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Human Fetal Behavior: 100 Years of Study

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The literature on spontaneous and stimulus induced human, fetal behaviour is reviewed. Spontaneous fetal behaviours, including body movements, fetal heart rate, coupling of body movements and fetal heart rate, breathing, and the association among behaviours have been characterized. In addition, maturation of behaviours have been described from conception to term. Stimulus induced behaviour, in particular fetal heart rate changes and body movements, have been used to examine sensory and cognitive development. Both spontaneous and stimulus induced behaviour are being employed to assess fetal well-being. Given a rich database, the focus of research is shifting from the characterization of behaviour to the identification and understanding of processes, mechanisms, and experiential factors underlying development. 1998 Academic Press

> Now at this time Mary . . . entered the house of Zacharias and greeted Elizabeth. And it came about that when Elizabeth heard Mary's greeting, the baby leaped in her womb; . . . And she cried out with a loud voice, . . . ''when the sound of your greeting reached my ears, the baby leaped in my womb for joy.''
>
> Luke 1:39–44.

Anecdotal reports of human fetal behavior have appeared at least since biblical times. However, it was not until the end of the 19th century that sporadic reports appeared in the scientific literature. By the end of the 20th century, when sophisticated ultrasound equipment with the application of image processing techniques became readily available, the area emerged as a distinct field within the disciplines of psychology and medicine. To date, the theoretical approach might best be described as nativist, with the majority of work focusing on descriptions of behavior, associations among behaviors, sensory sensitivity, and well-being. Reflecting the major divisions in the literature, the following review is divided into three sections. The first section focuses on the characterization of spontaneous fetal behaviors, including body movements, fetal heart rate (FHR), coupling of body movements and

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FHR, breathing movements, and the association among behaviors (i.e., behavioral states). The second section covers the research on stimulus-induced behavior used to examine two fundamental issues, sensory and cognitive development. The third section provides an overview of the usefulness of fetal behavior in the assessment of well-being, including obstetrical tests that are used to evaluate fetal health status. Not included in this review in any substantive way are studies from non-human species. There is no doubt that animal studies have contributed significantly to our understanding of human fetal development (e.g., body movement, state-of-arousal, sensory sensitivity, and habituation). In addition, most of our knowledge of fetal physiology and metabolism has been derived from animal studies. However, given the diversity of species (e.g., wasp, ant, frog, chicks, rat, lamb), the differences in maturity at time of birth (e.g., precocial vs altricial), and the differences in morphology (e.g., relative brain to body weight), which must be taken into consideration when comparing animal and human studies, the review is limited to human fetal studies.

SPONTANEOUS FETAL BEHAVIOR

It has been argued (e.g., Hepper, 1995) that observations of fetal behaviors and behavioral changes provide a noninvasive method of determining and assessing brain functioning. Analyses of fetal behaviors in healthy populations reflect functional development of the fetal nervous system during the prenatal period. The bulk of the literature assumes this perspective. However, whether phenomena observed during the prenatal period are best described as behaviors or activities is debated. For example, Levene (1993), while admitting that behavior can be observed in neonates of the same gestational age, argues that cortically modulated behavior in the fetus is unlikely and that observed activity is probably reflexive. Hence, the term behavior is considered inappropriate and activity is used to reflect observed phenomena. Although the issue is unresolved, this review uses the term behavior; it is the common assumption in the literature. Furthermore, as argued by Hepper and Shahidullah (1994), clearly, the process of development begins in the prenatal period with behaviors emerging and developing continuously over gestation and childhood.

The most common measures of spontaneous fetal behavior are body movements, FHR, and breathing[1] movements. Some of this work comes from observations of healthy, low-risk fetuses carried out specifically to describe the onset, type, and amount of a particular behavior observed at various gestational ages (GA). However, the vast majority of reports include observations

[1] Fetal breathing movements refer to simultaneous movements of the diaphragm (downward), thorax (inward), and abdomen (outward; de Vries, 1992). These movements, observed *in utero*, appear similar to those observed after birth. Although fetal breathing results in fluid movement, there is no air exchange.

made during non-stress[2] or biophysical profile[3] testing as part of routine obstetrical care in both high- and low-risk pregnancies.

A. Fetal Body Movements

Fetal body movement information is obtained from maternal reports, analog tracings using Doppler ultrasound, and real-time ultrasound observations. Each method has advantages and disadvantages. Maternal report of the perception of fetal movement is a simple, inexpensive method of obtaining fetal movement counts. Nevertheless, because spontaneous fetal movements are not felt by the mother until about 16 weeks gestation, this method cannot be used in early pregnancy. Furthermore, maternal perception is dependent on the duration of the movement (Sorokin, Pillay, Dierker, Hertz, & Rosen, 1981) and the number of fetal body parts contributing to the movement (Hertogs, Roberts, Cooper, Griffin, & Campbell, 1979; Rayburn, 1980). Mothers perceive more vigorous movements while slight movements of short duration may go unnoticed. With regard to analog tracings, it is now possible to obtain body movement information along with FHR during cardiotocographic recording. Melendez, Rayburn, and Smith (1992) compared simultaneously recorded movements and movements observed on ultrasound scan and demonstrated that both limb and body movements could be monitored. However, discrimination between the two types of movements was not possible. Hand and mouth movements, breathing, and rapid eye movements could not be recorded reliably. At present, this recording method is of limited value for research purposes because it results in a rather gross interpretation of a crude trace for patterns which indicate particular types of movement. Finally, real-time ultrasound scanning allows for the visualization of the fetus and direct observation of movements. However, after about 20 weeks, it is not possible to see the entire fetus and small localized movements, particularly limb movements, may go unnoticed. Considering the limitations of the three methods, real-time ultrasound scan observations may be the most accurate method of assessing body movements for research purposes. They have the added advantage of allowing for video recordings which can be used for inter- and intraobserver reliability.

Several groups have focused on describing the onset and development of fetal body movements. Using ultrasound observations, de Vries, Visser, and Prechtl (1985) characterized the onset of various spontaneously generated movement patterns in the fetus from 7 to 19 weeks GA. During the first 15 weeks GA, they noted that the onset of general movements of the head, trunk, and extremities occurred by 8.5 to 9.5 weeks GA and that fetuses were

[2] A non-stress test is a continuous, 40-min recording of FHR, uterine contractions, and body movements while the mother is at rest.

[3] A biophysical profile is a 20- to 30-min real-time ultrasound scan during which observations of fetal body movements, muscle tone, breathing, and amniotic fluid volume are made.

active for about 14% of a 60-min viewing period. By 14 to 19 weeks GA, fetuses were very active and the longest period without general movements was 5 to 6 min. Indeed, movement activity is so common in the first trimester that it is difficult to obtain a long period of inactivity needed to examine response to stimulation. From 16 to 32 weeks GA, several authors noted a decrease in the number of generalized movements per hour (e.g., Natale, Nasello-Paterson, & Turlink, 1985; Roodenburg, Wladimiroff, van Es, & Prechtl, 1991) and in the percentage of time during viewing in which movements were present (e.g., de Vries, Visser, & Prechtl, 1988). Although at 20 to 22 weeks GA, a diurnal variation in general movements with peak values at night was noted (de Vries, Visser, Mulder, & Prechtl, 1987), Nasello-Paterson, Natale, and Connors (1988) could not identify a periodicity to fetal movement and concluded that quiet–active cycles were not evident in the immature fetus. As fetuses approach term,[4] they develop their own pattern of activity and the gradual decline in the number of body movements continues (e.g., Patrick, Campbell, Carmichael, Natale, & Richardson, 1982a). At term, the average number of body movements observed over 1 hr was reported to be approximately 31 (range 16–45) with the longest reported intervals between movements ranging from 50 to 75 min (Patrick et al., 1982a). In summary, spontaneous body movements begin by the end of the second month of gestation, increase in incidence until a plateau is reached around the end of the first trimester, and then gradually decrease until term.

Few effects on spontaneous fetal body movements have been described and those that have been are difficult to categorize in any systematic way. For example, in first trimester pregnancies complicated by insulin dependent diabetes, fetuses show a delayed emergence of movement patterns (Mulder, Visser, Morssink, & de Vries, 1991). In pregnancies complicated by moderate to severe reductions in amniotic fluid volume, a decrease in the amplitude and speed of generalized fetal movements was reported (Sival, Visser, & Prechtl, 1990). In addition, decreases in the number of body movements was observed 20 min following cigarette smoking (Graca, Cardoso, Clode, & Calhaz-Jorge, 1991) and for 24 h following maternal injection of steroids for fetal lung maturation at 25 to 35 weeks GA (Katz et al., 1988). Induction of labor with intravaginal prostaglandin also has been shown to inhibit movements (Sorokin, Hallak, Klein, Kalderon, & Abramovici, 1992). However, uncomplicated intrauterine growth retardation (Sival, Visser, & Prechtl, 1992) and medications to stop premature labor (i.e., indomethacin, terbuta-

[4] The average gestation of the human fetus is 40 weeks counted from the first day of the woman's last menstrual period. A 38- to 42-week gestation is called term and is considered normal. A gestation <37 weeks is called preterm and one >42 weeks is called post-term. Infants born preterm or post-term are at increased risk for mortality and morbidity (e.g., Stewart, Reynolds, & Lipscomb, 1981; Hunt, Cooper, & Tooley, 1988; Klein, Hach, & Breslau, 1989).

line; Hallak et al., 1992) were shown to have no effect on body movements. Moreover, investigators examining the influence of maternal glucose intake on fetal movements have reported conflicting results. Several groups (Aladjem, Feria, Rest, Gull, & O'Connor, 1979; Gelman, Spellacy, Wood, Birk, & Buhi, 1980; Miller, Skiba, & Klapholz, 1978; Eller, Stramm, & Newman, 1992) reported an increase in fetal body movements after oral or intravenous glucose. Others (Bocking et al., 1982; Natale, Richardson, & Patrick, 1983; Patrick et al., 1982a) found no increase in movements, while some (Roberts, Little, Cooper, & Campbell, 1979; Edelberg, Dierker, Kalhan, & Rosen, 1987) found a decrease in movement activity. Differences in fetal gestational age, length of observation, and amount of glucose provided to the mother may account for the discrepancies among studies. The issue is unresolved.

De Vries (1992) postulated that movements of the embryo and fetus are a fundamental expression of early neural activity. However, to date, the neural substrates underlying human fetal movements and the functions which various movements may serve have not been identified. A thorough understanding of normal movement development as well as differential development as a function of newborn outcome may provide insights into neurological control.

B. Fetal Heart Rate

Typical FHR baseline and baseline variability, as well as spontaneous accelerations and decelerations, have been described. At term, fetal activity is the most common variable influencing normal baseline, baseline variability, and accelerations. No differences in FHR variables predictive of newborn outcome have been demonstrated (e.g., Freeman, 1990) between groups of low- and high-risk (i.e., at increased risk of morbidity and/or mortality) fetuses.

1. FHR baseline and baseline variability. FHR baseline is the primary heart rate in a given time period. In healthy fetuses the heart rate varies from about 120 to 160 beats per minute (BPM) with transitory values as low as 110 BPM, observed when the fetus is very quiet, and values as high as 180 BPM, observed during periods of high activity. At term, baseline FHR demonstrates a diurnal rhythm with a trough at night between 0200 and 0600 hours and is closely correlated with maternal heart rate (Patrick, Campbell, Carmichael, & Probert, 1982b). Baseline FHR is a result of spontaneous FHR modulated by the autonomic nervous system. Until about 25 weeks GA, FHR is controlled by the parasympathetic nervous system, an earlier developing structure than the sympathetic nervous system. Later in gestation, there is a complex interplay between the parasympathetic and sympathetic systems (e.g., see overview by Martin, 1978). Studies in the fetal lamb (Walker, Cannata, Dowling, Ritchie, & Maloney, 1978; Llanos, Green, Creasy, & Rudolph, 1980) have shown that parasympathetic stimulation produces cardiac slowing with a characteristic rapid reaction-recovery time. A sympathetic effect produces cardiac acceleration with a characteristic slower reaction time. In addition, FHR is affected by catecholamine release which begins early in fetal life; epinephrine infusion causes an initial fall then rise of heart rate (Jones & Ritchie, 1978).

Short- and long-term baseline variability are normally present in continuous recordings of FHR. Cycles of increased and decreased baseline variability occur throughout the day with more increased variability during the evening (Dalton, Denman, Dawson, & Hoffman, 1986). Decreased variability is present for 20 to 30% of the time during the day with periods of decreased variability averaging 18 min in length (range 6–38 min; Visser, Goodman, Levine, & Dawes, 1982). At term, variability is increased during fetal activity and decreased during quiescence (Nijhuis, Prechtl, Martin, & Bots, 1982). Short-term variability has been shown to increase (e.g., Dawes; Serra-Serra, Moulden, & Redman, 1994) or decrease (e.g., Derks, Mulder, & Visser, 1995) for 12–24 h following the administration of steroids to promote lung development in pregnancies threatening premature delivery. In addition, decreased variability has been associated with intrauterine growth retardation (Smith et al., 1988) and fetal hypoxemia or anemia at 20 to 26 weeks GA (Nicolaides, Sadovsky, & Visser, 1989). Baseline long-term variability is due to moment-to-moment differences of parasympathetic cardio-regulatory activity (Martin, 1978). However, research with the fetal lamb demonstrates that 35 to 40% of variability remains after both parasympathetic and sympathetic blockade, implying the presence of a major nonneuronal component to variability (Dalton, Dawes, & Patrick, 1977).

2. FHR decelerations. Spontaneous FHR decelerations were shown to vary with gestational age. Sorokin and colleagues (Sorokin et al., 1982) reported decelerations to be common in the very premature fetus, representing 97% of FHR changes between 20 and 22 weeks GA, decreasing to 34% between 28 and 30 weeks GA. Before 29 weeks GA, spontaneous decelerations are typical; by 35 weeks GA, greater baseline variability makes recognition of them more difficult (Wheeler & Murrills, 1978). In addition, Timor-Tritsch, Dierker, Hertz, Deagan, and Rosen (1978) described the frequent occurrence of a deceleration following an acceleration in normal, term fetuses. Sporadic decelerations, representing reflex parasympathetic cardiac slowing, are frequently encountered in the records of both low- and high-risk pregnancies (Meis et al., 1986).

3. FHR accelerations. Spontaneous FHR accelerations have been well described in the literature. They occur by 25 weeks GA and indicate the onset of sympathetic nervous system responsiveness. As gestation advances, they occur more frequently and attain a greater increase over baseline FHR (Wheeler & Murrills, 1978). By 28 to 30 weeks GA, 36% of FHR changes are accelerations (Sorokin et al., 1982); at term, the number of FHR accelerations average 34 per hour (range 0–130), with a greater frequency during the evening. The longest reported interval between accelerations is 37 min

(Patrick, Carmichael, Chess, & Staples, 1984) and the longest reported interval without 2 to 5 accelerations is 80 min (Patrick, Carmichael, Chees, Probert, & Staples, 1985). From 34 weeks GA, long-term changes in the pattern of FHR have been related to periods of fetal rest and activity (Wheeler & Murrills, 1978).

C. Coupling of FHR and Body Movements

There is an obvious relationship between FHR changes and body movements. In the premature fetus of 20 to 30 weeks GA, Sorokin (Sorokin et al., 1982) noted that most FHR accelerations and decelerations were associated with a fetal movement while 68% of fetal movements were associated with a FHR change. Navot, Yaffe, and Sadovsky (1984) agreed that, between 25 and 28 weeks GA, accelerations were synchronous with fetal movements, but observed accelerations in association with only 20% of fetal movements. Given that FHR accelerations first appear around 25 weeks GA, Navot et al.'s low percentage of coupling may have occurred because of the restriction of age range of the fetuses to a time of transition. Evidence to support this notion comes from the work of Natale and colleagues (Natale, Nasello-Paterson, & Turlink, 1984; 1985). They found a maturational aspect to the relationship with an increasing cooccurrence of fetal movements and FHR accelerations from 24 to 32 weeks GA. By term, the coupling of FHR accelerations and movements is striking. FHR accelerations occur with more than 90% of fetal movements (Timor-Tritsch et al., 1978) with a corresponding association of fetal movements with accelerations being observed (Dawes, Visser, Goodman, & Levin, 1981). Recently, in a longitudinal study of fetuses from 20 to 39 weeks GA, DiPietro and colleagues (DiPietro, Hodgson, Costigan, Hilton, & Johnson, 1996) demonstrated that the association of spontaneous FHR increases of a minimum of 5 BPM occurring within −5 to 15 s of body movements increased from 21 to 57%, while the latency to a FHR increase following movement decreased from 5 to 2.7 s over gestation. Timor-Tritsch et al. (1978) speculated that the nearly synchronous onset of the fetal movement and FHR acceleration suggests a coordinated control of both functions, presumably in the central nervous system. In addition, DiPietro et al. (1996) suggest that coupling reflects coactivation of the parasympathetic and sympathetic components of the autonomic nervous system for both motor and cardiac functions. These fetal observations are consistent with the infancy literature where tight coupling has been demonstrated in full-term newborns (Morrongiello & Clifton, 1984) and indicate fetal–newborn continuity of behavior.

D. Fetal Breathing Movements

Fetal breathing movements, first observed at about 10 weeks GA (de Vries et al., 1985), may occur at regular or irregular intervals or as a single event. Interpretation of the relevance of fetal breathing is complicated by the variable normal fetal breathing patterns (Patrick, Campbell, Carmichael, Natale, & Richardson, 1980; Andrews, Shime, Gare, Salgade, & Whillans, 1985) and the many factors influencing these patterns. Observations over 24 hr indicate that 24- to 28-week-old fetuses breathe about 14% of the time (Natale, Nasello-Paterson, & Connors, 1988) and that 32- to 40-week fetuses breathe about 30% of the time (Patrick et al., 1980). From 25 to 32 weeks GA, episodes of breathing lasting less than 10 s decrease and episodes lasting more than 30 s increase (Higuchi, Hirano, Gotoh, Otomo, Maki, 1991). Episodic breathing is interspersed with apnoeic periods which vary in length from as long as 14 min in the premature fetus (Natale et al, 1988) to 122 min at term (Patrick et al., 1980). The rate of breathing, measured by breath-to-breath intervals, increases from 16 to 19 weeks GA (de Vries et al., 1985) and then decreases from 30 weeks GA (Trudinger, Aust, & Knight, 1980). In addition, at term, breathing exhibits a circadian rhythm with decreased breathing between 1900 and 2400 hours and increased breathing overnight, between 0100 and 0700 hours (Patrick et al., 1980; Natale et al., 1988). Finally, also at term, breathing is influenced by fetal activity. Breathing is greater during periods of activity compared to quiescence (Van Vliet, Martin, Nijhuis, & Prechtl, 1985; Pillai & James, 1990). Gestational changes in breathing patterns are thought to result from the morphological maturation of the fetal lung and the functional development of the respiratory and sleep centers of the fetal central nervous system (Kozuma, Nemoto, Okal, & Mizuno, 1991).

Unlike FHR and fetal body movements, fetal breathing has been shown to be influenced by a number of internal and external factors. Decreases in fetal breathing have been observed following maternal alcohol ingestion in normal pregnancies (McLeod et al., 1983), during the first 2 weeks after premature rupture of membranes (Roberts, Goldstein, Romero, & Hobbins, 1991), and following intravaginal prostaglandin for induction of labor (Sorokin et al., 1992). Increases in fetal breathing have been noted following an excess of carbon dioxide in the blood (Ritchie, 1980; Connors, Hunse, Carmichael, Natale, & Richardson, 1988) and maternal ingestion of coffee (Salvador & Koos, 1989). From 19 weeks GA to term, numerous studies have demonstrated that raising the maternal blood glucose level results in increased fetal breathing (e.g., Adamson, Bocking, Cousin, Rapoport, & Patrick, 1983; Harper et al., 1987). The long-term effect of increasing maternal glucose on fetal/newborn outcome is unknown. In studies with the fetal lamb, it appears to be related to an increase of low-voltage electrocortical activity (Richardson, Hohimer, Mueggler, & Bisonette, 1982). Clearly, fetal breathing is sensitive to a number of external and internal factors, increasing or decreasing depending upon the specific stimulus employed.

In addition to studies with human fetuses, a number of drug studies carried out with animals demonstrate that the influence on fetal breathing is drug specific. Fetal breathing is decreased by barbiturates (Boddy, Dawes, Fischer, Pinter, & Robinson, 1976), diazepam (Piercy, Day, Neims, & Williams, 1977), prostaglandins (Kitterman, Liggins, Fewel, Clements, & Tooley, 1980), and general anesthesia (Maloney, Adamson, Brodecky, Dowling, & Ritchie. 1975). Fetal breathing is increased by catecholamines (Murata et al., 1979), caffeine (Piercy et al., 1977; Salvador & Koos, 1989), and prostaglandin synthetase inhibitors (Patrick, Challis, & Cross, 1981).

Finally, labor has been shown to influence breathing. There is a decrease of fetal breathing during the 3 days prior to the onset of labor with suppression of fetal breathing during the active phase of labor (Richardson, Natale, & Patrick, 1979; Besinger, Compton, & Hayashi, 1987). Even in the absence of labor, a reduction in the percentage of fetuses demonstrating fetal breathing was noted in women with premature rupture of membranes (65%) compared to a control group (90%) with intact membranes (Kivikoski, Amon, Vaalamo, Pirhonen, & Kopta, 1988).

The relevance of increased or decreased fetal breathing on growth and development of the fetus is unknown. Whether this behavioral shift reflects an attempt to compensate for the effects of internal and/or external changes in the fetal environment in order to facilitate normal development at the local level of the lung or whether it mirrors changes in brain development needs to be determined. Moreover, preliminary evidence suggests that fetal breathing may predict premature delivery and/or health status. For example, lack of fetal breathing has been associated with imminent premature delivery, regardless of membrane status (Besinger et al., 1987). As well, episodes of breathing lasting less than 30 s in conjunction with increased body movements in fetuses less than 33 weeks GA with ruptured membranes have been associated with intraamniotic infection (Goldstein et al., 1988). In order to resolve the issue of the relevance of fetal breathing, studies of breathing in groups of high-risk fetuses need to be carried out so that breathing patterns can be linked to fetal–newborn outcome.

E. Association of Fetal Behaviors

Descriptions of an association among FHR, body movements, and eye movements in the term fetus and rest–activity cycles in the premature fetus have led to the concept of fetal behavioral states (for discussion see Martin, 1992). Behavioral states are defined as both physiological and behavioral variables that are stable over time, recur in the same infant, and, in a similar form, in all infants (Nijhuis, 1992). Nijhuis et al. (1982), simultaneously recording FHR, body movements, and eye movements in fetuses 38 to 40 weeks GA, identified four distinct states, quiet sleep (F1), active sleep (F2), quiet awake (F3), and active awake (F4), which correspond to four previously described newborn states. Although there are instances of poor agreement among laboratories with respect to the occurrence of awake states (e.g., Arduini et al., 1993), the general consensus is that behavioral states are established by 36 weeks GA (Romanini & Rizzo, 1995). At term, fetuses show diurnal variations in the length of the quiet phase with longer periods occurring at night (Muro et al., 1996). Examining the continuity of sleep states in fetuses at term and then as neonates, Groome, Swiber, Atterbury, Bentz, and Holland (1997) found that the proportion of time spent in active and quiet sleep by fetuses and neonates was the same. However, fetuses made fewer transitions between quiet and active sleep states and took longer to complete a state change. Furthermore, the ordering of heart rate and eye movement changes during state transitions for fetuses and newborns was similar for quiet to active sleep transitions but not active to quiet sleep transitions, suggesting that the control of active sleep undergoes changes in the 4 weeks spanning the fetal and neonatal periods. In fetuses less than 36 weeks GA, states or state transitions are not well organized or recognizable electrophysiologically. However, rest–activity cycles can be classified reliably (Dierker, Pillay, Sorokin, & Rosen, 1982; Visser, Poelmann-Weesjes, Cohen, & Bekedam, 1987) and diurnal variations in fetal activities have been described as early as 20 to 22 weeks GA (de Vries et al., 1987). The underlying mechanism controlling behavioral states has not been identified. A link between maternal steroids and fetal behavior has been suggested. Evidence to support this hypothesis comes from studies reporting a relationship between maternal plasma cortisol concentrations and fetal activity (e.g., Arduini et al., 1987) as well as a decoupling of FHR–body movement responses in pregnancies with maternal perceptions of increased daily stress (DiPietro et al., 1996).

Using Doppler velocimetry (i.e., measurement of blood flow velocity waveforms) at 36 to 40 weeks gestation, fetal behavioral state-dependent changes in circulation have been observed (for review, see Wladimiroff, 1994). Researchers examining blood flow in the foramen ovale (e.g., van Eyck, Stewart, & Wladimiroff, 1990) and the atrioventricular valves (Rizzo, Arduini, Valensise, & Romanini, 1990) in active sleep (F2) and quiet sleep (F1) states, found an increased left ventricular output during state F2, suggesting a redistribution of cardiac output during this state. Increased blood flow in the internal carotid artery (i.e., increased fetal cerebral blood flow) during state F2 but no difference in umbilical artery blood flow between states F1 and F2 suggests a fetal origin for state-dependent changes in circulation (van Eyck et al., 1987). Studies relating changes in blood flow velocity waveforms to behavioral state/motility patterns demonstrate that fetal behaviors are expressions of more complex and encompassing physiological states.

EXPERIMENTAL STUDY: STIMULUS-INDUCED FETAL BEHAVIOR

In the late 1800s, informal observations of neonatal behavior, stimulation of the fetus with sound, and the fact that the fetal ear canal was filled with fluid led Preyer (1885/1937) to conclude that the human fetus had no auditory sensitivity. This view prevailed for the first half of the 20th century and few investigators (e.g., Pieper, 1925; Sontag & Wallace, 1936) examined the issue of fetal sensory sensitivity. Nevertheless, those who did challenged Preyer's conclusion. From studies using techniques that would be judged crude by today's standards, evidence emerged of fetal sensitivity to sound and vibration. For example, placing a hand on the mother's abdomen, Pieper (1925) noted that the sudden honking of an automobile horn within a few feet of the mother's abdomen late in pregnancy caused well marked movements of the fetus about 25 to 30% of the time. Using a stopwatch and stethoscope to monitor heart rate in 5- to 9-month-old fetuses, Sontag and colleagues (e.g., Bernard & Sontag, 1947; Sontag & Wallace, 1936) observed that a reliable FHR acceleration was first elicited by a vibratory stimulus at 7 months and that FHR acceleration and maternal reports of body movement responses cooccurred in 71% of fetuses tested.

By the 1970s studies employing new ultrasound technologies were reporting conflicting results. Some researchers were successful in eliciting fetal responding to sensory stimulation (e.g., 36- to 40-week GA fetuses, Dwornicka, Jasienska, Smolarz, & Wawryk, 1964; third-trimester fetuses, Gelman, Wood, Spellacy, & Abrams, 1982) while others were not (e.g., fetal age unspecified, Bench & Vass, 1970; Patrick, 1984). Finally, by the mid-1980s, a hundred years after Preyer's (1885/1937) assertion that the fetus had no auditory sensitivity, there was an accumulation of incontrovertible evidence that fetuses responded to sound and vibration with body movements and FHR accelerations (for review see Lecanuet, Granier-Deferre, & Busnel, 1995). Interestingly, more precise measurement confirmed the accuracy of early estimates. For example, Schmidt, Boos, Gnirs, Auer, and Schulze (1985) found a 30% response rate to acoustic stimulation in 37- to 42-week fetuses. Kisilevsky, Muir, and Low (1992) determined that FHR acceleration responses to vibroacoustic stimulation begin at about 29 weeks GA (i.e., the 7th month of pregnancy), and Grimwade, Walker, Bartlett, Gordon, & Wood (1971) found 83% coupling of FHR acceleration and body movement responses at 38 to 42 weeks gestation. Given a robust phenomenon and sophisticated technologies, the study of fetal behavior moved the frontier of developmental psychology from the newborn infant to the developing embryo and fetus. In little more than a decade, researchers have laid a solid foundation, characterizing the development of sensory sensitivity and employing response to sensory stimuli in the study of cognitive development.

A. Sensory Sensitivity and Development

Typically, sensitivity to sensory stimuli has been examined using acoustic or vibroacoustic probes to elicit FHR acceleration and body movement with fetuses from about 23 weeks GA to term (for review see, Kisilevsky, 1995). Methodology is particularly important in eliciting and observing fetal responses. For example, results from studies comparing maternal perceptions and ultrasound scan observations of vibroacoustic stimulus-induced body movements indicate that, over gestation, mother's perceive 27 to 75% fewer movements (Kisilevsky, Killen, Muir, & Low, 1991) and that mothers perceptions are influenced by the particular transducer used (Kisilevsky, Kilpatrick, & Low, 1993). Moreover, the particular acoustic or vibroacoustic stimulus (Kisilevsky & Muir, 1991; Kisilevsky et al., 1993), auditory stimulus intensity (e.g., Kisilevsky, Muir, & Low, 1989; Lecanuet, Granier-Deferre, Cohen, Le Houezec, & Busnel, 1986), and frequency (e.g., Lecanuet, Granier-Deferre, & Busnel, 1988) as well as vibroacoustic stimulus duration (Pietrantoni et al., 1991) have been shown to modulate the threshold and magnitude of the response. Kisilevsky et al. (1989) reported that the threshold for a reliable FHR acceleration to airborne white noise at term is between 100 and 105 dB (Note: The uterine attenuation of sound is 20 to 70 dB; Walker, Grimwade, & Wood, 1971; Querleu et al., 1986). Threshold was established by comparing responding on stimulus and no-stimulus control trials. In addition, the magnitude of the FHR acceleration has been shown to increase with increasing frequency (Lecanuet et al., 1988) and to decrease with repeated stimulus applications (e.g., Kisilevsky & Muir, 1991). The threshold for responding to airborne sounds in the premature fetus has not yet been determined. Moreover, for a vibroacoustic stimulus, an immediate (i.e., within 5 to 7 s of stimulus onset) FHR acceleration response was reliably elicited from fetuses beginning at 29 weeks GA (Kisilevsky et al., 1992). At term, Gagnon and colleagues (Gagnon, Hunse, Carmichael, Fellows, & Patrick, 1987, Gagnon, Hunse, Carmichael, Fellows, & Patrick, 1988b) describe an extended FHR acceleration response occurring between 10 and 25 min following 5 s of vibratory stimulation. Both the incidence and time of the response was reduced in growth-retarded fetuses between 26 and 40 weeks GA (Gagnon, Hunse, Fellows, Carmichael, & Patrick, 1988c, Gagnon, Hunse, Carmichael, & Patrick, 1989a). Because of the compound nature of the stimulus delivered by a vibroacoustic transducer (i.e., airborne sound and mechanical vibration), the stimulus characteristics essential to eliciting a response and controlling the magnitude of the response have not yet been identified. Furthermore, it should be noted that many of the acoustic stimulation studies controlled for experimental bias by rendering the mother naive to stimulus onset. None of the mechanical vibration studies could do so. Thus, maternal response to the stimulus is a possible confounding variable and it may be that maternal–fetal responsiveness is being examined.

Behavioral state also has been shown to influence fetal responding with fetuses more responsive in active than in quiet states (Schmidt et al., 1985). However, for studies across gestation, the discrimination of spontaneous fetal activity and fetal responding to sensory stimulation is problematic because behavioral states are difficult to identify in fetuses less than 36 weeks. To overcome the problem, some sensory studies include no-stimulus control trials (e.g., Kisilevsky et al., 1992). Comparison of behavior on stimulus and no-stimulus trials is used to determine stimulus-driven behavior.

Maturational changes in sensory-elicited responses are beginning to be characterized (e.g., Kisilevsky et al., 1992). For vibroacoustic stimuli, the onset of an immediate body movement (i.e., within 1 to 5 s of stimulus onset) is observed at 24 to 26 weeks GA, with the amount of movement increasing gradually as gestation advances. The picture appears more complex for a FHR response. A discontinuous function has been observed, beginning with a small, about 2 BPM, FHR deceleration at 26 to 28 weeks GA. Subsequently, at 29 to 31 weeks GA, a response shift occurs. Both immediate ($<$20 s following stimulation; Kisilevsky et al, 1992) and delayed ($\geq$10 min following stimulation; Gagnon, Hunse, & Patrick, 1988a) FHR acceleration responses are described. Furthermore, a number of researchers (e.g., Birnholz & Benacerraf, 1983; Crade & Lovett, 1988; Kisilevsky et al., 1992) demonstrated that the magnitude of FHR acceleration responses, the number of body movement responses, and the number of trials on which a response is elicited increase over gestation. The number of fetuses responding increases from about 30% at 24 weeks GA to 95% at 37 weeks GA (e.g., Crade & Lovett, 1988).

Maturation of responses to airborne sounds has not been characterized. Using a broad band noise (80–2000 Hz), played at 110 dB (A) and delivered by a speaker coupled to the maternal abdomen, Shahidullah and Hepper (1993) reported body movement responses at 20 and 25 weeks GA. Because the cochlea may have high thresholds and very poor discriminative properties at 20 weeks GA (Pujol, Lavigne-Rebillard, & Uziel, 1991), the authors suggest that the earliest response was probably mediated by the hair cells of the vestibular system of the ear rather than the auditory system. They place the onset of an auditory response at about 25 weeks GA, a time when auditory-evoked potentials in infants born preterm demonstrate cochlear function (Starr, Amlie, Martin, & Saunders, 1977). What remains to be characterized are the maturational changes in behavior using airborne sounds, including systematic observations of the threshold for a response as a function of stimulus frequency and intensity, and changes in the magnitude of the response with maturation.

Coupling of FHR and body movement responses has been observed. However, differential fetal response latencies found in studies using sensory stimulation raise the issue of whether elicited FHR accelerations are secondary to body movements. Fetal movements have a latency of 1 to 2 s (e.g., Granier-Deferre, Lecanuet, Cohen, & Busnel, 1985), depending upon stimulus intensity, while FHR accelerations have a latency of approximately 7 s (e.g., Kisilevsky et al., 1989). In explaining cooccurrence as a response to stimulation one might posit a longer latency from the autonomic nervous system to account for the delayed FHR acceleration response. Alternatively, differential latencies may reflect an initial movement response with FHR acceleration being subsequent to fetal movement rather than response to a stimulus per se. To date, this issue is unresolved. When examining responding in the premature fetus, the issue is even more complex. Unlike infancy where decelerations occur in the absence of body movements when the infant quiets/attends and accelerations cooccur with movements when there is generalized activation, at 26 to 28 weeks GA, FHR decelerations cooccur with movement responses (Kisilevsky et al., 1992). This observation suggests that movement and heart rate responses may be independent in early development. Of course, it may be that spontaneous and stimulus-induced behavior are controlled by different mechanisms. A comparison of spontaneous and stimulus-induced FHR acceleration/deceleration and movement latencies is needed to determine whether the same mechanisms are controlling coupling under both conditions.

B. Fetal Cognition

Fetal responses to sound and vibration are being used to examine fetal cognitive development. Evidence to support fetal cognitive functioning comes from studies demonstrating FHR decelerations to auditory probes, FHR acceleration and movement response habituation to repeated acoustic and vibroacoustic stimulation, and newborn preferences for auditory stimuli (e.g., the maternal voice) experienced during fetal life. In infants and adults, heart rate decelerations in response to sensory probes are considered evidence of attention. Recently, such decelerations have been elicited in fetal studies. At 35 to 39 weeks GA, Lecanuet and colleagues (Lecanuet, Granier-Deferre, & Busnel, 1989; Lecanuet, Granier-Deferre, Jacquet, & Busnel, 1992) elicited small but reliable FHR decelerations of 1 to 3 BPM to a 500-Hz octave band noise played at 105 dB, a musical sequence played at 85 dB, and a speech sequence recited by male and female speakers at 90 to 95 dB. Stimuli were delivered during periods of low heart rate variability using a method adapted from Clarkson and Berg (1983), who recorded newborn heart rate responses to a novel sound inserted among the continuous repetition of a low-intensity sound. This work provides convincing evidence of the term and near-term fetus' ability to attend to airborne sounds. What is even more impressive is that Lecanuet and colleagues (Lecanuet et al., 1989) also established that fetuses could discriminate sounds. Using a consonant vowel series, they showed that a second deceleration was elicited when the stimulus was changed, for example, from ''BABI'' to ''BIBA.'' Zimmer et al. (1993) extended this work demonstrating that consistently repeated speech stimuli elicited reliable FHR decelerations of about 0.4 to 0.8 BPM in preterm fetuses, 26 to 34 weeks GA. Clearly, small FHR decelerations, suggesting fetal attention, can be elicited under very limited conditions. This result is impressive given that normal FHR variability is 3 to 6 BPM.

Using a classical habituation paradigm,[5] FHR acceleration response de-

[5] Classical habituation is characterized by response decline to a repeated stimulus followed by renewed responding to the original stimulus following the presentation of a novel, dishabituating stimulus (Groves & Thompson, 1970; Thompson & Spencer, 1966).

cline and recovery were shown using an airborne noise and a vibroacoustic dishabituating stimulus (Kisilevsky & Muir, 1991). Habituation of vibroacoustic-elicited movement responses are well documented (Leader, Baillie, Martin, & Vermeulen, 1982; Kuhlman, Burns, Depp, & Sabbagha, 1988; Madison et al., 1986). However, the influence of gestational age (i.e., identification of age of onset and maturation) on habituation is unknown and studies of the premature fetus are needed to explore the issue. Habituation is an important phenomenon in the study of fetal development because some theorists (e.g., Kuhlman et al., 1988; Madison, et al., 1986; Hepper, 1994) argue that dishabituation (i.e., renewed responding) is evidence of early cognition and that the habituation process assumes sensory and selective attention capacity as well as short-term memory. Thus, demonstrations of habituation to sensory stimuli by term fetuses is considered to be evidence of early cognition/learning.

With regard to auditory preferences, seminal work by DeCasper and colleagues, exposing fetuses to a sound stimulus and then determining their preference for the sound after birth, provides convincing evidence of fetal cognition/learning. Using a nonnutritive sucking paradigm, they showed that neonates preferred their mother's voice (DeCasper & Fifer, 1980), a melody sung prenatally (Panneton, 1985 reported in Cooper & Aslin, 1989), and a maternal filtered voice (Moon & Fifer, 1990). Neonatal preference for a story read prenatally was demonstrated with both a nonnutritive sucking paradigm (DeCasper & Spence, 1986) and a HR deceleration measure (DeCasper, Lecanuet, Busnel, Granier-Deferre, & Maugeais, 1994). Clearly, knowledge regarding the onset and maturation of fetal sensory sensitivity is critical not only for an understanding of the development of sensory abilities but also because of the potential to identify periods when sensory stimulation might influence functional and behavioral development.

FETAL BEHAVIOR AND TESTS OF WELL-BEING

Recently, there has been a focus on determining the usefulness of fetal behaviors in the assessment of fetal well-being. Lack of a systematic approach has resulted in an assemblage of clinical studies that are difficult to organize with respect to specific normal or abnormal behavior. Researchers have tended to examine behavioral states or sensory-elicited responses in selected high-risk fetal (e.g., intrauterine growth-retarded) and maternal (e.g., diabetic) populations or to examine one dimension of fetal behavior in relation to certain criteria of newborn compromise. For example, differential development in behavioral states in intrauterine growth-retarded and hydrocephalic fetuses (Romanini & Rizzo, 1995) as well as fetuses of insulin-dependent diabetic mothers (Mulder, Visser, Bekedam, & Prechtl, 1987) compared to those of healthy fetuses have been reported. Furthermore, vibroacoustic-elicited FHR responses, which showed decline in a group of healthy fetuses, failed to demonstrate habituation in intrauterine growth-retarded fetuses and those of women with hypertension severe enough to be treated with medication (Leader, 1995). Studies also have shown that fetal response to vibroacoustic stimulation is indicative of a normal umbilical cord blood pH (i.e., pH greater than 7.25; Smith, Phelan, Platt, Broussard, & Paul, 1986) at delivery.

Systematic observations of fetal behavior are carried out during non-stress, biophysical profile, and vibroacoustic stimulation testing. To date, these tests are the most widely used measures of spontaneous and stimulus induced FHR changes, body movements, and breathing in obstetrical clinical practice. An extensive literature has increased our understanding of spontaneous behavior observed during non-stress testing and biophysical profile scoring, providing insight into fetal health at the time of testing as well as information about fetal development, impending labor, and infection. Nevertheless, the current consensus of the value of these tests in the term fetus is that they reflect the health status of the fetus at the time of testing but do not predict fetal or newborn outcome (Devoe, Castillo, & Sherline, 1985, Devoe, Ramon, Searle, & Searle, 1988; Freeman, 1990; Manning, 1990; Thacker & Berkleman, 1986). Although vibroacoustic stimulation is the most widely used measure of elicited fetal behavior, it is the least well standardized or evaluated behavioral assessment measure.

A. Non-Stress Test

A non-stress test is a continuous, 40-min recording of FHR, uterine contractions, and body movements while the mother is at rest. The latest electronic monitoring equipment simultaneously records both FHR and body movements. With older equipment, movement information is dependent upon the mother using an event marker to indicate perceived fetal movements on a FHR strip recording. Non-stress tests are interpreted by clinicians as reassuring (i.e., reactive), non-reassuring (i.e., non-reactive), or equivocal on the basis of the number of FHR accelerations coupled with body movements. A standard criteria for scoring has not been adopted (e.g., Borgatta, Shrout, & Divon, 1988). As the criterion for a reassuring test in the healthy, term fetus, many investigators (e.g., Evertson, Gauthier, Schifrin, & Paul, 1979) recommend, in a 40-min recording, the occurrence of 2 to 5 FHR accelerations of a minimum of 15 BPM lasting 15 s coupled with fetal body movements. Time of day may influence the results of the test since diurnal variations have been observed, with longer durations of FHR accelerations and higher incidence of reassuring tests noted at 2100 compared to 0900 hours (Petrikovsky & Kaplan, 1996). Results of studies with preterm fetuses (24 to 32 weeks GA) suggest that the testing time should be increased and that the magnitude of acceleration should be decreased (Castillo et al., 1989). Some authors include FHR baseline, baseline variability, accelerations, and decelerations in the identification of the compromised fetus, arguing that a composite score is more discriminating than accelerations alone (Flynn et al., 1982; Lumley, Lester, Anderson, Renou, & Wood, 1983; Brioschi et al., 1985). Typically, scoring requires a visual interpretation of the FHR record by experienced observers who have demonstrated interobserver reliability (Trimbos & Keirse, 1978). On-line microprocessor systems (e.g., Dawes, Redman, & Smith, 1985) that provide consistent analysis also are available. However, the nature and sensitivity of the raw data are lost because such systems summarize events over extended time periods (i.e., 10 min or more) providing a judgment of reassuring or non-reassuring for the overall test based on a set of clinical criteria. Thus, although the commercially available computer-automated scoring systems may be useful clinically, the inability to analyze the raw data precisely restricts their usage for research purposes. Thus, the continued use of visual interpretation by experienced observers seems prudent.

B. Biophysical Profile

A biophysical profile is a 20- to 30-min real-time ultrasound scan during which observations of fetal body movements, muscle tone, breathing, and amniotic fluid volume are made. A non-stress test may or may not be included. At present, there is no established scoring method for the biophysical profile. Most frequently cited is an 8- or 10-point scale with 2 points given for the observation of each of the following ''normal'' behaviors: 3 body movements; brisk flexion or extension of the limb, head, or trunk; 30 s of continuous breathing; at least one, 2-cm pocket of amniotic fluid or, alternatively, an amniotic fluid index score appropriate for gestational age; and, if included, a reassuring non-stress test (Manning, Baskett, Morrison, & Lange, 1981; Manning et al., 1987; Manning, 1990). Differences in scoring methods generally relate to whether a dichotomous scale (yes = 2, no = 0) is used or whether a third category, equivocal behavior, is included (equivocal = 1; Vintzileos, Campbell, Ingardia, & Nochimson, 1983). Scoring for clinical purposes is done by a trained technician who performs the scan. Generally, for a 10-point scale, a score of 8 or 10 is considered normal, 6 is considered equivocal, and 0 to 4 is considered abnormal (Manning, 1990; Manning & Harman, 1990).

C. Vibroacoustic Stimulation Testing

The impetus for the use of vibroacoustic stimulation in the assessment of fetal health was generated by the incidental observation (Murphy & Smyth, 1962) of the stillbirths of two high-risk fetuses who responded to sound at 30 weeks GA and then failed to respond at 34 weeks GA. Based on this observation, Read and Miller (1977) postulated that fetal response to sound might be useful in determining fetal well-being. Vibroacoustic stimulation is the most common type of stimulus administered, probably because it has been shown to elicit the highest fetal response rates (75 to 100% by Gagnon et al., 1988a and Kisilevsky et al., 1992). However, at present, there is no standard procedure for administering the stimulus with respect to transducer, maternal or fetal placement, duration, number of stimulus applications, or interstimulus interval. Investigators have used such diverse transducers as an electric toothbrush (e.g., Leader et al., 1982), a mini-shaker (Gagnon, Foreman, Hunse, & Patrick, 1989b), a commercial massager (Kisilevsky et al, 1992), and an artificial larynx (e.g., Birnholz & Benacerraf, 1983). In North America, the most common transducer in clinical use is an artificial larynx. However, reports that it induces tachycardia (Gagnon et al., 1988a), increases FHR baseline, produces unusual FHR patterns (Thomas et al., 1989), and disorganizes behavioral states (Visser, Mulder, Wit, Mulder, & Prechtl, 1989) make it unsuitable for research purposes. Furthermore, there are no established criteria to evaluate responding. Given that spontaneous activity is common, FHR acceleration and movement responses on stimulus trials need to be compared to those occurring on no-stimulus control trials to determine reliable stimulus-elicited responding. This has rarely been done. Furthermore, before fetal response to vibroacoustic stimulation can be interpreted meaningfully, differential behavior as a function of fetal/newborn outcome needs to be described. Given that stimulation stresses the system, it may be an appropriate method for identifying fetal signals of distress and targeting mechanisms controlling the responses.

Augmentation of standard behavioral tests with vibroacoustic stimulation improved the fetal biophysical profile score (Inglis, Druzin, Wagner, & Kogut, 1993) and decreased the number of non-reassuring or equivocal non-stress tests (Davey, Dommisse, Macnab, & Dacre, 1984; Smith, et al. 1986). Augmentation also decreased the time necessary to demonstrate a reassuring non-stress test (e.g., Serafini et al., 1984). Because spontaneous activity is dependent upon fetal rest–activity cycles, augmentation of the biophysical profile and non-stress tests with vibroacoustic stimulation has been used to elicit behavior when the fetus is quiet during testing. When the fetus is quiescent, the clinician does not necessarily know whether the fetus is compromised and unable to respond or merely in a quiet state. Sensory-elicited responding is an attempt to differentiate the two conditions. However, whether the nature of spontaneous and/or stimulus-induced behaviours differ when a fetus is compromised, compared to when it is quiet, is unknown. Identification and description of differential behavior as a function of newborn outcome are a necessary first step in addressing this issue. Such descriptions may allow not only for the assessment of well-being and the prediction of pregnancy outcome but also for the identification of the mechanisms controlling fetal behaviors (such as when the observation of maternal alcohol-induced suppression of fetal breathing movements was subsequently found to be mediated by increased prostaglandins; see review by Brien & Smith, 1991). A systematic examination and comparison of spontaneous and stimulus-induced behavior of high-risk and low-risk fetuses as a function of newborn outcome are necessary.

D. Behavioral Assessment of the Term and Preterm Fetus

A number of factors may account for the present limited usefulness of the behavioral observations made during non-stress testing, biophysical profile, and vibroacoustic stimulation to predict fetal and neonatal outcome. The vast majority of studies examining the value of using these behavioral assessments have tested term fetuses. In order to predict outcome, a large number of pregnancies require observation over a long time period. Moreover, prediction is constrained by the periodic nature of such surveillance which, in many cases, results in an interval of days or weeks between the time of the last assessment and the fetal complication or delivery. Finally, the prevalence of mortality and morbidity is low in the term pregnancy. These factors may not influence assessment of the fetus threatening to deliver prematurely to the same degree. Those pregnancies that deliver prematurely (about 5% of pregnancies in Canada; Millar, Strachan, & Wadhera, 1991) have a high occurrence of mortality and morbidity (40–50% by 5–8 years of age; e.g., Hunt et al., 1988; Klein et al., 1989) and require frequent surveillance over a relatively short period of time. Furthermore, Low and co-workers (Low, Robertson, & Simpson, 1989; Low, Simpson, & Ramsay, 1992) suggest that fetal insults occur in association with complications leading to premature delivery or during the period of threatened premature delivery. Clearly, human fetuses develop neuropathology. However, no clinical markers have been identified, to date, that reliably identify the pathophysiology in the fetus leading to brain damage. It seems reasonable to speculate that, at least in some instances, premature delivery is a response to fetal signals of distress. Moreover, fetal signals of distress should be mirrored in fetal behavior. Therefore, identification of differential behavior as a function of newborn outcome is critical to the identification of fetal signals of distress. No studies could be found that addressed either the issue of differential fetal behavior as a function of fetal/newborn outcome or the issue of the predictive value of fetal behavioral assessments in the premature fetus. Both issues need to be addressed before fetal signals of distress can be identified during behavioral assessments of the high-risk fetus.

In summary, to date, most fetal investigations have been focused on describing spontaneous behavior and changes in behavior when the fetus is stimulated with sensory or biochemical probes. Although there is still work to be done, these descriptions have formed a solid foundation upon which to build. Given a rich database, behavior continues to be characterized. Moreover, the focus is shifting to the identification and understanding of processes, mechanisms, and experiential factors underlying development.

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