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Hush Little Baby…
Operant Learning Methods Using Maternal Singing to Reinforce the Reduction of Fetal Movement

By

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Master of Arts

Psychology

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Operant Learning Methods Using Maternal Singing to Reinforce the Reduction of Fetal Movement

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Abstract

The present study explored adaptive behavior in the human fetus. Despite the importance of adaptive behavior in human development, there remains a paucity of evidence on adaptive behavior in the human fetal organism. This study's overall aim was to develop and explore whether contingencies of reinforcement for motor activity, and attention-holding in the human fetus could be elicited and measured by using maternal singing as a reinforcer. In Experiment 1, the identification of maternal singing as a reinforcer was examined to establish internal validity of operant conditioning experiments. Cumulative record responses from 3 individual participants showed few responses occurring before reinforcement, with an increase in frequency of responses during continuous reinforcement. The increase in Highly Moderated Activity during reinforcement confirmed that a functional relationship exists between maternal singing and fetal movement. Experiment 2 explored how different variable interval schedules of reinforcement affect fetal movement and examined whether fetal operant behaviors are governed by matching law. Herrnstein's equation was fitted to the data obtained for each participant (n=2) using Wilkinson's method. The single-alternative form of matching law accounted for 79% (Highly Moderated Activity) and 84% (Moderated Fetal Activity) of the variance in fetal conditioning of motor inhibition/attention for a 39w GA male. Matching law accounted for 21% (Highly Moderated Activity) and 9% (Moderated Fetal Activity) of variance in fetal conditioning of motor inhibition/attention for a 34w GA female. The magnitude and mean duration of fetal motor activity also differed significantly across various schedules of reinforcement and when compared to baseline conditions. This study suggests that maternal singing could serve as an effective reinforcer in operant conditioning using variable intervals of reinforcement to decrease the magnitude of fetal motor activity, while increasing the duration of moderated fetal movement.

DEDICATED TO

Elianna Iretioluwa Faboyede

“There is no foot too small that it cannot leave an imprint on this world”

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Thank you for teaching me that paper, pencils, rulers and hand calculations still breed innovative scientists; and for helping me understand that closeness with physical raw data creates space for novel ideas.

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To my family, and friends who I consider family – thank you for allowing me time away from you to research and write. I plan to make up for all the lost time…whether you like it or not!

I would like to thank my parents, William and Olubukola Faboyede, whose love and guidance are with me in whatever I pursue.

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INTRODUCTION

Before you were even aware that you needed air upon being born, you practiced the motion of breathing, filling your lungs with amniotic fluid and moving your diaphragm up and down. You practiced sucking as well, which prepared you to feed after birth. In fact, in choosing the thumb you sucked prenatally, you may have also chosen your current dominant hand (Peter G Hepper, Wells, & Lynch, 2005). You might not remember this, but the first accomplishment you attained was movement itself. You constantly moved your entire body, and eventually, your mother felt your presence. You felt her presence as well: as you prepared for the world, and she prepared for your birth; you may have felt her anxiety, and stress. In your dim, amniotic cocoon, you somehow found the time to learn the complexities of your mother’s voice (Kisilevsky & Hains, 2011). You learned it so well, that you could tell the difference between her voice and a stranger’s voice(Voegtline, Costigan, Pater, & DiPietro, 2013). As a matter of fact, you were so good at perceiving your mother’s voice, you could tell her voice apart from a recording of her own voice (Voegtline et al., 2013). You were naturally curious, playing and exploring various substances inside the womb. Likewise, you were also curious about events occurring on the other side of that mysterious skin wall. Although muffled, you heard a lot of the world before you even seen it. You also tasted a lot of what the world had to offer and developed a preference for some of the foods your mother ate while you were being carried (Piontelli et al., 2015). And many times, you attempted to interact with the outside world: either moving in response to a multitude of stimuli, or by quietly and calmly paying attention and learning about timing, patterns, and the environment. It was time well spent building the necessary skills for survival and adaptation into a new world you had not yet seen, but was very eager to connect with.

By this time, you may gather that an unborn baby is not just passively waiting to be born while inside the womb. It is well known that during gestation, the fetus develops capabilities which allows for physiologically adaptation to the environment (Amiel-Tison & Pettigrew, 1991; Smotherman & Robinson, 1991). However, the way in which the fetus behaviorally adapts to various sensory stimuli in the environment is poorly understood. Questions still arise pertaining to the underlying processes that promote fetal sensorimotor experiences. Seemingly trivial fetal movements, such as fetal breathing, yawning, REM sleep, and hiccups remain a mystery to researchers. The mechanisms and processes by which certain sensory-driven fetal movements emerge also remain unanswered: what are the underlying processes that initiate fetal thumb-sucking? What are the underlying functions that influence, or impede fetal preferences for maternal voice, olfactory preferences, facial expressions, and other movements involving the development of brain-behavior connections? The concept of adaptive behavior offers an approach to potentially address these questions. Adaptive behavior has played an integral role as the foundation for research in developmental psychopathology (Carver & Scheier, 2012; Rueda, Posner, & Rothbart, 2004). Despite the importance of adaptive behavior in human development, there remains a paucity of evidence on adaptive behavior in the human fetal organism. This is the first study to undertake a behavioral experiment examining adaptive behavior in the human fetus.

SIGNIFICANCE AND AIMS

From a clinical perspective, adaptive behavior can be defined as the collection of conceptual, social, and practical skills learned by people to enable them to function in their everyday lives. Adaptive behavior consists of those skills learned throughout development, becoming increasingly more complex with age, and performed in response to the expectations placed on us from our community and society at large (Wehmeyer, 2013). From a more scientific, falsifiable standpoint, adaptive behavior are behaviors that occasionally produce consequences(Skinner, 1963). Some of the consequences adaptive behavior produces may be positively valued items or events to an organism. Adaptive behavior may also produce consequences that result in escape/avoidance of a threat. The latter definition offers a concrete description, applicable to the fetal organism.

Extensive research from experiments with many vertebrate species, including humans, has provided a detailed understanding of how consequences regulate adaptive behavior(McDowell, 1988). Understanding ways in which adaptive behavior may function before birth could allow researchers and clinicians to better understand many psychopathological disorders that have identified dysfunctional adaptive behavior as its core, defining feature. Operant Conditioning is a reliable and valid method used in measuring adaptive behavior(McDowell, 1988). Extant behavioral studies involving premature newborns have shown potential for operant conditioning in the human fetus since behaviors observed in premature newborns at 32 weeks GA is relatively identical to 32-week-old fetuses. However, major limitations exist for measuring adaptive behavior in the fetus. Observational restrictions, as well as the restriction of intrauterine space, contribute to a limited range of specific behaviors to target that could potentially be conditioned. Although these limitations and challenges remain, the current study introduces methods for eliciting and measuring operant conditioning of fetal behavior.

This study’s overall aim was to develop and implement contingencies of reinforcement for the human fetus and implement an operant conditioning experiment for which fetal motor activity, and attention could be elicited and measured. Maternal singing was tested as a reinforcer to effectively increase durations of fetal movement suppression, for which attentional control is inferred. The specific fetal behaviors targeted were decreased durations of fetal movement, or magnitude of fetal motor activity. Since it is well known that the rate in which behaviors occur are affected by the rate in which reinforcers are presented, we aimed to test various schedules of reinforcement (i.e. various rates of reinforcement). Behavior analysis using well established quantitative models and dimensions of behavior were employed to provide a comprehensive analysis of fetal behaviors during operant conditioning. This approach allowed us to observe empirically supported operant behavioral patterns, specifically Hernstein's Hyperbola, beyond the bounds of formal statistical modeling or hypothesis testing.

If the magnitude of fetal motor activity serves as a valid behavioral measure for examining operant behavior, and maternal singing serves as an effective reinforcer, then the magnitude of fetal motor activity will differ significantly across various schedules of reinforcement. Further, if the proposed contingencies, and schedules of reinforcement are configured appropriately for the human fetus, then a hyperbolic function will be observed (i.e. Herstein's Hyperbola) to describe these fetal behaviors as being governed by matching law.

There are three primary questions this study sought to answer: Is maternal singing an effective reinforcer for fetal behavior? Is human fetal behavior governed by matching law? And could maternal reinforcement promote attention-holding?

AIM 1

The first aim of this study was to establish internal validity of operant learning experiments by evaluating maternal singing as an effective reinforcer for the inhibition of fetal movement. If a functional relationship exists between maternal singing and fetal movement, an experimental manipulation of the maternal singing is expected to strengthen the targeted behavior.

Before proceeding to address the potential for the assessment of adaptive behavior in the human fetus, it is important to consider the process of reinforcement. A reinforcer is a stimulus that follows a behavior. A reinforcer, if effective, should increase the frequency, duration, magnitude, and/or shorter latency of the behavior. It is important to identify a stimulus as an effective reinforcer not only for experimental validity, but also for the purpose of contributing to existing scientific literature on fetal development. Although some research exists on fetal responsiveness to maternal singing, no previous study has confirmed maternal singing as an effective reinforcer that would strengthen specific fetal behaviors. The purpose of experiment 1 was to examine maternal singing as a reinforcer by using a continuous reinforcement schedule to elicit fetal behaviors, and analyzing these behaviors by using cumulative response records.

AIM 2

The second aim was to explore how different variable interval schedules of reinforcement affect fetal movement and verify patterns of behavior that conform to principle laws known to govern the behavior of adaptive organisms (i.e. Matching law as observed by hyperbolic functions). If the human fetus is capable of expressing adaptive behavior, and the proposed contingencies are configured appropriately, then a hyperbolic function will be observed (i.e. Herstein’s Hyperbola) to describe these behaviors as being governed by matching law.

When viewed under naturalistic conditions, it is evident that the human fetus responds to changes within its intrauterine environment. The nature of adaptive behavior allows certain mechanisms that govern behavior at one age to eventually transform, or become replaced by mechanisms that govern behavior later in development. As described above, these behaviors become more complex, and conceptual with age. It is important to understand the emergence of adaptive behavior, and competence to adapt, during fetal development to better understand the more complex behavioral processes observed later in development (Smotherman, & Robinson, 1998). One promising approach in studying adaptive behavior is to directly observe and analyze fetal behavior from a quantitative standpoint by applying the principles of matching law. Extensive literature has shown that human behavior is governed by widely accepted mathematical equations shown to accurately describe individual-subject behavior. In a multitude of studies, these equations have been shown to account for large proportions of variance in individual behavior (Herrnstein, 1979). One purpose of this study was to assess the extent to which fetal behaviors can be described by mathematical functions of matching law.

Matching law describes various quantitative relationships between the rates of behavior and the rates of reinforcement within operant conditioning; therefore, it is important to consider methods for adapting a contingency paradigm for the fetal organism. There are three important factors to consider in adapting a reinforcement contingency paradigm for the human fetus: the stimulus used as an effective reinforcer, behavior(s) that should be targeted to be reinforced, and the employment of the reinforcer (i.e. schedule of reinforcement) that would produce optimal increases of the targeted behavior(s). One general goal for this specific aim is to develop procedural and analytical methods to explore these questions.

AIM 3

The third aim was to explore the extent to which maternal reinforcement promotes longer durations of attention-holding in the fetus.

If the presentation of a repeated stimulus (i.e. Maternal Singing) is placed in appropriate schedules of reinforcement, it will prevent fetal habituation (also referred to as satiation) while promoting increased durations of attention.

In addition to examining adaptive behavior in the fetus, this study is also interested in cognitive features associated with adaptive behavior, specifically, attention. Attention in the fetus is expressed behaviorally as decreased motor activity with a decelerated heart rate response. "Attention-getting" or fetal orienting behaviors are brief responses that can be elicited by presenting a stimulus. Attention-holding, or sustained attention, are prolonged periods of decreased motor activity and decelerated heart rate response.

It is of extreme importance to differentiate between decreased motor activity during attention holding with decreased motor activity associated with fetal distress and pathological risk. Although attention-holding, and signs of fetal distress/risk may both involve decreases in fetal motor activity, the underlying mechanisms are extremely different. Operant conditioning of decreased fetal motor activity using sensory stimuli (i.e. maternal singing), would target mechanisms involved in fetal attention, learning, and adaptive behavior. Attention-holding by using a sensory stimulus is challenging due to habituation; the fetus tends to decrease/cease behavioral responses that occur after repeated presentation of a stimulus. This study aims to avoid fetal habituation the stimulus by employing variable interval schedules of reinforcement. We presume that the unpredictable, and varied presentation of a repeated stimulus would be masked as "novel", thereby preventing the fetus from habituating to the stimulus, and consequently, promoting longer periods of attention-holding.

BACKGROUND AND REVIEW OF LITERATURE

During gestation, the fetus develops in a systematic manner, gradually integrating all physiological and cognitive systems, in preparation to survive the stress of birth and transition into postnatal life. Newborns are born with specific programmed biological processes, reflexes, sensory capabilities and even social behaviors (e.g. smiling, facial expressions). Many of these systems are automatic, such as digestion and blood flow. Some functions are reflexive and occur only when stimulated (e.g. sucking). Some other mechanisms involve intentionality and goal directed behaviors (e.g. thumb sucking). Furthermore, other processes fit into more than one category (e.g. crying), highlighting the complexities involved in studying fetal behavior. The following section gives a brief overview of fetal movement, prenatal sensorimotor experiences, and cognitive processes inferred from fetal motor activity.

The Mechanics of Fetal Movement in Normal Fetal Development

Historically, the term "fetal movement" also referred to as "fetal motor activity" has been used to describe sequences of movement involving the whole fetal body. It is important to note that the term "fetal movement" embodies a multitude of motor activities which have separate terms, and even slightly confusing meanings. This section reviews basic mechanics of fetal movement as it pertains to the present study. The present study will be using the term "fetal movement" and "fetal motor activity" to refer to the general activity the fetus displays across gestation which include: general fetal movement (FGM, GM); localized or isolated movements; fetal breathing movements; swallowing, sucking, and mouthing movements; startles, twitches and clonuses; and facial motions and expressions. Appendix A provides an illustration, outlining these terms and the organization of fetal behavior.

The onset of fetal movement sequences, referred to as ‘events’, occur periodically as bursts that vary in intensity, force and speed. The sequence of fetal movements could involve various patterns and parts of the fetal body. Fetal movement events may last from a few seconds to a minute, varying qualitatively and quantitatively across gestation. Fetal Movement was once thought to be reflexive in nature; however, it is now well established from a variety of studies that fetal motor activity is not only generated within the spinal cord, but subdivisions of the brainstem which regulate most forms of fetal movement until the last weeks of pregnancy (Piontelli, 2015).

General movement is amongst the first types of movement to occur, emerging right at the beginning of fetal development (7-7.5 weeks) and lasting through gestation and into postnatal life. Although this outwardly simple form of movement appears during the very beginning stages of fetal development, it is the most frequent and complex form of movement, and is the most used clinical tool to assess risks for mortality and birth defects (Hadders-Algra, 2004). Contrary to popular belief, fetal movement does not decrease towards the end of gestation, however, the types of movement do change. Towards the end of gestation, there are decreases in general movement and increases in other types of movement, such as localized and isolated movements. These movements may be perceived to feel different by mothers, and some interpret these differences as a decrease in fetal movement overall.

There are various theories that attempt to explain possible causes for changes in fetal movement throughout pregnancy. One possible explanation for these changes recognizes that movements physically restricted by the uterine environment later in term, leading to more inhibition of general movement (Piontelli, 2015). Since general movement promotes physical growth earlier in gestation (e.g. bone and tissue formation.), it is necessary to have ample amounts of general movement during a period where the uterine environment is not physically restricting. Later in gestation, after most of the physical growth occurs, rigorous movements may no longer be the vital focus in preparation for extrauterine life. Instead, finer, isolated movements that elicit sensory experiences (e.g. grasping) emerge. Another explanation considers the brain's maturation and inhibitory responses in preparation for extrauterine life (Piontelli, 2015). Towards the end of term, various cognitive processes emerge, and similarly to 1st and 2nd trimester, movements must be executed to promote development in this area. In addition, neural substrates change in the third trimester, thus driving fetal movement from being regulated purely by spinal control to becoming regulated by the brainstem, and cerebrum. This shift in fetal movement and the emergence of cerebral regulation may cause behavioral inhibition.

Collectively, it appears that fetal movement has unique relationships with physical and cognitive mechanisms depending on the gestational period. Furthermore, changes in movement towards the end of gestation may not only be due to the lack of space, but also an increase in central inhibitory control (Piontelli, 2006). It appears that previous studies have attempted to define and categorize fetal movement by "behavioral state", which mainly considers arousal and sleep. Although behavioral state and state change are considered in the methodology of the current experiments, this study focuses on the magnitude that fetal movements collectively produce. More specifically, we categorized fetal movement into four categories by varying magnitudes. Specific technical and conceptual definitions for each category are described in the methodological approach of the next sections.

Fetal Behaviors within Sensory Driven Contingencies

Fetal movement should be considered as more than simple sequences of movement. Fetal movement should be viewed as sensorimotor events which elicit proprioceptive and vestibular sensations. The fetus uses information it receives through sensory mechanisms (sensory feedback), and performs what Piontelli refers to as “corrective input”. The fetus may need to adjust its behavior (through trial and error of various sequences) and perform general movement sequences to receive stimulation for neural, physical, and regulatory functioning in preparation for postnatal life. This theory of sensory-feedback in the fetal organism offers a convincing explanation for the changes seen in fetal movement across gestation. Sensory-feedback systems and corrective input could also indicate the emergence of adaptive competencies involved in the adjustment of behaviors produced by the fetus towards the final weeks of gestation. Similarly, Delafield-Butt (2013) proposed a theory of sensorimotor intentionality which describes fetal movements being guided by anticipation, with even the most simplistic events being actions of intent. Evidence from several studies supports these theories as well. Anticipatory movements, such as opening the mouth as the hand approaches, was observed in one study using 4D Ultrasound imaging on fetuses from 24 weeks to term (Reissland, N., Francis, B., Aydin, E., Mason, J., & Schaal, B., 2014). This study (Reissland, 2014) also found that this anticipatory movement increased with gestational age. Brumley’s (2013) findings also suggest that movement-related feedback modulate spontaneous motor activity in newborn rats, suggesting a role for proprioception during motor development. It appears that fetal movement facilitates and drives the development of sensory capabilities through a series of learning experiences. Sensory experiences could be viewed as naturally occuring reinforcers within the uterine environment. These experiences are important for cognitive growth and are especially gratifying. These sensory experiences may also include tactile and auditory stimulation which could be provided by maternal voice/singing. Consequently, Fetal activity, through trial and error, may cause these sensory reinforcers to occur more often. Therefore, “intrauterine contingencies” may already be at play. Evidently, there is indication of a contingent relationship between operant-like fetal behaviors (e.g. thumb sucking) and the intrauterine environment. However, no scientific evidence of contingent relationships between fetal behavior/movement and the extrauterine environment. This study aims to create an extrauterine contingency in order to examine the possible existence of a governing relationship between fetal behaviors and maternal stimuli.

Operant Conditioning in the Developing Organism

When viewed under naturalistic conditions, it is evident that the human fetus responds to changes within its intrauterine environment. Certain events, or features within the fetal environment (which includes sensory input from the extrauterine environment), appears to influence organized behavior, and movement. Other events, or features within the fetal environment appear to constrain, inhibit behavior, or the production of movement (Robinson & Smotherman, 1990). It appears that the fetus, under naturalistic conditions, may be developing and expressing adaptive behaviors.

Although no single study has been published using operant conditioning of human fetal behavior, studies over the past half century have provided important information about operant behavior, and ‘exposure’ learning (i.e. classical conditioning) early in life. Both animal models and newborn/infant studies provide sufficient evidence for the capacity to learn associations between behaviors and the consequences they produce.

Animal studies of fetal behavior and various forms of experimentation, give us fundamental information and essential understandings into fetal behavior. Operant conditioning tasks are generally used in animal models to study the effects of drugs, or other conditions hypothesized to affect aspects of learning. Researchers have also studied physiological responses associated with learning an operant conditioning task. For example, Coe and colleague’s study (1983), investigating rats’ adrenal responses during operant conditioning tasks, found differences in adrenal secretion between reinforcement sessions (which caused a decrease) and extinction (which caused rapid increases in corticosterone). Furthermore, they found differences across subjects showing that this difference in adrenal response to reinforcement and extinction was not dependent on the responses/behaviors themselves, but rather on the withdrawal of the expected reward. These studies provide evidence of the physiological foundations associated with the expectancy of consequences from learned behavior early in development. In general, animal models of fetal behavior offer evidence of prenatal adaptive behaviors, as well as the continuity of these learned behaviors into postnatal life. These models provide evidence of learned motor patterns (Robinson, 2008), and capacity to maintain a “behavioral trace” for important stimuli (Varlinskaya, 1997).

Although evidence of instrumental learning in the human fetus is unsupported, the earliest observations of associational learning in the human fetus has been exhibited at 32 weeks of gestation. The first accounts of fetal conditioning were published in 1932 by Wilbert Ray, and in 1948 by David K. Spelt. Ray reported to have classically conditioned one human fetus by pairing a loud noise (UCS) with vibratory stimulus (CS). Similarly, Spelt (1948) found that 15-20 paired stimulations between a vibrotactile (CS) and a loud noise (US) were required to establish a conditioned response in the human fetus during the last two months of gestation. This study was later replicated by Peter G. Hepper using pure tones (CS) and a vibro-acoutic stimulus (UCS) on fetuses between 32 and 39 weeks of gestation (Hepper, 1996). He found that half the fetuses exhibited conditioned responses after 10-20 trials. In attempts to understand why some fetuses exhibited conditioned responses, it is important to first consider the experimental methodology itself. Factors such as poor experimental paradigms, inappropriate stimuli, or response measures could have contributed to low rates of conditioning. In 1975, Feihoo classically conditioned near term human fetuses by pairing maternal relaxation (UCS) with music (CS) and recorded responses before and after birth. This study found that only after 24 pairings of music (CS) caused increased fetal movement, decreased crying, and fewer clonic movements in newborns who were conditioned as fetuses (Feihoo, 1975, 1981). This study not only indicates prenatal learning capacities, but also continuity of cognitive processes after birth.

Up to now, a multitude of studies have successfully adapted operant and classical conditioning paradigms during infant development. What is more compelling, and relevant to the present study, are the findings from studies using operant conditioning amongst pre-term human neonates. Since premature neonates and 32w (GA) fetuses are behaviorally similar, studies using operant conditioning methods on pre-term neonates offer valuable insight into possible fetal capabilities for operant conditioning. Current research has focused on integrating operant conditioning principles with early interventions in neonatal intensive care units in several hospitals. By developing a medical device to promote the development of sucking behaviors, researchers have conditioned neonatal sucking, thereby improving the quality of premature newborns' nourishment. This medical device uses maternal voice, and music as reinforcers to modulate the frequency and intensity of sucking (Chorna, 2014, Cevasco, 2005, Standley, J. M., 2003). This intervention provides some evidence that these operant behaviors may exist before birth. Furthermore, research in this area offers support for clinical utility of operant learning paradigms earlier in life.

Matching Law offers accurate mathematical descriptions in approaching adaptive behavior, by utilizing operant conditioning methods to analyze behavior. Matching law involves mathematical statements describing adaptive behavior in environments that continuously afford opportunities for choice (McDowell, 2013). Extensive literature has shown that human behavior is governed by widely accepted mathematical equations shown to accurately describe individual-subject behavior. In a multitude of studies, these equations have been shown to account for large proportions of variance in individual behavior (Herrnstein, 1979). This study involves utilizing operant conditioning methods to elicit fetal behaviors while utilizing these mathematical statements to analyze, describe and interpret fetal behaviors.

Cognitive Processes Inferred by Operant Behaviors

Learning theorists, who have debated over the theoretical differences concerning the level of cognition involved in operant conditioning, have moved toward a more synthesized theory providing roles for both cognitive and automatic processes (Kirsch, Lynn, Vigorito, & Miller, 2004). The agent's ability to adapt its behaviors to receive stimuli is mediated by cognitive functions such as sensorimotor control, intentionality, attention, and expectancy. Operant conditioning during early infant development has been longstanding in the literature, with experiments of choice and reward in 6 month old infants being first reported by Myer in 1908 (Myers, 1908). Since then, there have been discussions regarding the implications of using operant conditioning for clinical interventions in early development (Lancioni, 1980).

There is growing support for the claim that operant conditioning could induce and enhance the development of activity-driven neural mechanisms in the human fetus. Operant learning is known to modulate the survival of new neurons (Mandairon, Sultan, Nouvian, Sacquet, & Didier, 2011) as well as increase dendritic branching and the numerical spine densities of CA3 pyramidal neurons of the hippocampus(Mahajan & Desiraju, 1988). Results from an animal study evaluated cell proliferation, neurogenesis, astrogliogenesis, survival and neuronal maturation in the medial prefrontal cortex (mPFC) and the hippocampus (HIPP) while learning an operant conditioning task (Rapanelli, Frick, & Zanutto, 2011). The results of this study showed for the first time that learning a reward-dependent task (i.e. operant conditioning) promotes neurogenesis, astrogliogenesis, survival and neuronal maturation, depending on the learning phase in the mPFC-HIPP circuit

(Rapanelli et al., 2011). The available evidence indicates that there are biological correlates associated with operant conditioning and the process of operant learning could lead to a change in the neural underpinnings associated with cognitive constructs such as attention, expectancy, and inhibition.

METHODOLOGICAL APPROACH

Participants

This study was reviewed and granted approval by the Institutional Review Board at Emory University, Atlanta, Georgia. Participation in this study was voluntary.

Participants in both experiments included pregnant women (n=9) between the ages of 22-25 years old with gestational ages between 24 and 39 weeks (1 female, 7 males). Case study data from 3 participants are included in Experiment 1 using continuous reinforcement; and 2 participants in Experiment 2 using variable interval reinforcement schedules. Data from 4 participants were not included in the analysis due to: Behavioral state change: active sleep (n=1); self-reported exposure to illicit drugs (n=1); and maternal discrepancy between perception and fetal movement data (n=2). All mothers in this study were volunteers and were recruited from a Vocational Training Program at Stinson and Associates, Decatur, Georgia. Demographic data were collected and are included in the Appendix C.

Materials

Toitu MT-516 fetal monitors (Actocardiogram) were used to directly measure fetal motor activity via single wide array Doppler transducer positioned on the mother’s abdomen. Although this monitor generates both fetal heart rate and body movement, this study focused on analyzing fetal body movement output alone. Fetal movement, detected by ultrasound, was recorded and displayed as spike shape waveforms or dot marks corresponding to the movements detected. In addition, a remote marker switch was used to mark events (e.g. maternal perception, delivery of reinforcer). All detected information was transmitted to the main unit where the signals were processed and printed out on the recording chart paper (example below). Printed waveforms were then measured by hand using an electronic caliper, and entered into Excel and SPSS databases for further analysis. The validity of this brand of monitor to accurately detect fetal motor activity has been well documented, with identification of 91 to 95% of all ultrasound-visualized movements whether agreement is based on time intervals or individual movements, and is equally reliable in detecting periods of quiescence (Besinger & Johnson, 1989; DiPietro, Costigan, & Pressman, 1999; Maeda, Tatsumura, & Nakajima, 1991; Maeda, Tatsumura, & Utsu, 1999; Ohta, 1985). Most movements undetected by the actograph are small, isolated movements of extremities; virtually all (97–98%) trunk and sustained (> 1 s) movements are detected; conversely, the actograph can detect those movements that occur beyond the ultrasound field. Three movement measures were computed from the digitized actograph data and are detailed later in this section.

Design and Procedures

The study was explained to a group of potential participants and voluntary participation was accepted. Each mother was monitored in a supine position with a slight lateral incline. Each participant completed one visit which occurred between 9 AM and 1 PM and lasted between 10 minutes to 1 hour. After placement of the transducer, and location of the fetus, each participant completed a baseline condition prior to their respective experiment. On average, baseline measures lasted for 8 minutes. During this time, participants were instructed to press the event marker when decreased motor activity was perceived. This data was used to verify maternal accordance between perception of activity and waveform data of fetal activity. Following experimental conditions, a second baseline condition was completed when possible.

As discussed in the previous sections, reinforcement is the key element in operant conditioning and strengthens behaviors if followed closely in time by a stimulus. This should result in an increase the probability that future behaviors would occur. If a stimulus increases the future frequency of that behavior, it is known as a positive reinforcer. Maternal singing was used across all experiments as a stimulus and possible reinforcer. Maternal singing was scheduled to follow fetal reduction of motor activity (i.e. targeted response) according to a schedule of reinforcement. These schedules of reinforcement were used to determine when the targeted response will be followed by the reinforcer (i.e. maternal singing).

Schedules of Reinforcement

The current study piloted two different schedules: continuous reinforcement (CRF) and variable intervals (VI).

CRF schedules are considered simple schedules in which every occurrence of the desired response is followed by the reinforcer. Mothers who participated in this experiment were asked to sing when they perceived the desired response (i.e. decreased fetal movement) and continued singing until fetal activity increased. This schedule was specifically chosen for this study with the purpose of examining the effectiveness maternal vocalization in establishing an association between targeted behaviors and reinforcement. A cumulative record could then be used to assess the slope of cumulative observed behaviors. If maternal singing is truly a reinforcer, then the slope of observed cumulative responses should also increase.

VI schedules are intermittent schedules reinforcers follow the desired behavior, but only after an interval of time. For the present study, 100 time intervals were randomly arranged across schedules per the procedure used by Flessinger and Hoffman (1962) and Bradshaw method (Bradshaw, Szabadi, & Bevan, 1976). There were 20 intervals per schedule, varying around a predetermined mean set for each schedule. There were a variety of reasons why VI schedules were selected for 3rd term fetuses. These are: (1) VI schedules closely resemble ways in which the natural environment controls behavior, which means that the behavior exhibited may also resemble ways in which the fetus adapts to its environment naturally; (2) VI schedules operate under the assumption that the organism may already have steady state behaviors. If these steady state fetal behaviors exist, then VI schedules could be used to direct behaviors towards a new steady state.

Maternal Stimuli

For this study, we were interested in using maternal singing as a stimulus that would occur once the targeted behavior is met. Maternal singing immediately after perceiving the targeted response is one of the more practical ways of employing an efficient contingency; immediacy of a reinforcer strengthens target behaviors. A stimulus can be described by: its physical features (topographically), when it occurs (temporally), and by its effect on behavior (functionally). Topographically, for this study, mothers were given specific instructions. Mothers were asked to sing the first one or two verses of “Mary had a Little Lamb” aloud. They were instructed to sing at the same volume each time, and at a level that is typical for them. For training, prior to baseline, mothers were provided with an audio model of the song (via headphones). In addition, changes in tone, pitch, and volume were identified. With regards to temporal descriptions of maternal singing, schedules of reinforcement were selected to control the times that singing could occur. Regarding function, extant literature provides a considerable amount of evidence displaying the effects of maternal vocalization on fetal behavior and neurological function (DeCasper, Lecanuet, Busnel, Granier-Deferre, & Maugeais, 1994; Peter G. Hepper, Scott, & Shahidullah, 1993; Peter G. Hepper & Shahidullah, 1994). More specifically, fetal motor activity tends to decrease during maternal vocalization. This study is particularly interested in the temporal extent of decreased behavior, inferring cognitive and attentional control.

Although there are benefits in using maternal singing as a stimulus, there are some drawbacks associated with relying on maternal perception as one of the leading determinants for stimulus delivery. Previous research findings into the accuracy of maternal perception of fetal movement have been inconsistent and contradictory(Brown, Higgins, Johnstone, Wijekoon, & Heazell, 2016; DiPietro, Costigan, & Pressman, 1999; Hantoushzadeh, Sheikh, Shariat, & Farahani, 2015; Hertogs, Roberts, Cooper, Griffin, & Campbell, 1979; Johnson, Jordan, & Paine, 1990). This study used several methods to decrease the possibility of maternal error during the experiment. During the baseline, the experimenter verified maternal accuracy by comparing event marks (pushed by the participant) with waveform data of motor activity. In addition, prior to starting baseline, the experimenter engaged the participant in a short “Fetal Feedback Training”. During this training, the experimenter familiarized the participant with the printed waveform data and then guided participant observation of fetal waveforms in comparison with perceptual awareness of movement. Further, body position is associated with decreased awareness of fetal movement(Brown et al., 2016), participants sat in a reclining chair, at a slight incline. Finally, during analysis, women were excluded if event markers and/or stimuli were discrepant with targeted fetal behavior (excluded if %error >10%).

Measurement and Analysis

Specific forms of behavior are referred to as topography. Since the current study is limited to having information only on the magnitude (i.e. analog waveform) of fetal motility, four categories were predetermined for the classification of fetal movement by magnitude. Each level of magnitude was specified as events and the duration of each event was measured, by hand, in millimeters using a digital caliper which was then converted into seconds. The fetal ACG signals were transmitted into arbitrary units (a.u.s.) ranging from 0 to 100. The figure below is an illustration of a fetal strip with analog waveforms overlayed by the 4 predetermined categories. For this study, fetal behavior may be broken down into two main classes: Intensified Fetal Activity (IFA) and Moderated Fetal Activity (MFA). IFA behaviors consisted of waveforms that fell between 50 to 100 a.u.s., and MFA consisted of waveforms that fell below 50 a.u.s.

MFA may be broken down further into two subcategories: Mildly Moderated Fetal Activity (MMA) which included all waveforms between 30 and 50 a.u.s. and Highly Moderated Fetal Activity (HMA) which included waveforms under 30 a.u.s. It is important to note, that although MMA and HMA are subconstructs of MFA, they were measured separately, as opposed to aggregating HMA and MMA to form MFA. This approach was taken since other behavioral dimensions (event duration and frequency count) would be affected, thereby leading to a misinterpretation of the MFA data.

Name of Category	a.u.s. range	Figure
Intensified Fetal Activity (IFA)	**50-100**	**A**
Moderated Fetal Activity (MFA)	**<50**	**B**
Mildly Moderated Fetal Activity (MMA)	**30-50**	**C**
Highly Moderated Fetal Activity (HMA)	**<30**	**D**

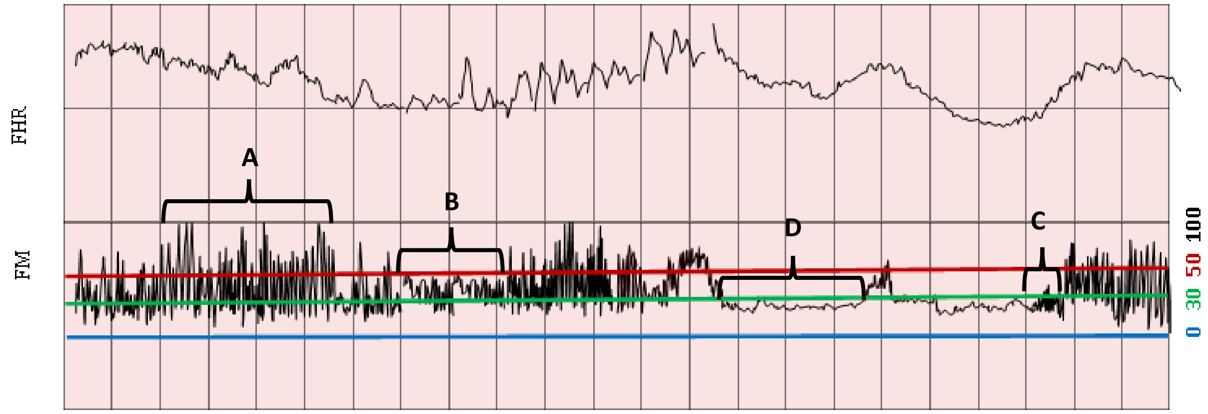


Figure 1: Simulation of Topography of pre-identified behaviors

RESULTS

This study’s overall aim was to develop and implement contingencies of reinforcement for the human fetus and implement an operant conditioning experiment for which fetal motor activity, and attention could be elicited and measured.

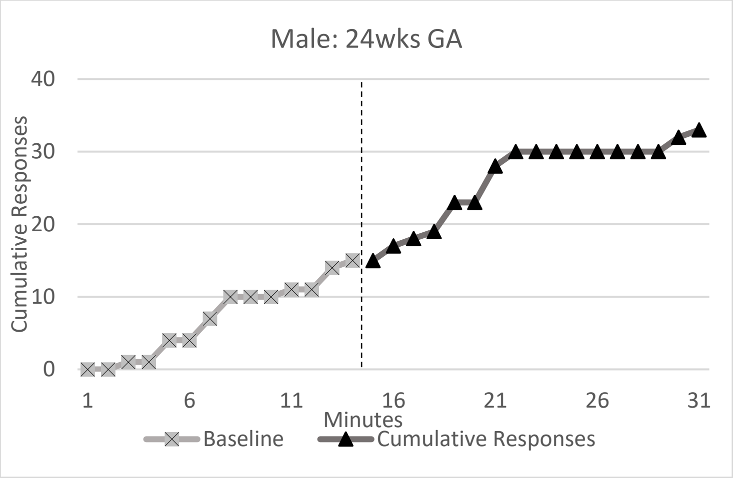
Experiment 1- Continuous Reinforcement Learning

In Experiment 1, the identification of maternal singing as a reinforcer was examined. Our first aim was to establish internal validity of operant learning experiments by evaluating maternal singing as an effective reinforcer. If a functional relationship exists between maternal singing and fetal movement, an experimental manipulation of maternal singing is expected to increase the targeted behavior.

Figure 2 below shows cumulative response records, as well as the minimum and maximum duration spent in Highly Modified Activity (HMA) for 3 male fetuses between 24-28 weeks' gestational age. Cumulative frequency responses are behavioral observations that only consider response class properties of behavior when plotting across time. This is especially useful when observing the number of behavioral events such as pecks, or kicks. The present study, however, is limited to the temporal extent and rate/frequency of movement. Therefore, a method was piloted to adapt cumulative record responses to study fetal movement in a continuous reinforcement paradigm. In other words, we converted each *movement event* into a *response* that could be plotted over time.

The predetermined magnitude for all participants were set to Highly Moderated Activity (HMA). This means that each behavioral event that occurred below 30 a.u.s.were measured. The duration of each behavioral event that occurred during baseline and below this magnitude were measured, and then averaged. The mean duration of HMA that occurred during baseline became the "target" behavior criteria for *one* response. In other words, in order to count the movement *event* towards the cumulative frequency response, the fetus is required to spend a duration of time in set "target" requirement. For instance, figure 2d displays a 28w GA male whose target behavior criteria is 16 seconds (mean of HMA during baseline). During continuous reinforcement, he must stay in HMA for a duration >=16 seconds in order for that event to count as one response. If the event lasted for 30 seconds, the event would be plotted as one response. If an event lasted for 36 seconds, that event would be plotted as 2 responses.

In all records, maternal singing continued until fetal movement was perceived. Mothers were told to sing after they perceived their baby to be quiet/alert. The experiment ended after 30 reinforcers, or 20 minutes lapsed. The cumulative record responses from each of the participants show a few responses occurring before reinforcement, with an increase in frequency of responses during continuous reinforcement. Figure 2d also shows slight differences in the minimum and maximum duration of events between baseline and continuous learning, with continuous reinforcement having the longest durations of highly moderated fetal activity. Although the 24w GA male's behavior did not increase between 23-28minutes, he spent longer durations of time in HMA during continuous reinforcement.



Part	***Target*** ***(Avg. Baseline)***	***B Min***	***B Max***	***CR Min***	***CR Max***
28w	16	0	27	11	31
25w	12.5	0	33	0	35
24w	10	0	15	0	43

Fig. 2. Cumulative records for three fetal participants ages 24-28wks gestation.

Fig. 2d. Minimum (min) and Maximum (max) durations of behavioral events, in seconds, occurring at Baseline (BMin, BMax) and during Continuous Reinforcement (CRMin, CRMax). The Target criterion (in seconds) for each fetus was determined by the mean duration of HMA events during baseline.

Experiment 2: Variable Interval Schedules of Reinforcement in 3rd Trimester Fetuses

Experiment 2 explored how different variable interval schedules of reinforcement affect fetal movement and examined whether fetal operant behaviors can be described as hyperbolic, following Matching law. Conceptually, if the fetus exhibits adaptive behavior, it should follow similar behavioral patterns of organisms that also exhibit adaptive behavior. Ideally, the fetus should produce rates of behaviors, that when plotted against maternal rates of reinforcement, demonstrates a hyperbolic pattern. To test for these relationships, the present study utilizes methodology and experiments similar to that of Beardsley and McDowell (1992), which studied durations (time allocation) of human behavior in natural environments. Experiment 1 assessed the degree to which 2nd trimester fetal behaviors changed across a continuous reinforcement schedule using maternal singing as a reinforcer. Based on the results of experiment 1, confirming the effectiveness of maternal singing as a reinforcer, Experiment 2 proceeded to further assess patterns of behaviors produced by 3rd trimester fetuses on a variable interval schedule of reinforcement which also used maternal singing as a reinforcer. If the human fetus is capable of expressing adaptive behavior, and the proposed contingencies are configured appropriately, we would expect the plotted data to follow a hyperbolic function

One male fetus (39wks), who will be referred to as Elbert Cox, and one female fetus (34wks) who will be referred to as Katharine Johnson, were included in this study. Elbert Cox was given five variable interval schedules, containing 20 intervals in each schedule (2s, 7s, 15s, 30s, and 60s). Katharine Johnson was given four variable interval schedules (2s, 7s, 15s, and 30s), containing 20 intervals in each schedule. The mother of Elbert Cox was asked to look at a countdown timer clock that would signal for her to sing he stopped moving. The mother Katharine Johnson was given headphones, with no visual stimulus. A clicking sound was presented, signifying the completion of an interval and alerting the mother to sing once Katharine stopped moving. Elbert Cox's data was analyzed using the methodology previously discussed. To analyze operant only behaviors (as opposed to stimulus-response), all behaviors that occurred during maternal singing were excluded from the analysis presented below. Katharine Johnson's analysis included both behaviors that occurred during maternal singing, as well as outside maternal (all behaviors).

Matching law describes various quantitative relationships between the rates of behavior and the rates of reinforcement within operant conditioning. To address the relationship between the rates of fetal behavior, and the rates of maternal singing, each rate was calculated for each schedule, by magnitude of fetal movement (including only MFA, HMA). For each magnitude category, the rate of behavior was plotted against the rate of resource acquisition (i.e. acquired maternal reinforcement). Each data point on the graphs in Figure 3 represent the rate of behavior and rate of resource acquisition, for each V.I. schedule. The hyperbolic curve was fit to the data using the hyperbolic expression below:

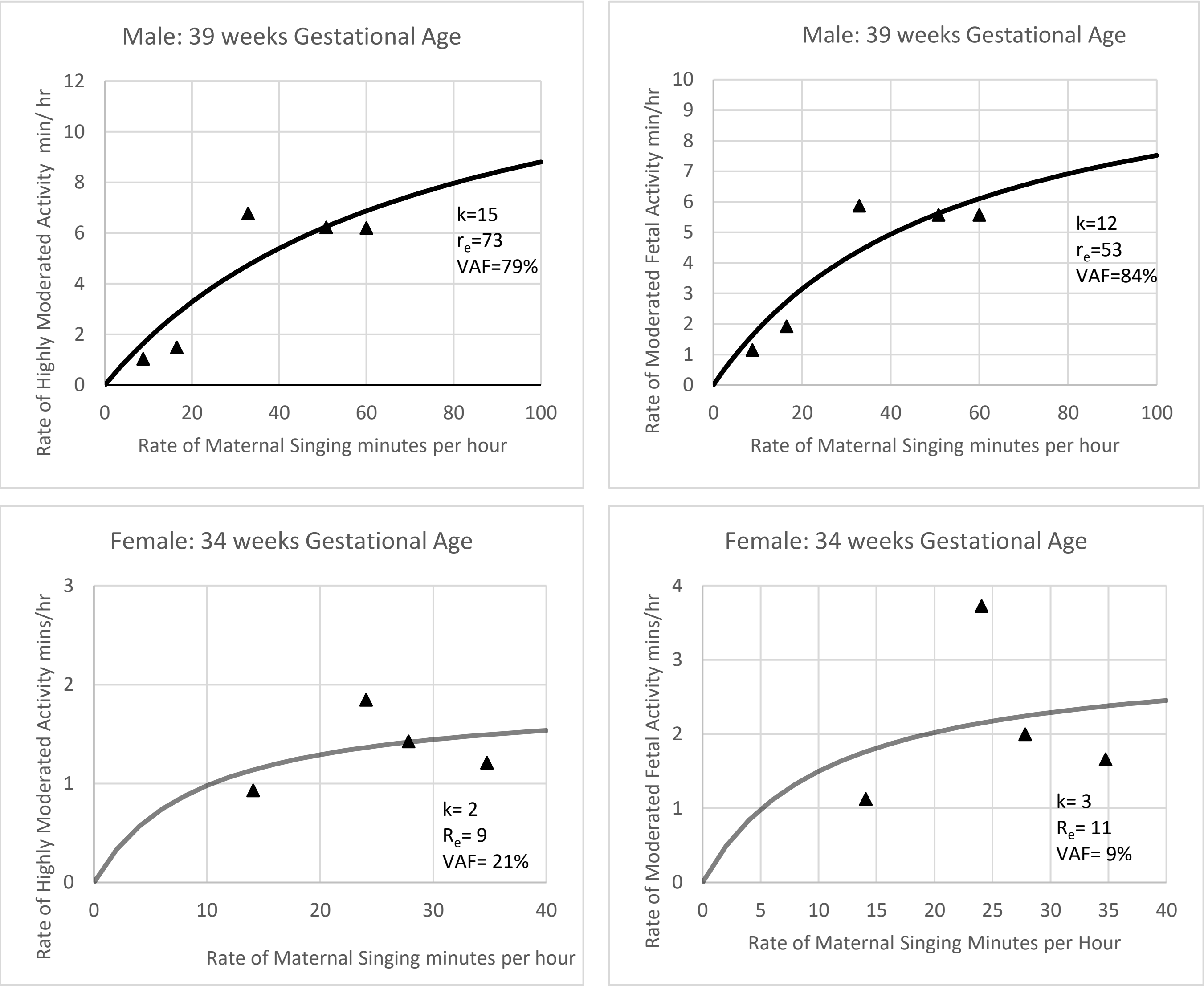
$$B = \frac{kr}{r + r_e},$$

Where B is the absolute rate of behavior. The k parameter represents the total absolute rate of behavior. The k includes the B and B_{e}. The B_e represents "other", extraneous behavior. This parameter ($\mathrm{B_e}$) is theorized as being constant in any environment. The R_e is an aggregate rate of extraneous behavior that occasionally produces benefits to the organism. Because all behavior is choice (according to matching law), this parameter is necessary even when there only appears to be single-alternative behavior.

Herrnstein's equation was fitted to the data obtained for each subject using Wilkinson's method. (McDowell, 198lb). Wilkinson's method provides the percentage of variance accounted for (%VAF) by the fitted hyperbolic functions. As indicated in Figure 3, the single-alternative form of matching law accounted for 79% (HMA) and 84% (MFA) of the variance in fetal conditioning of motor inhibition/attention for Elbert Cox. Matching law accounted for 21% (HMA) and 9%(MFA) of variance in fetal conditioning of motor inhibition/attention for Katharine Johnson.

For Highly Moderated Activity, a smooth hyperbolic function that reached its asymptote, k, at a value of 15 was obtained for Elbert Cox and the estimated value of r was 73. Katharine Johnson reached an asymptote at a value of 2 and the estimated value of r was 9.

For Moderated Fetal Activity, a smooth hyperbolic function was also obtained for Elbert and Katharine. The k reached a value of 12, and the estimated value of r was 53. Katharine Johnson reached an asymptote at a value of 3, and the estimated value of r was 11.



Male: 39 weeks Gestational Age

Male: 39 weeks Gestational Age

Female: 34 weeks Gestational Age

Female: 34 weeks Gestational Age

Figure 2 Fetal movement inhibition governed by the single-alternative hyperbola. The filled triangles represent rates of HMA or MFA fetal activity and rates of maternal singing. The smooth curve is a plot of the equation highlighted above. Listed in the lower right corner are the percentage of variance accounted for by the equation, and estimates of k and r_e.

Attention Holding: Duration of Fetal Movement Inhibition

Further analysis of data collected from Elbert Cox, and Katharine Johnson was used to explore the extent to which maternal reinforcement promotes longer durations of attention-holding in the fetus.

Several analyses were performed to examine changes in duration of time spent in Mildly Moderated Activity, Highly Moderated Activity, and Intensified Fetal activity across schedules (see figure 4 and 5 below). Data from 1 session lasting approximately 1.5 hours (including baselines) were collected for both Elbert and Katharine. Below are tables of descriptive statistics for fetal movement during V.I. schedules for Elbert Cox (Appendix D), and Katharine Johnson (Appendix E).

Elbert Cox: An independent-samples t-tests (two tailed) was performed to examine significant differences in fetal movement between behavior during the first baseline (no singing) with combined VI schedules (singing condition- MFA, MMA, HMA, and IFA). The singing condition had longer durations of Mildly Moderated Fetal Activity (M=11.54, SD=8.83) than the non-singing, baseline conditions (M=6.27, SD=2.41), t(59)=4, p<0.001, d= -0.47. The singing condition had shorter durations of Intensified Fetal Activity (M=10, SD=6.12) than baseline conditions (M=16.42, SD=12.48), t(21)= -2.2, p=0.043, d= -0.35. Post-hoc comparisons using Bonferroni test indicated that the mean duration of Mildly Moderated Fetal Activity was significantly longer during VI-15 schedule (M= 22, SD=19) than baseline (M=6.3, SD=2.4) with a mean difference of 15 seconds. The mean duration of Intensified Fetal Activity was also significantly longer during VI-2 schedule (M= 10, SD=8.2) than baseline (M=16.42, SD=12.5) with a mean difference of 6 seconds.

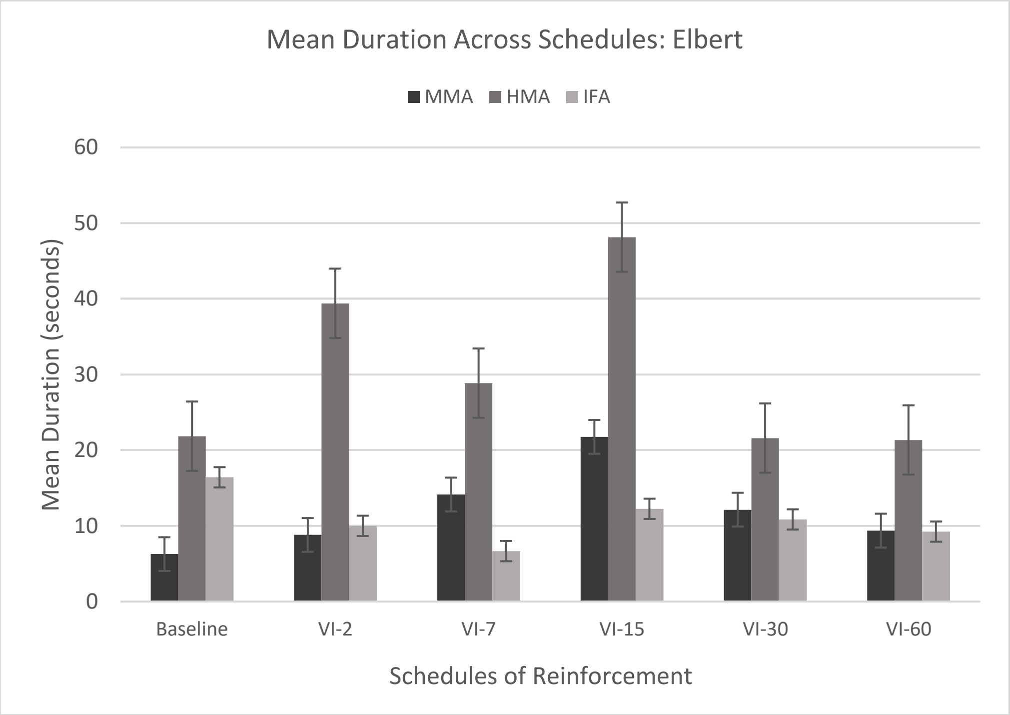


Fig. 4: Mean duration of time spent in Mildly Moderated Activity (MMA), Highly Moderated Activity (HMA), and Intensified Fetal Activity (IFA) across variable interval schedules of reinforcement.

Katharine Johnson: An independent-samples t-tests (two tailed) was performed to examine significant differences in fetal movement between combined baseline 1 and 2 measures (no singing) with combined VI schedules (singing condition- MFA, MMA, HMA, and IFA). The singing condition had longer durations of Moderated Fetal Activity (M=22.16, SD=22.87) than the non-singing, baseline conditions (M=9.91, SD=5.53), t(112) = -3.6, p=0.001, d= -0.31. The singing condition had longer durations of Highly Moderated Activity (M=16, SD=17) than baseline conditions (M=9, SD=3.5), t(112)= -3.6, p=0.001, d= -0.34. The singing condition had shorter durations of Mildly Moderated Activity (M=6.52, SD=3) than baseline conditions (M=8.9, SD=5.24), t(37)=2.1, p=0.039, d=0.29. The baseline conditions had longer durations of Intensified

Fetal Activity (M=15, SD=11) than the singing conditions (M=10, SD=7), t(70)=2.5, p=0.015, d=0.26. Post-hoc comparisons using Bonferroni test indicated that the mean duration of Moderated Fetal Activity was significantly longer during VI-15 schedule (M= 45, SD=73) than baseline (M=10, SD=6) with a mean difference of 34 seconds. Moderated Fetal Activity was also significantly longer during VI-15 (M= 45, SD=73) than VI-30 (M=13.5, SD=10), and Baseline-2 (M=9.6, SD=5.2) with mean differences of 31 seconds, and 35 seconds, respectively.

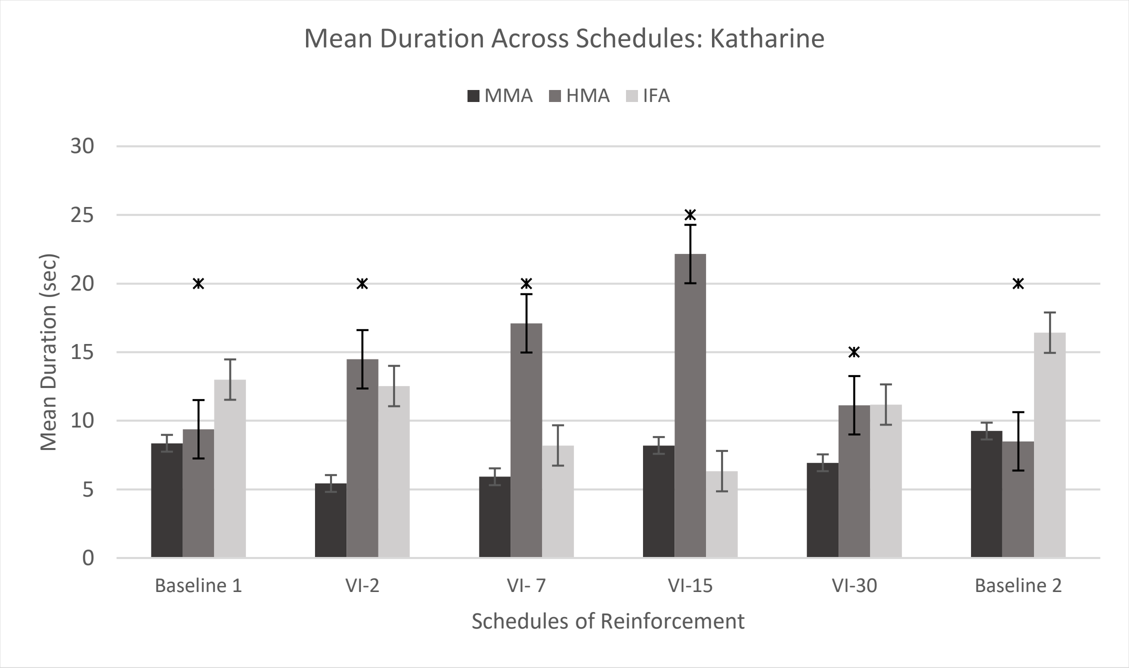


Fig. 5: Mean duration of time spent in Mildly Moderated Activity (MMA), Highly Moderated Activity (HMA), and Intensified Fetal Activity (IFA) across variable interval schedules of reinforcement.

DISCUSSION

This study's overall aim was to design a contingency for which attention-holding, and adaptive behavior could be assessed in the human fetus. In this investigation, the first question we sought to answer was whether maternal singing could be used as an effective reinforcer. We hypothesized that if maternal singing is an effective reinforcer, it will strengthen the pre-determined, targeted behaviors, showing a marked increase in responses over time. In Experiment 1, the identification of maternal singing as an effective reinforcer to increase the reduction of highly moderated fetal activity was confirmed. Cumulative record responses from 3 individual participants showed few responses occurring before reinforcement, with an increase in frequency of responses during continuous reinforcement. In addition, longer periods of movement suppression were observed during continuous reinforcement than baseline. Taken together, these findings suggest that a functional relationship exists between maternal singing and fetal movement when placed into a contingency. These experiments provided confirmation of internal validity of operant conditioning experiments using maternal singing contingent upon fetal reduction of movement.

The second question we addressed aimed to understand fetal behavior as being governed by matching law. We wanted to understand whether the rate of fetal behaviors were proportionate to the rate of maternal reinforcement. We explored how different variable interval schedules of reinforcement affected fetal movement and whether these patterns of behavior had a hyperbolic function. In doing so, we confirmed that the human fetus is capable of expressing adaptive behavior. The data points show the rate of behavior and reinforcement for each variable interval schedule. Herrnstein's hyperbola was fit over these data points, showing the extent to which fetal behavior uniquely followed a hyperbolic function and the extent to which this relationship was accounted for by the experiment itself (as opposed to extraneous behaviors). In general, therefore, it seems that the relationship between fetal behavior and maternal reinforcement indicates two concepts: (1) the environment, even in utero, could control behavior early on in development, and (2) adaptive behavior in the human fetus can be quantitatively assessed.

The results from Elbert Cox showed that the percentage of variance accounted for was greater than that of Katharine Johnson. There are several reasons why this may be. Elbert Cox was given five schedules, as opposed to Katharine who was given four. The extra, leaner, schedule (VI-60s) may have allowed for more variance in Elbert Cox's behavior, which accounted for a higher variance overall. Procedural differences may have played a role in having the higher variance accounted for in Elbert's behavior. During the experiment, Elbert Cox's mother used visual cues (countdown interval clock) to signal when the reinforcer will become available to the fetus. The researchers observed maternal behavioral changes as the countdown clock approached completion of the interval (e.g. deep breathing, physically adjusting her body). The fetus may have thereby associated maternal behavioral cues with maternal singing, and responded with anticipatory behavior, which then became reinforced immediately when the interval ended. Another important possibility for the differences in variance accounted considers analytical procedures. As described earlier, Elbert Cox's behaviors included only movement that occurred outside of maternal singing. Therefore, the behaviors that were analyzed involved only operant responses, rather than including responses during the reinforcer itself. Ideally, this is the standard method of analyzing behaviors in operant conditioning. However, in Katharine's case, excluding the behaviors that occurred during maternal singing was more of an arduous task due to altered procedural methods.

Nevertheless, the case of Elbert Cox confirmed the importance of considering operant-only versus all-behaviors when using matching law to describe fetal behavior. Fetal movement in response to maternal vocalization is mixed. Our study, although not formally through statistical analyses, confirmed the variability of fetal movement during maternal singing. When using all-behavior, that is, including behavior that occurred during maternal singing, Elbert Cox's data was not consistent with a hyperbolic function. After excluding responses during maternal singing, that is, operant-only behavior, the data followed a hyperbolic patter, with a marked increase of %VAF. Lastly, another possibility for this differences in %VAF could be due to gestational age. Katharine Johnson (34w GA) was 5 weeks younger than Elbert Cox (39w GA). The VI schedules may have a developmental function. The schedules may have been appropriate for Elbert Cox, but less optimal for Katharine. Therefore, variable interval schedules may need to be adjusted according to gestational age.

This study further analyzed all the behaviors that occurred during Experiment 2 to explore the extent to which maternal reinforcement promotes longer durations of attention-holding in the fetus. Attention in the fetus was operationalized in this study to be expressed behaviorally as decreased fetal motor activity with a decelerated heart rate response. "Attention-getting" or orienting behaviors are brief responses which can be elicited by presenting a stimulus. "Attention-holding", or sustained attention, are prolonged periods of decreased motor activity with a decelerated heart rate response. For this analysis, we were interested in the average duration, as well as the maximum duration, of "attention-holding" during experimental conditions (singing at variable intervals) compared to baseline (no singing-minimal quiet conversations). The results confirmed that increased durations of movement suppression occurred when the presentation of a repeated stimulus (i.e. Maternal Singing) is placed in appropriate schedules of reinforcement. Overall, these results strengthen the idea that: the unpredictable, and varied presentation of a repeated stimulus would be masked as novel, thereby preventing the fetus from habituating to the stimulus, and consequently, promoting longer periods of attention holding. The current data highlight the importance of analyzing both magnitude and duration of fetal behaviors. Herrnstein's Hyperbola takes into account the rate of behavior (mean divided by the total duration of the schedule), however, through statistical examination, we can assess whether the means of multiple schedules/conditions are statistically different from each other. This is especially when equal variances are not assumed. The findings of this study provide insights for several future considerations. First, consideration of behavioral classifications according to fetal movement magnitude. This study was the first of its kind to consider the magnitude of fetal movement, rather than event counts, or specific observable behaviors (i.e. isolated events). By classifying these pre-defined categories, this study was able to quantitatively parse different rates of behaviors to better understand what might be extraneous behaviors apart from targeted behaviors. The majority of studies that investigate fetal responses to various stimuli typically analyze heart rate as the main outcome, rather than performing thorough analysis of movement. This may be due to the complex nature fetal movement, as well as the lack of resources, and methodology available within this area of research. The findings of this study also provide insights into maternal perception of movement suppression. The mothers were asked to perceive when she felt her baby stop calmed down or stopped moving. Therefore, the mother was in control of what she perceived to be the target behaviors. For this reason, the pre-defined magnitudes of fetal movement (especially between HMA and MFA) may result in different rates within and between individuals. For this reason, and as mentioned before, it is important to have multiple levels of magnitude when analyzing fetal movement. In general, it appears as though both HMA and MFA are being reinforced, however the rates may vary per participant depending on maternal perception/reinforcement.

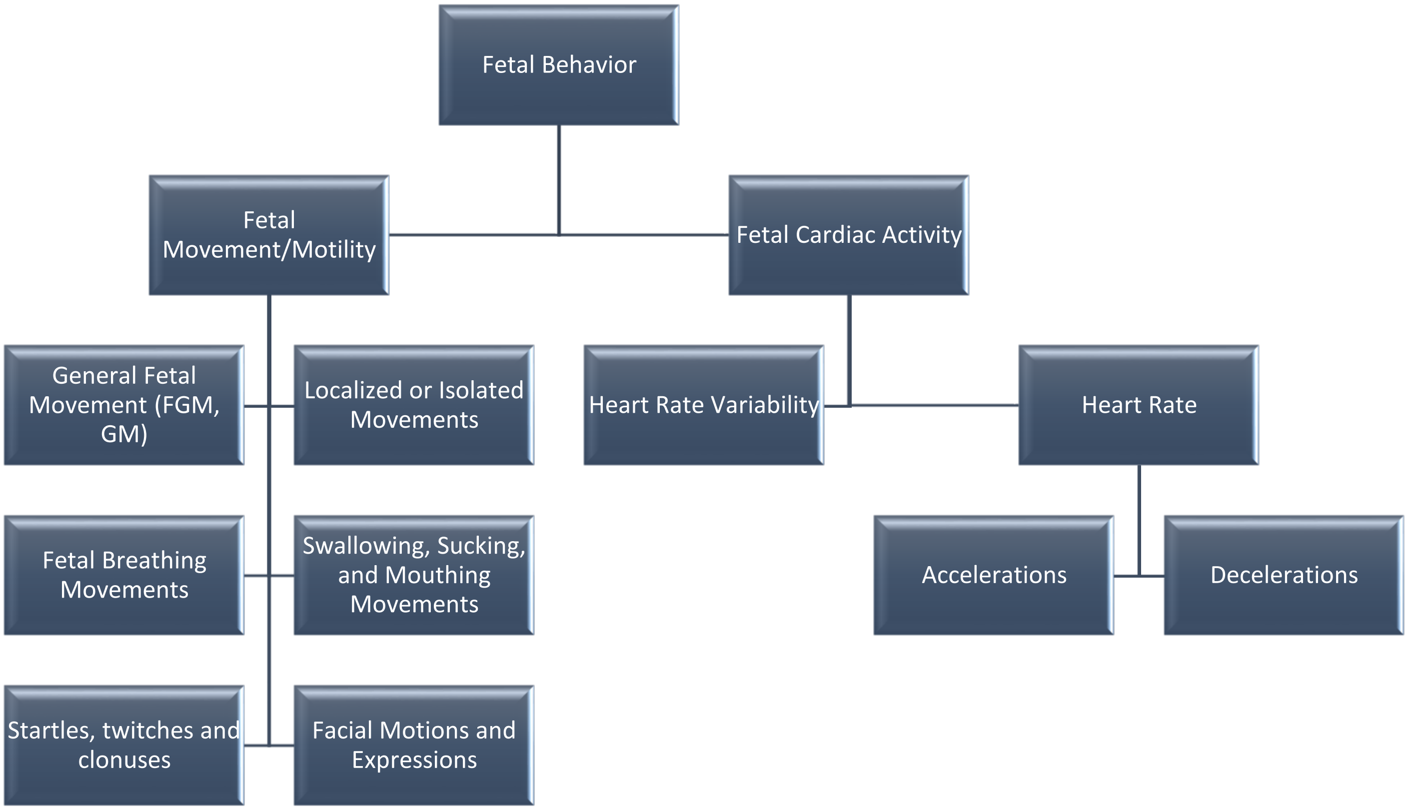
Overall, the present study was met with several limitations. This study is limited by the lack of information on fetal learning outside of stimulus-response to habituation, and heart rate responses. There was also a lack of studies on matching law, and operant conditioning early in development. This created many challenges in arranging initial parameters to construct appropriate schedules and contingencies of reinforcement for the human fetus. In addition, the small sample sizes in experiment 2 did not allow for a pooled analysis. Although the findings for each individual were not limited in itself, a pooled analysis would facilitate a better understanding of patterns of fetal behavior across gestation as well as provide a more accurate description (i.e. increase %VAF) of the function of these behaviors (e.g. hyperbolic). An additional uncontrolled factor that limited this study was the timing/delivery of each reinforcer. Aside from the schedules of reinforcement, the mothers were in control of delivering the reinforcer. The mothers were instructed to sing immediately after the interval ended, and when she felt a significant reduction in fetal movement. Delivery of reinforcers could have been inconsistent at times, thereby affecting the rate of responses, or the duration of movement suppression during the experiment. This study also did not further evaluate latency of responses, or behavior that occurred only during maternal singing. Analyzing these parameters across schedules may offer significant details towards the cognitive implications of operant conditioning. Despite its exploratory nature, this pilot study’s results are significant in at least two major respects: it adds to the existing literature on matching theory in adaptive organisms, and offers possible insight into cognitive processes before birth.

There are several important areas where this study makes an original contribution. This study adds to matching law literature which can now include human fetal behavior as an adaptive organism that is governed by matching law. Another area where this study may significantly expand our understanding is the area of cognitive development, more specifically, the prenatal antecedents of attention control/holding, goal orientation, and expectancy/anticipation. An additional area where this study could significantly impact is developmental psychopathology. Recent findings in developmental psychopathology have heightened the need for studies to include prenatal/fetal factors that may play a role in developing psychological disorders later in life (e.g. genotyping, exposures to teratogens, maternal functioning). Such approaches, however, have failed to address the role of fetal movement and the (uterine) environment in which they occur. Research on fetal behavior has been mostly restricted to limited comparisons of stimulus-responses before and after birth. This study contributes to these areas of research by directly testing ways in which the environment affects fetal behavior.

Extensive literature has been published on fetal responses to specific stimuli (Graham & Clifton, 1966; Jardri et al., 2012; Kisilevsky, Muir, & Low, 1992; Kiuchi, Nagata, Ikeno, & Terakawa, 2000; Lecanuet, Granier-Deferre, Cohen, Le Houezec, & Busnel, 1986), highlighting significant relationships between fetal behavior and the extrauterine environment. However, they suffer from a very important oversight in that: “No account of the interchange between organism and environment is complete until it includes the action of the environment upon the organism *after* a response has been made” (Skinner, 2014). In other words: the extent to which we understand learned fetal behavior is incomplete until we include the contingencies of reinforcement. The fetus may naturally adjust its behavior (through trial and error of various sequences) and perform general movement sequences to receive stimulation for neural, physical, and regulatory functioning in preparation for postnatal life. The fetus also adapts to the intrauterine environment by responding and recovering from stressful stimuli (Amiel-Tison & Pettigrew, 1991) as well as producing physiological changes that facilitate adaptation to extrauterine life(Bozynski, 1986). These observations indicate the need to further understand adaptive behaviors within the fetal organism.

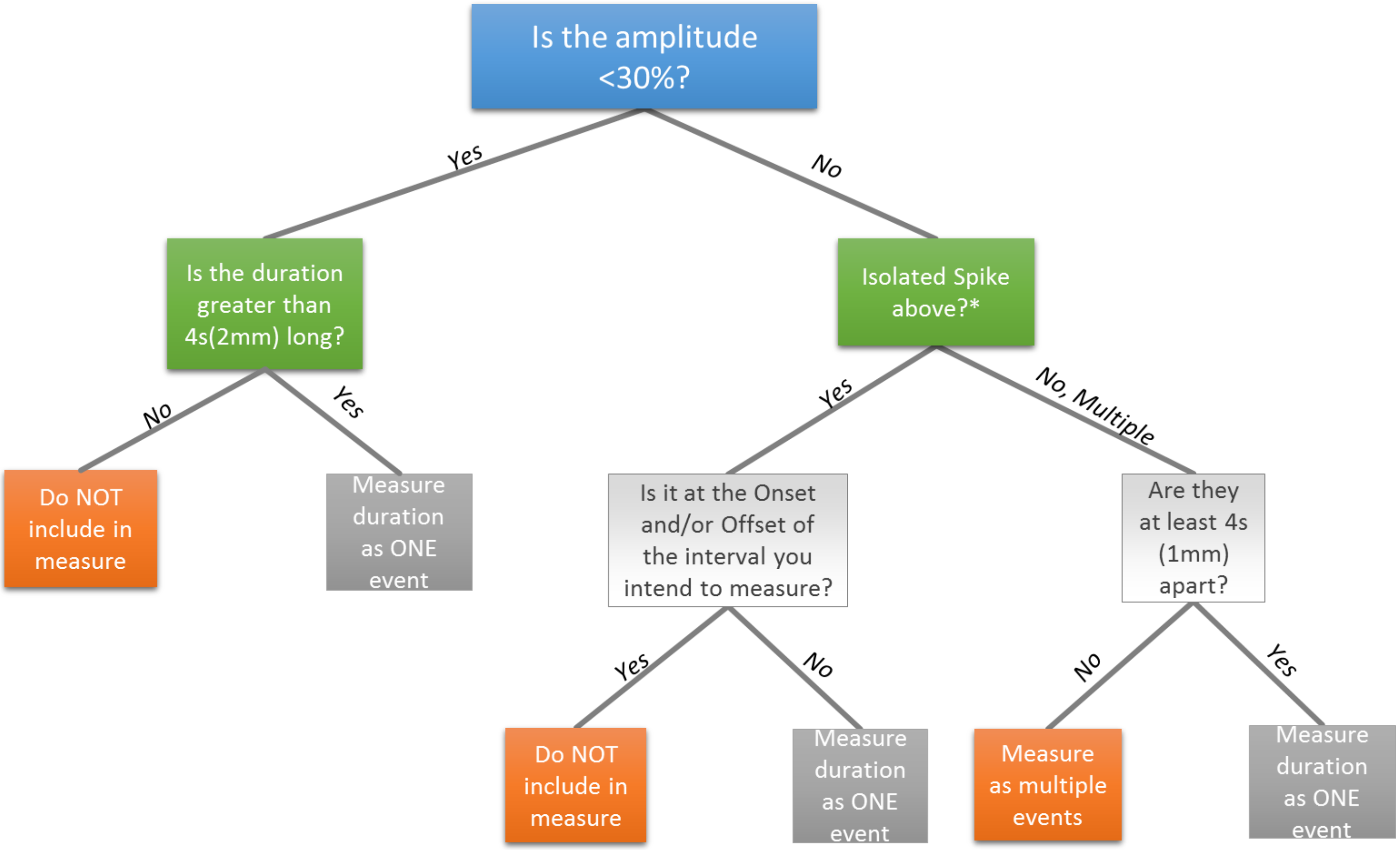
Additionally, early sensorimotor experiences play a key role in cognitive development later in life (Emory, 1998). Within the womb, fetal motor activity generates proprioceptive feedback and, multisensory consequences. It also may play a critical role in perceptual learning, cognition, and social development (Piontelli, 2015). The relationship between fetal behavior and the extrauterine environment, as well as the ways in which both interact to support cognitive development, are poorly understood. This study offers an approach towards better understanding the ways in which the environment governs fetal behavior is to directly examine the desired behaviors within a contingency. Although the results revealed that fetal behavior is consistent with a hyperbolic function, it is not safe to rule out other functions that may better explain fetal behavior. Future studies should consider other possible functions that could mathematically describe fetal behaviors (e.g. power function). Although the results offer some insight into cognitive processes before birth, one question that needs to be asked is whether these processes have continuity into post-natal development; and whether these constructs that we defined prenatally (i.e. attention-holding, adaptive behavior) can be validated by post-natal measurement. To conclude, this study offers potential future studies to consider investigating adaptive behavior and attention prenatally as a potential approach for measuring central nervous system functioning and behavioral adaptation in the fetal organism. However, the usefulness and validity of studying cognitive processes across pre-postnatal periods awaits the establishment of methodological confirmation which would ensure equivalence of these constructs during fetal and neonatal assessment.

APPENDIX A: BASIC OUTLINE OF FETAL BEHAVIOR

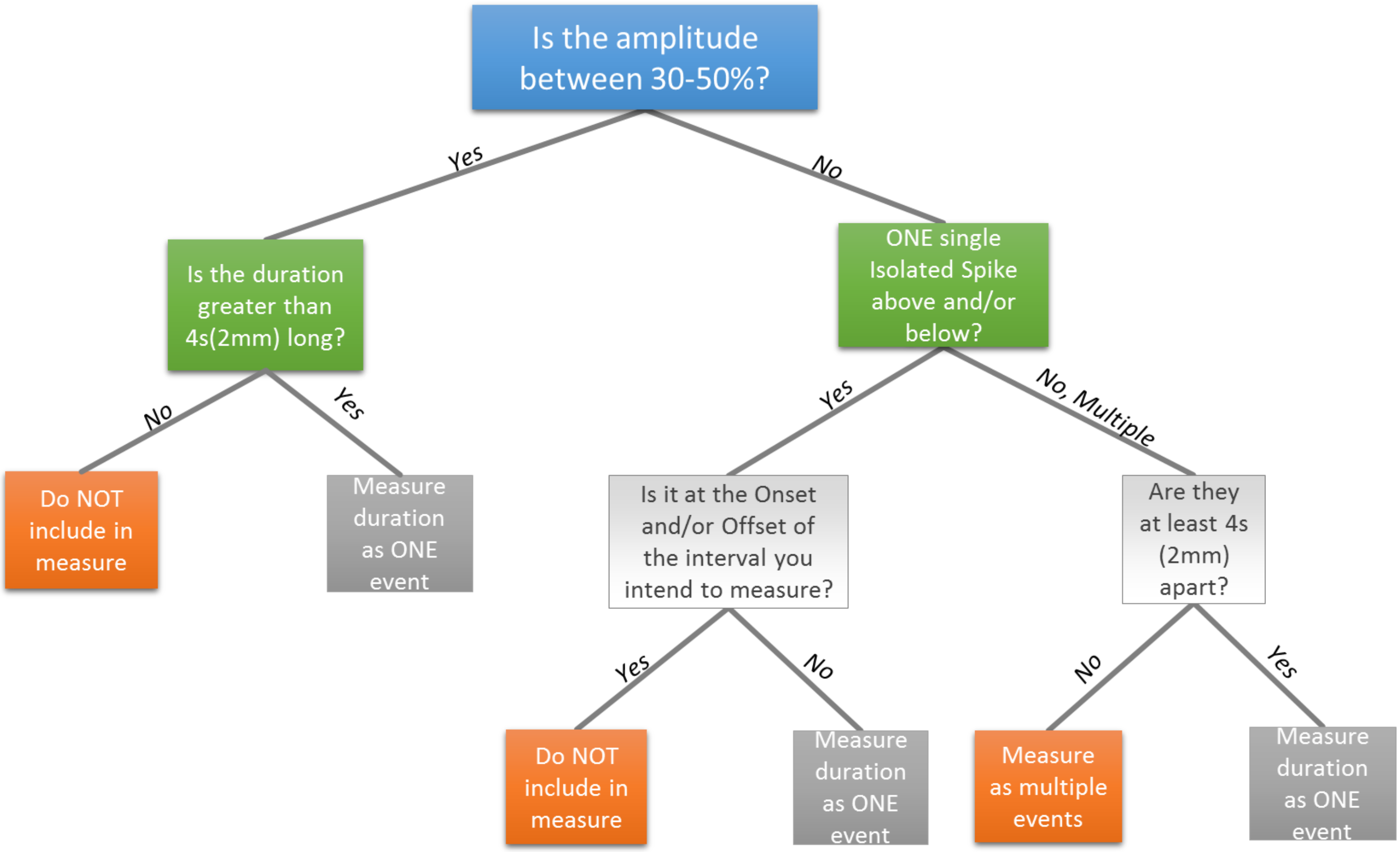


APPENDIX B: MEASUREMENT CRITERIA FOR FETAL ACTIVITY

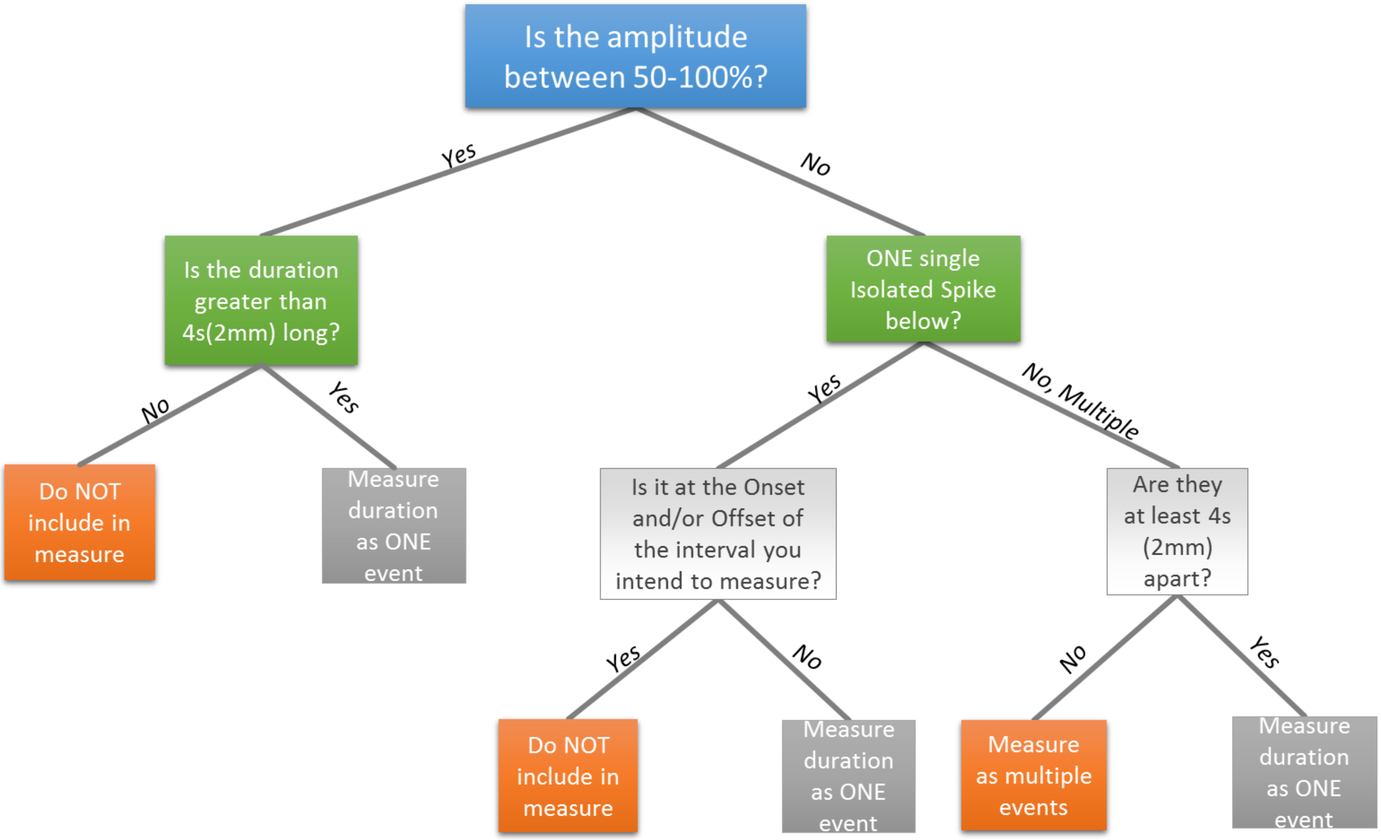
Measurement Criteria for Highly Moderated Fetal Activity (HMA)



Measurement Criteria for Mildly Moderated Fetal Activity (MMA)



Measurement Criteria for Intensified Fetal Activity (IFA)



APPENDIX C: PARTICIPANT DEMOGRAPHIC PROFILES

	Katharine	***Ernest***	***David***	***Charles***
Sex/Gestational Age	Female/34w	Male/28w	Male/24w	Male/25w
Maternal Age	26	25	24	26
Race/ethnicity	Black American	Black American	Black American	Black American
Highest level education	High School/GED	High School/GED	High School/GED	High School/GED
Currently Employed	No	No	No	No
Relationship Status	Single	Single	Single	Single
Annual Income	Under 10k	Under 10k	Under 10k	Under 10k
# Previous Pregnancies	3	1	1	2
# of miscarriages/still births	0	0	0	0
Previous C-section	0	0	1	0
Being treated for a medical condition	No	No	No	Morning Sickness
Current Medications	Iron; Vitamins	Vitamins	Iron	Zofran; Tylenol
Drugs/Alcohol During Pregnancy	No	No	No	No
Frequency/Duration of Singing/Humming	>10min/day, daily	>10min/day, daily	<10min/day, daily	>10min/day, 1-2 times weekly
Frequency/Duration Maternal perception of movement per day	Every 10-20 mins	Every 5-10 mins	Every 5-10 mins	Every 5-10mins

Note: Missing data for one participant Elbert, Male/39w

APPENDIX D: DESCRIPTIVE STATISTICS: ELBERT COX

Table 1. Descriptive statistics for Fetal Movement during Variable Interval Schedules: Elbert Cox

Variable and statistic	IFA (n=71)	MFA (n=127)	MMA (n=76)	HMA (n=105)
Baseline Mean	16	24	6	22
SD	12	22	2	23
Minimum	4	4	4	4
Maximum	48	90	12	90
VI-2 Mean	10	40	9	39
SD	8	58	5	67
Minimum	4	9	4	4
Maximum	22	158	16	158
VI- 7 Mean	7	33	14	29
SD	1	44	8	53
Minimum	6	4	6	4
Maximum	7	147	27	147
VI- 15 Mean	12	42	22	48
SD	16	51	19	61
Minimum	4	7	6	6
Maximum	36	144	46	144
VI-30 Mean	11	25	12	22
SD	6	23	8	27
Minimum	4	4	4	4
Maximum	21	125	35	120
VI- 60 Mean	9	24	9	21
SD	4	26	7	28
Minimum	4	4	4	4
Maximum	16	144	37	134

APPENDIX E: DESCRIPTIVE STATISTICS: KATHARINE JOHNSON

Table 2. Descriptive statistics for Fetal Movement during Variable Interval Schedules: Katharine Johnson

Variable and statistic	IFA (n=104)	MFA (n=158)	MMA (n=76)	HMA (n=105)
Baseline-1 Mean	13	10.29	8.36	9.38
SD	9.055	6.025	4.781	3.403
Minimum	3	3	3	4
Maximum	30	30	17	15
VI-2 Mean	12.53	19.92	5.43	14.48
SD	9.646	22.047	3.599	14.222
Minimum	4	3	2	3
Maximum	38	80	13	80
VI- 7 Mean	8.2	23.92	5.92	17.1
SD	5.808	25.76	2.813	16.668
Minimum	3	4	4	4
Maximum	23	92	14	92
VI- 15 Mean	6.33	44.67	8.2	22.15
SD	2	73.166	5.02	26.599
Minimum	4	4	4	4
Maximum	10	285	15	130
VI-30 Mean	11.18	13.47	6.94	11.13
SD	6.084	9.921	1.952	6.121
Minimum	4	4	4	4
Maximum	27	44	10	28
Baseline-2 Mean	16.42	9.61	9.61	8.5
SD	11.628	5.194	5.194	3.559
Minimum	4	4	4	4
Maximum	60	23	23	16

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