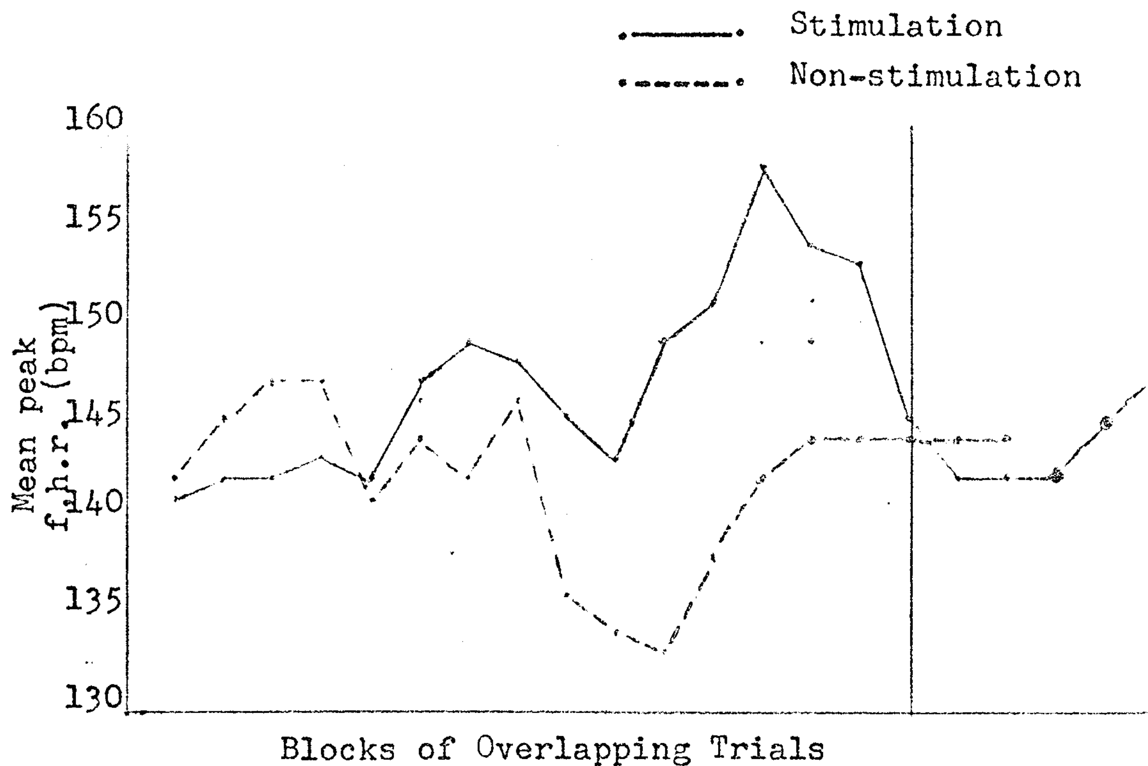

Fig. 10. Moving mean graph of mean peak foetal heart rate of foetus No. 2, S.F. group, L-H condition, during stimulation and non-stimulation periods. The vertical line at the right of the graph cuts off the last three data points in the first period, followed by the first three data points in the second period.

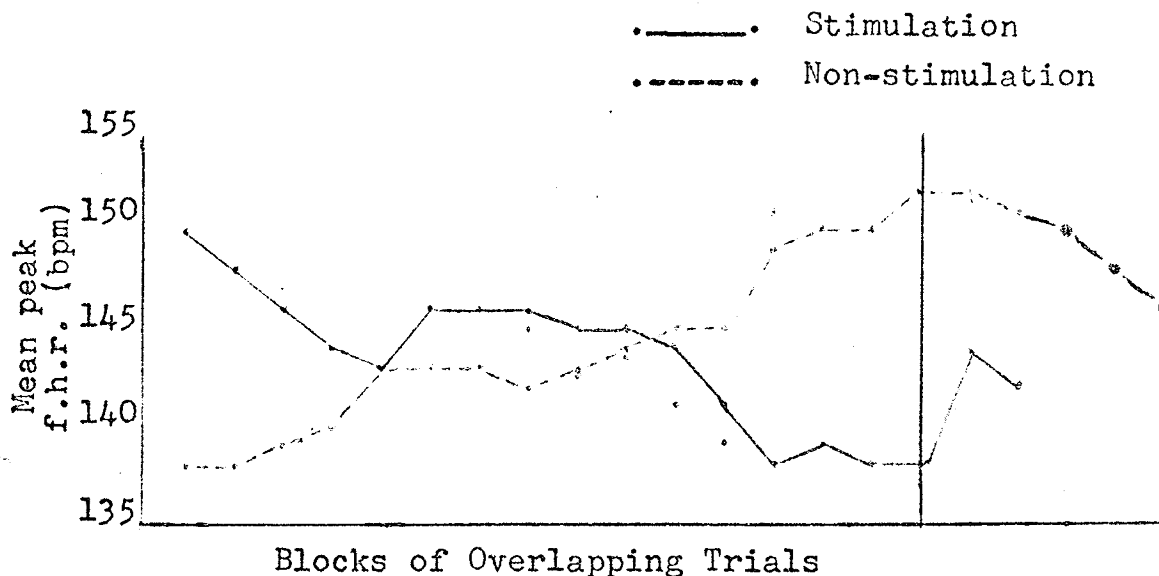

Fig. 11. Moving mean graph of mean peak foetal heart rate of foetus No. 3, S.S. group, L-H condition, during stimulation and non-stimulation periods. The vertical line at the right of the graph cuts off the last three data points in the first period, followed by the first three data points in the second period.

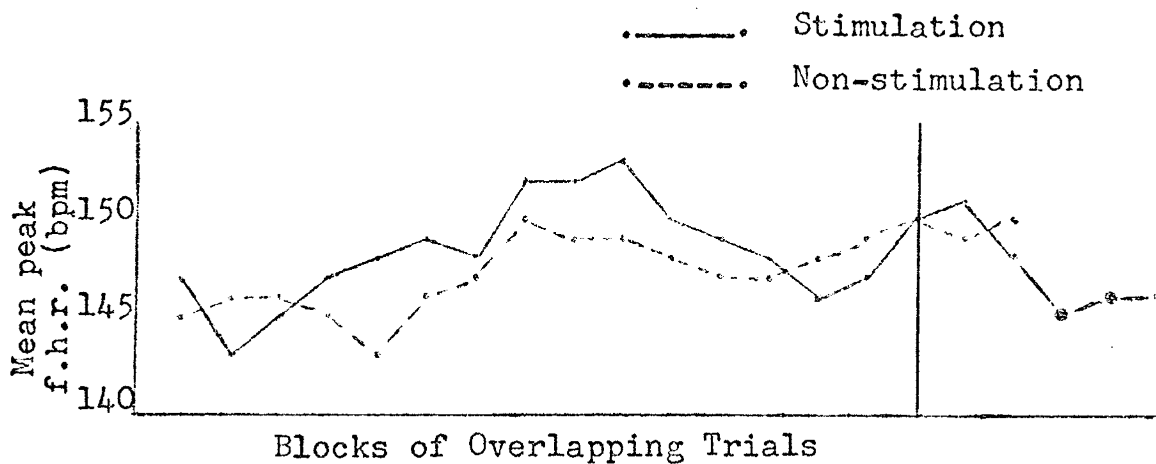

Fig. 12. Moving mean graph of mean peak foetal heart rate of foetus No. 4, S.F. group, H-L condition, during stimulation and non-stimulation periods. The vertical line at the right of the graph cuts off the last three data points in the first period, followed by the first three data points in the second period.

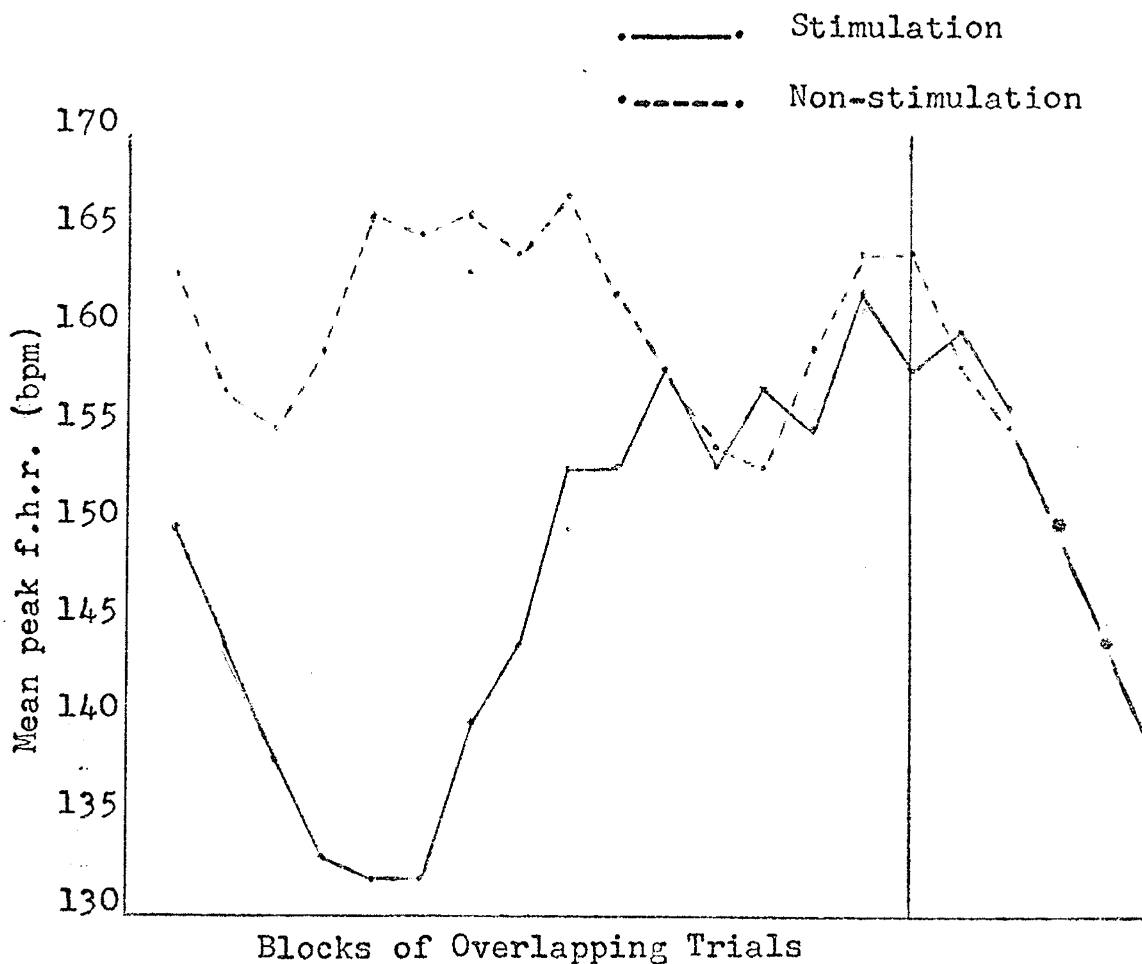

Fig. 13. Moving mean graph of mean peak foetal heart rate of foetus No. 5, S.S. group, L-H condition, during stimulation and non-stimulation periods. The vertical line at the right of the graph cuts off the last three data points in the first period, followed by the first three data points in the second period.

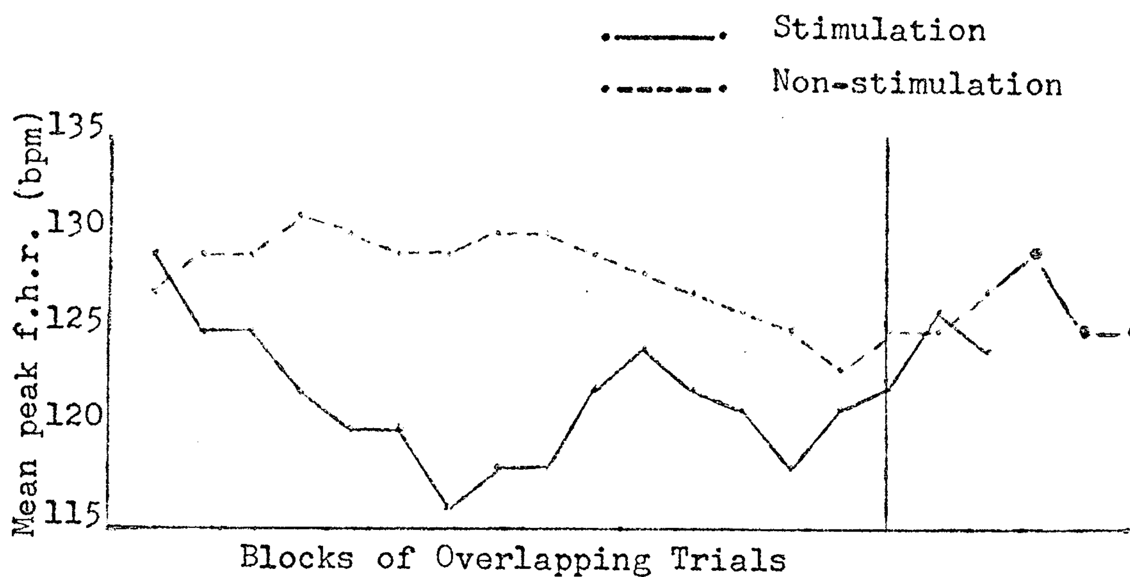

Fig. 14. Moving mean graph of mean peak foetal heart rate of foetus No. 6, S.S. group, L-H condition, during stimulation and non-stimulation periods. The vertical line at the right of the graph cuts off the last three data points in the first period, followed by the first three data points in the second period.

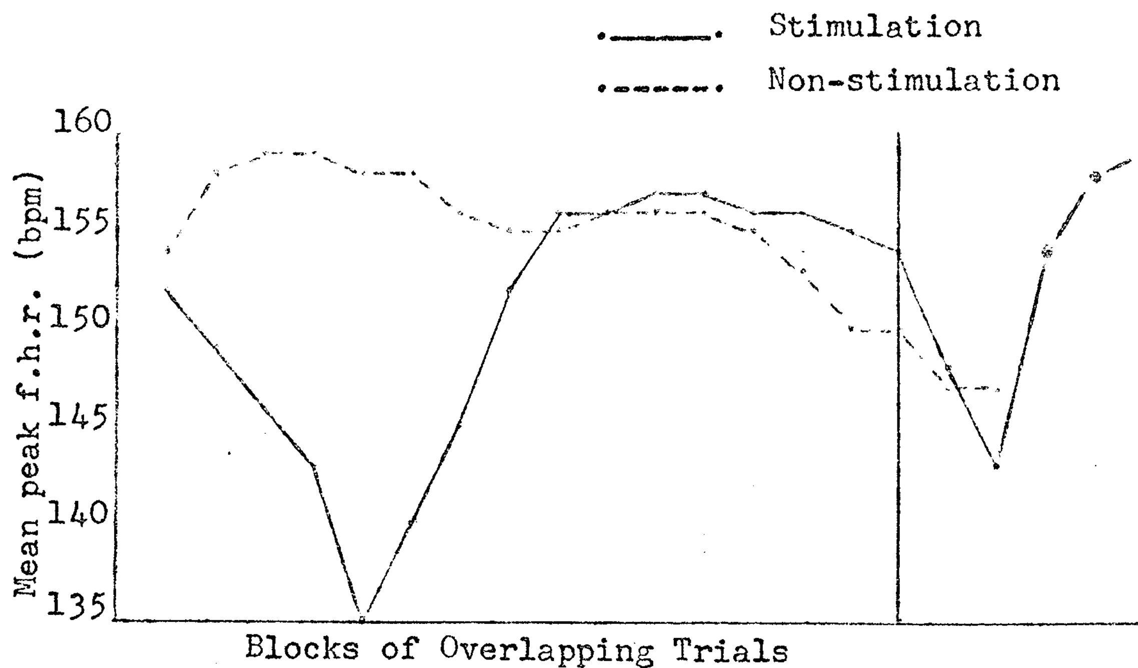

Fig. 15. Moving mean graph of mean peak foetal heart rate of foetus No. 7, S.F. group, H-L condition, during stimulation and non-stimulation periods. The vertical line at the right of the graph cuts off the last three data points in the first period, followed by the first three data points in the second period.

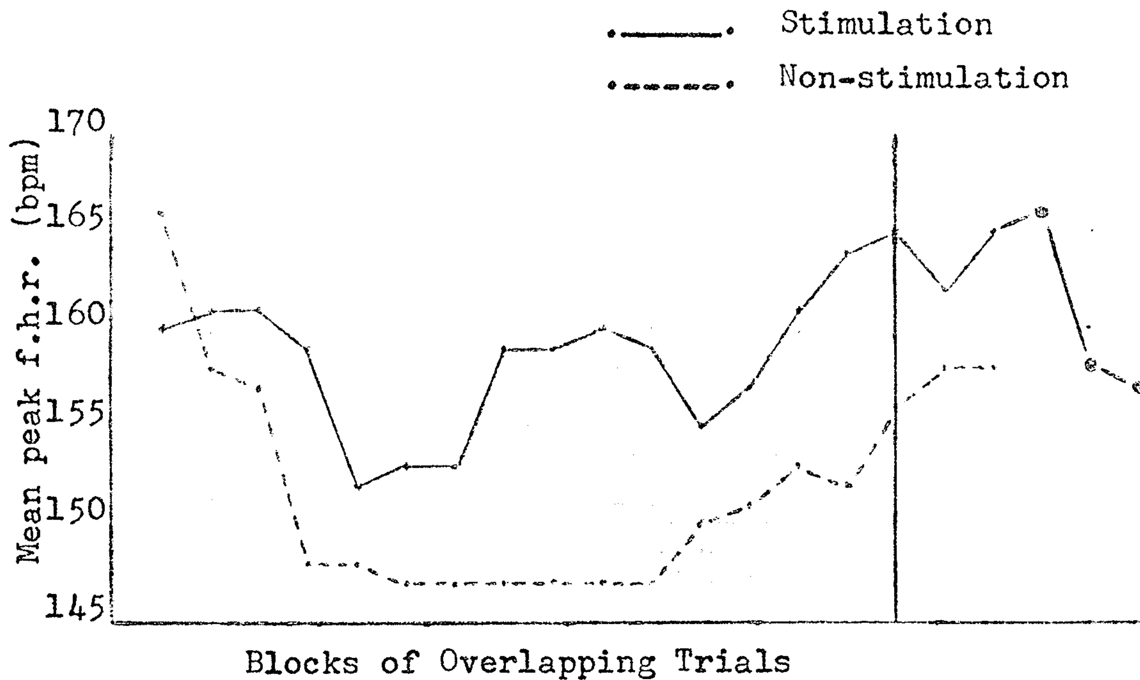

Fig. 16. Moving mean graph of mean peak foetal heart rate of foetus No. 8, S.F. group, L-H condition, during stimulation and non-stimulation periods. The vertical line at the right of the graph cuts off the last three data points in the first period, followed by the first three data points in the second period.

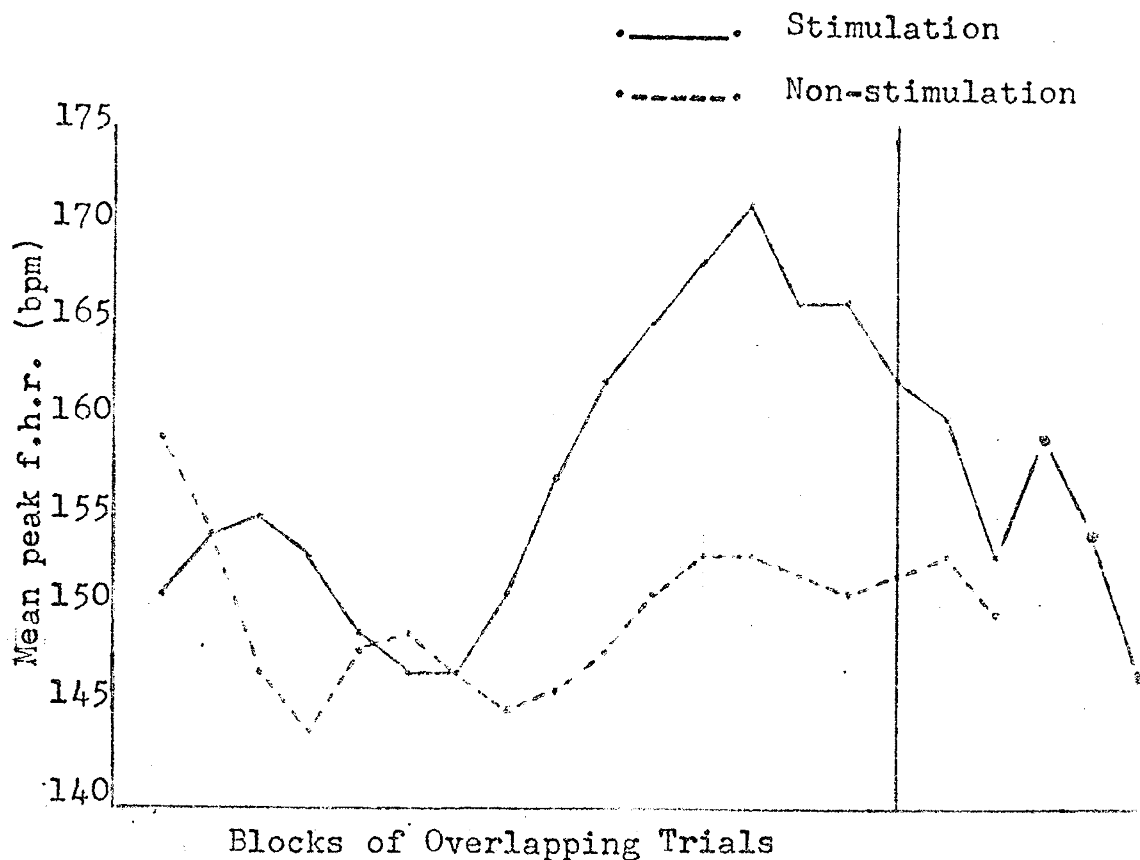

Fig. 17. Moving mean graph of mean peak foetal heart rate of foetus No. 9, S.F. group, H-L condition, during stimulation and non-stimulation periods. The vertical line at the right of the graph cuts off the last three data points in the first period, followed by the first three data points in the second period.

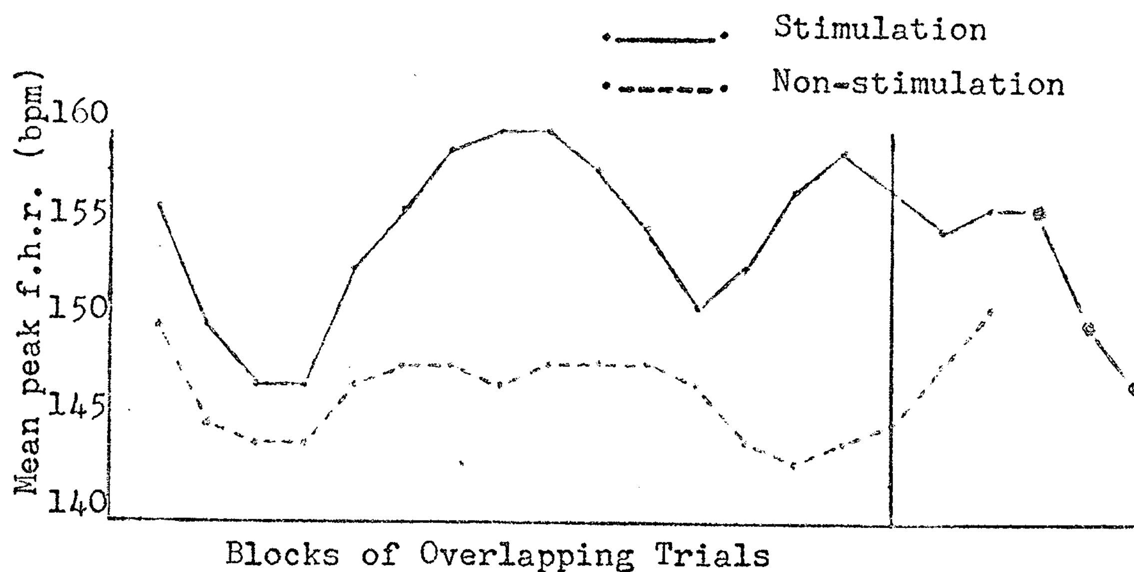

Fig. 18. Moving mean graph of mean peak foetal heart rate of foetus No. 10, S.S. group, H-L condition, during stimulation and non-stimulation periods. The vertical line at the right of the graph cuts off the last three data points in the first period, followed by the first three data points in the second period.

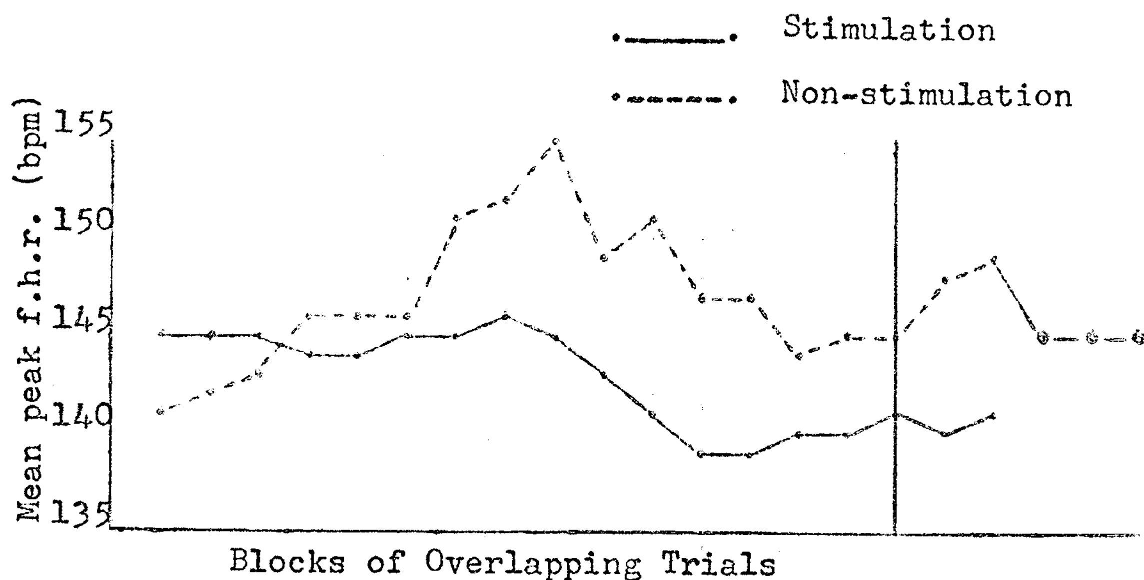

Fig. 19. Moving mean graph of mean peak foetal heart rate of foetus No. 11, S.S. group, H-L condition, during stimulation and non-stimulation periods. The vertical line at the right of the graph cuts off the last three data points in the first period, followed by the first three data points in the second period.

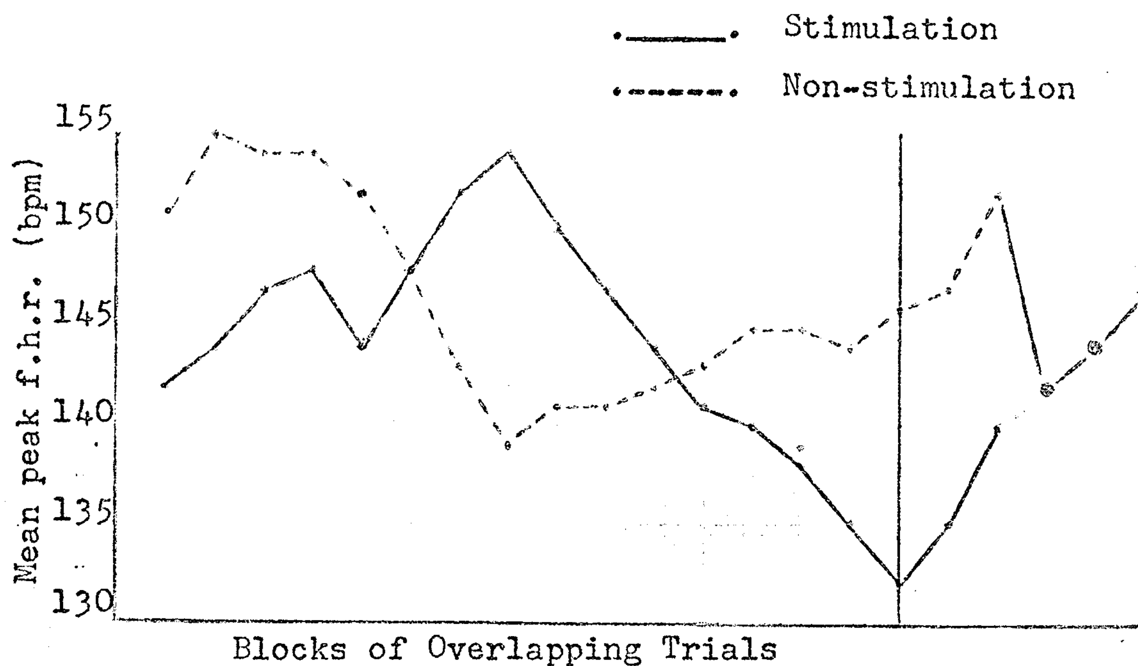

Fig. 20. Moving mean graph of mean peak foetal heart rate of foetus No. 12, S.S. group, H-L condition, during stimulation and non-stimulation periods. The vertical line at the right of the graph cuts off the last three data points in the first period, followed by the first three data points in the second period.

DISCUSSION

Cardiac Responsivity to Sound

The results of the quantitative analysis of the data indicated that external sound had no effect on cardiac responding. The moving mean pattern during stimulation for all subjects was characterized by a fall and subsequent rise in mean peak f.h.r. This pattern differed from the pattern during non-stimulation, which was more regular. However, the pattern illustrated during stimulation was also observed during periods 1 and 2 for all subjects and during both stimulation and non-stimulation periods for several individual foetuses, e.g., Figures 5 and 10. The pattern in question, therefore, did not seem to be related to the sound.

Not only was there no significant difference in mean peak f.h.r. and mean variability in the periods of stimulation and non-stimulation, there was no significant difference in average responding between matched control (non-stimulation) trials in these two groups.

There was no significant difference in cardiac behavior between the foetuses in the H-L condition and in the L-H condition during the periods of stimulation and non-stimulation. There was no significant difference in mean peak f.h.r. when levels of stimulation were changed.

The S.F. group showed a tendency towards a slight increase followed by a decrease in mean p.h.r. when the stimulation period ended. The S.S. group tended on the average to show a decrease when stimulation began. Goodlin and Schmidt (1972) stated that the initial cardiac response to sound was often an initial deceleration followed by an acceleration, with repeated stimuli. However, they did not provide evidence to substantiate their findings. An examination of the responding of the individual foetuses indicated that the directionality of change did not seem to be related to any condition. Moreover, the initial average decrease by the S.S. group does not meet the requirements of an orienting response to a novel situation, since there was no evidence for a corresponding average decrease in the S.F. group when the stimulation ceased (Graham and Clifton, 1966).

The quantitative finding which indicated a trials effect on mean peak hr. was consistent with the moving mean patterns observed in the first and second periods for all foetuses. Mean peak f.h.r. was higher in period 1. The effect of trials on mean variability was not illustrated by the moving mean in this study. The moving mean could be adapted for this purpose for further research.

The significantly different responding of the L-H foetuses in period 1 compared with period 2 could be due to variables that were not controlled. While assignment to conditions was random, the E.M.'s of two foetuses in the

H-L group were receiving valium for medical reasons. Valium is a tranquilizing drug which passes through the placenta and stabilizes foetal cardiac activity (Goodlin and Schmidt, 1972). Also, included in the L-H group was the foetus of the one E.M. who described herself as "tense" and "uncomfortable." It should be noted, however, that while such variables may have affected foetal cardiac responding differentially in period 1 and period 2, the effect did not appear when the stimulation period was compared with the non-stimulation period, across subjects, due to the counterbalanced research design, i.e., the foetuses in question were distributed differently with regard to placement in the S.F. and S.S. groups.

The Question of State

Findings indicated that the pre-experimental state of cardiac excitation was reflected in cardiac behavior during the stimulation period. Stabile foetuses had the lowest mean peak hr., moderate foetuses the next lowest, and labile foetuses responded with the highest mean peak f.h.r. The effect on mean variability was not as apparent. State in relation to heart rate variability has not been studied to any extent. Further research is required to assess a possible relation.

Neonatal research, previously cited, has demonstrated a relationship between state and heart rate, particularly with regard to the operation of the law of initial value (LIV). The results of this study do not provide evidence

for LIV. If LIV were in effect and if subjects had responded to the external stimulation, then stabile subjects would have shown high reactivity, and labile subjects low reactivity. LIV has been shown to hold in the case of a general arousal or startle response (Bridger, 1971). This response can occur when stimulation is moderate. Such a response does not seem to have occurred. Rather, findings point to the possibility of early activation patterns within the autonomic system. Evidence for this is shown in the moving mean illustrations of such patterns. The foetuses would have to be observed over several weeks and after birth in order to assess the stability of such patterns.

Effect of Maternal State on Cardiac Activity

There appeared to be almost no relationship between maternal and foetal cardiac activity. However, maternal measures were not based on a large sampling nor on continuous recording as were the foetal measures, so that the finding only suggests that foetal cardiac behavior was independent of that of the E.M.'s. This supports the finding of Welford et al (1967), whose comparative measurements were based on continuous recording of cardiac activity of both E.M.'s and foetuses.

However, the finding that mean peak f.h.r. appeared to decrease and mean variability to increase over trials may be partly due to the fact that most of the E.M.'s remained in one position and inactive for over an hour. Several

E.M.'s expressed relief at being able to move and get up at the end of the session. Schmeidler (1941) reported a relation between maternal activity and decrease in foetal activity, followed by an increase, observed over an hour. Maternal inactivity may also affect foetal behavior. The relationship between specific behaviors of the E.M. and of the foetus is an area which requires further research.

The average heart rate of individuals changes considerably with age (Kesson, Haith, and Salapatek, 1970). Therefore, heart rate cannot be used as a measure to compare pre- and post-natal cardiac activity. On the other hand, heart rate variability in adults is relatively stable (Welford et al, 1967). It is not known how early in life heart rate variability stabilizes. If it can be established that such stability occurs at the foetal stage of development, then heart rate variability could become a measure used for pre- and post-natal studies. Escalona (1968) conceptualized a reaction tendency in existence at birth which she regarded as the basic factor leading to developmental change and growth. This reaction tendency would be formed by many behaviors in addition to cardiac activity, all of which would be characteristic of the individual, and expressed post-natally through interaction with environmental conditions. The variables involved in the development of the hypothesized reaction tendency are largely unknown. One variable may be the patterns of activity of the E.M.,as suggested by this study.

Individual Differences

Foetuses were observed once only, with one exception (No. 3 and No. 5 was the same foetus, seen twice). Therefore, discussion of individual differences was confined to their bearing on general questions. To compare one individual with another would require samplings of behavior from several sessions, with gestational age matched. This was beyond the scope of this study.

CONCLUSIONS

While previous investigations have reported a foetal heart rate acceleration to sound, the results of this study pointed to a lack of relationship between sound and foetal cardiac responding. A trend was found towards a decrease in mean peak f.h.r. and an increase in mean variability related to the duration of the session.

The apparent contradiction in the findings may be due to several factors. As previously discussed, the levels of stimulation used were conservative, the design used differed considerably from those employed in earlier studies, and the sample of foetuses studied may not have been representative of a normal population since the E.M.'s were patients in a high risk category. Further research could clarify the importance of these variables.

This study has not demonstrated that the foetus in utero cannot respond to sound. It has questioned the findings of previous investigators, and tested out a design and measures which might be of use for other studies in foetal cardiac activity.

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