Fetal Movements. Though They May Be Spontaneous, Yet There is Method in Them

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Contents

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Abstract

- The spontaneous movements of the newborn infant have a long prenatal history: from 7 weeks and 2 days onward, the human embryo moves.
- Already 2–3 weeks later, the spontaneously generated motility shows a rich repertoire of coordinated and identifiable patterns.
- Once a movement pattern is stabilized, it remains present for at least until term, but usually for longer, sometimes even for life.
- Embryonic and fetal movements are necessary for the proper development of the skeletal, muscular, and neural systems, or vice versa; normal fetal development requires adequate fetal activity.
- Hence, function is an integral part of normal development, and the prenatal use of an (albeit immature) structure is necessary for the continuing and normal development of the very structure.

1 Introduction

The English-German physiologist William T. Preyer (1841–1897) placed a stethoscope on the mother's abdomen and thus "heard" the fetal movements. He concluded that the movements were definitely present by a gestational age of 12 weeks, but most probably earlier. Furthermore, Preyer was convinced that those early movements were spontaneously generated (Preyer 1885). A few years later, also the obstetrician Ahlfeld, who recorded fetal breathing movements by means of a kymograph, considered those movements to be spontaneously generated (Ahlfeld 1888). However, the phenomenon of spontaneous movements was not yet pursued, since, at that time, scientists were convinced that such movements had to be evoked (Coghill 1929; Barcroft and Barron 1939). In his studies on exteriorized embryos and fetuses, Davenport Hooker observed movements without any evident prior tactile stimulation, and described them as “a spontaneous reflex for which the stimulus was not yet known” (Hooker 1952).

The first sonar studies of fetal movements, although not yet real time, were reported by the Viennese obstetrician Emil Reinold in 1971. He got the impression that fetal movements were actually comparable to the darting movements of fish. He further stated that it is not before the 10th week of gestation that fetal movements were forceful enough to alter the position of the fetal body. And, lastly, he came to the conclusion that the observed movements of the fetus were spontaneous rather than caused by external influences (Reinold 1971). Nowadays, we have extensive experimental evidence that embryonic and fetal movements are endogenously generated, and that motor output to the developing muscles can occur even in the absence of sensory input (Hamburger et al. 1966; Oppenheim 1982; for a review: Einspieler et al. 2004, 2010).

With the advent of real-time ultrasound scanners, an attempt was made to determine the age at which fetal movements first occur. Van Dongen and Goudie (1980) observed embryos with a crown-rump length of 5–12 mm, and saw the heart pulsating at 6 weeks' gestation, with tiny movements occurring in one pole of the embryo at 7–8 weeks of age. At that time, the door has opened to both the behavioral and the neurological assessment of the human fetus (Ianniruberto and Tajani 1981; de Vries et al. 1982; Nijhuis et al. 1982). Today, dynamic fetal MRI allows an additional detailed behavioral observation of the fetus (Prayer and Brugger 2007).

From a methodological point of view, our studies on fetal behavior come very close to the approach of developmental neurology, where the observation of movement patterns, of their quantity and, above all, their quality, serves as a basis for the investigation of neural development and for the assessment of the condition of the nervous system (Prechtl 1990, 2001; Einspieler et al. 2004).

2 The First Body Movements

Hippocrates (460–370 BC) already suspected that fetal movements might set in a few weeks earlier than the expectant mother feels them. More precisely, he suggested that the fetus could start moving as soon as 70–90 days after conception, which corresponds to a gestational age of 12–15 weeks (Needham 1959).

Owing to recent transvaginal ultrasound recordings following in vitro fertilization, we by now know that the earliest body movements occur at 7 weeks and 2 days (Lüchinger et al. 2008). They consist of slow, small, noncomplex sideward bending of the head or the rump or both, sometimes accompanied by a little activity in the arms or legs a few days later. A week later, speed and amplitude of the movements start to vary to some degree, although no variation in sequence or direction can be seen as yet. By 10 weeks' gestation, the duration of this sideward bending increases to 5 s, while at the same time, its frequency of occurrence decreases.

Coinciding with the appearance of the first movements, axodendritic synapses are rapidly formed in the cervical spinal cord – initially between interneurons and motoneurons, then between afferent fibers and interneurons. In the lateral motor column, axodendritic synapses increase from one synapse per 200 μm^2 at 8 weeks to 10 synapses at 9 weeks (Okado 1981).

3 Startles and General Movements

By 8–10 weeks' gestation, movements emerge in the entire body (de Vries et al. 1982). They can be either quick and forceful, i.e., in the form of startles, or slower and more complex. The latter are referred to as general movements (Prechtl et al. 1979), which comprise the rotation of the thorax, partial rotation of the head, and displacement of the limbs. As startles promote a displacement of the thorax, they often induce a general movement (Lüchinger et al. 2008). It would seem plausible, therefore, that the simultaneous ontogenetic onset of these two movement patterns (Table 1) has an adaptive function.

A startle is initiated in the limbs and spreads to the neck and trunk. Depending on whether the initial limb posture is extended or flexed, the limbs either flex or

Table 1 The first occurrence of specific spontaneous embryonic and fetal movement patterns

8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Startles															
General movements															
Hiccup															
	Isolated arm movements														
	Isolated leg movements														
	Breathing movements														
	Micturation														
		Side-to-side movement of the head													
		Ante- and retroflexion of the head													
		Jaw opening													
			Hand–face contact												
				Opening and closing of fingers											
				Stretch											
				Yawn											
					Isolated finger movements										
					Tongue protrusion										
						Sucking and swallowing									
								Slow eye movements							
												Rapid eye movements			
														Blinking	

Age in gestational weeks

extend, respectively. With progressing gestational age, startles increasingly set out from flexed extremities, resulting in an extension of the limbs (de Vries et al. 1982; Roodenburg et al. 1991).

General movements comprise the entire body and manifest themselves in a variable sequence of arm, leg, neck, and trunk movements. They appear and cease gradually and vary in intensity and speed (Prechtl 1990, 2001; Einspieler et al. 2004). Rotations and frequent slight variations of the direction of motion make them look complex but smooth.

From 9.5 weeks' gestation onward, the majority of general movements show a substantial degree of variation not only in speed, amplitude, and direction but also in the sequence of the participating body parts. At this early stage, the sideward bending of the head and rump still coexists with general movements (Lüchinger et al. 2008). At 10–12 weeks gestational age, the general movements become more forceful, albeit smooth in appearance. They frequently cause a shift in the fetal position. After 12 weeks, they come and go, but vary more in speed and amplitude, lasting up to 5 min. However variable these movements may be, they are always graceful and fluent in character (Einspieler and Prechtl 2005; Einspieler et al. 2010).

General movements increase during the first weeks of pregnancy; then they reach a plateau and remain at this level for the first two trimesters, only to decrease again around term (Roodenburg et al. 1991; ten Hof et al. 1999). Although the space within the uterus becomes increasingly limited during the end of pregnancy, it seems more likely that the decrease of general movements is a result of the central nervous system development. Interestingly enough, the incidence of general movements also decreases in low-risk preterm infants until term age, even though there is no space limitation (Prechtl et al. 1979).

3.1 Minimal Structures are Capable of Generating Well-Organized Movements

The synaptic innervation of cervical motoneurons only sets in at 8–9 weeks' gestation (Okado and Kojima 1984; Konstantinidou et al., 1995), when startles and general movements emerge. By the end of week 10, the number of axodendritic synapses on the motoneurons has increased about eightfold, while axosomatic synapses only increase at 14–15 weeks (Okado and Kojima 1984). The first appearance of definite myelinated fibers is in the lateral portion of the ventral marginal layer at 12 weeks' gestation (Okado 1982). The differentiation of skeletal muscles is yet at an early phase as well, as it is even several weeks after the onset of general movements (Fidziańska and Goebel 1991).

Observations on anencephalic fetuses have demonstrated that minimal neural structures are sufficient to generate fetal movements. Isolated arm movements, breathing movements, and hiccups can be seen, although only fetal meninges, glial tissue, ectopic motoneurones, and dorsal ganglia are present at the level of the spinal cord (Visser et al. 1985). However, the quality of the movements is abnormal. It is clear, therefore, that a normal fetal nervous system, albeit age-specifically still poorly developed, is needed in order for movements to be executed normally.

3.2 Abnormal General Movements

The variability and complexity of general movements is an indicator for the integrity of the young nervous system (Prechtl and Einspieler 1997). If the nervous system is impaired, general movements become monotonous and repetitive; they loose their fluent appearance and become fragmented, jerky, and abrupt. This can be observed in fetuses with prenatally acquired leukomalacia (Prechtl 1997), in fetuses exposed to antiepileptic drugs (Swartjes et al. 1992), in fetuses of mothers with type-I-diabetes (Kainer et al. 1997), or in growth-retarded fetuses, especially after the occurrence of abnormalities in the fetal heart rate (Bekedam et al. 1985; Sival et al. 1992).

Fetuses with brain malformations have usually forceful and abrupt general movements with large amplitude. Anencephalic fetuses, for example, have also an abnormal temporal patterning: the excessive activity is either scattered throughout the observation time or movements occur in burst–pause patterns (Visser et al. 1985; Kurauchi et al. 1995).

Interestingly, fetuses with spina bifida do show leg movements of an even normal quality (Sival et al. 1997). Also, postnatally – during the first 2 days of life – movements can be normal, especially if the meningomyelocele is caudal from L3. Only thereafter, leg movements become abnormal until they disappear (Sival et al. 2006).

4 Specific Motor Patterns of the Limbs

One might assume that, at this early stage, isolated movements should be more difficult to produce for the nervous system than global motor activity while, in fact, the isolated movements of particular limbs emerge only a few days after the general movements (de Vries et al. 1982; Prechtl 2001). And, here is yet another unexpected finding: it has traditionally been taken for granted that the early ontogenetic process goes from cranial to caudal (Saint-Anne Dargassies 1979). Although this assumption is primarily based on stimulation experiments (Hooker 1952), the motor system does not follow that rule: isolated arm and isolated leg movements emerge at the same time, at 9–10 weeks (Table 1). It is a fact, however, that isolated arm movements occur more frequently than isolated leg movements, which certainly biases the results of short-lasting recordings (Prechtl 2001; Einspieler et al. 2010).

4.1 Arm, Hand and Finger Movements

Isolated arm movements, rapid or slow, may involve extension, flexion, external or internal rotation, abduction or adduction of an arm without movement in other body parts. Fast, jerky arm movements can either appear as single events (twitches) or as rhythmical movements at a rate of 3–4 per second (clonus). Cloni only appear after 14 weeks, but are rare even then (de Vries et al. 1982).

Fetuses start to clench and unclench their fists at 12–13 weeks' gestation (Ianniruberto and Tajani 1981). Isolated movements of one or more fingers appear from 13 to 14 weeks onward (Pooh and Ogura 2004). Some hand postures resemble postnatal hand gestures (Fig. 1).

From 11 to 13 weeks' gestation onward, the hand regularly touches the head, face, and mouth (Ianniruberto and Tajani 1981). These contacts are most frequent between 14 and 20 weeks, before decreasing again (van Tol-Geerdink et al. 1995). The hand slowly touches the face, with the fingers extending and flexing. Insertion of finger(s) into the mouth, occasionally even thumb-sucking, is observable.

There are several case reports of third-trimester fetuses who grasp (Fig. 2), manipulate, and even squeeze the umbilical cord. Partial or intermittent complete cord occlusion alters the blood flow in the umbilical cord, increases the afterload, and decreases

Fig. 1 MRI print of a 27-week-old fetus with pointing index finger

Fig. 2 MRI prints of a 27-week-old fetus grasping the umbilical cord

the fetal oxygen content (Ball and Parer 1992), which results in increased vagal activity causing variable fetal heart rate decelerations by up to 15–60 beats per minute (Petrikovsky and Kaplan 1993; Habek et al. 2006). Such a significant heart rate deceleration may result in diminished fetal cardiac output due to a poorly developed Frank-Starling mechanism at low fetal heart rates. Any hypoperfusion thus engendered is likely to be transient, however, because the brainstem-mediated grasp reflex would soon be abolished due to sustained hypoperfusion of the fetal central nervous system. Still, it sometimes takes a motor provocation test (vibroacoustic stimulation) for the fetus to release the umbilical cord. On release, heart rate decelerations disappear immediately (Heyl and Rath 1996).

4.2 Leg Movements

Isolated leg movements, rapid or slow, may involve extension, flexion, external or internal rotation, abduction or adduction of a leg without movements in other body parts (de Vries et al. 1982). A sporadic kick can be of sufficient strength to displace the fetus from its resting position. Slow leg movements are rare. Fast and jerky leg movements occur either as a single event (twitch) or as rhythmical movements at a rate of 3–4 per second (clonus). Leg twitches and cloni occur not only as isolated phenomena but may also be superimposed on general movements or, in fact, precede them.

The so-called stepping movements, as observed after birth are most probably a remnant of a specific fetal function, namely alternating leg movements, which enable the fetus to change the position (Prechtl 2001).

5 Diaphragmatic Movements

The formation of the diaphragm sets in at 8 weeks' gestation and is completed by 10 weeks (Wells 1954), providing the anatomical substrate for the onset of hiccups and breathing movements. While motoneurons need a critical number of functional synapses in order to discharge spontaneously, phrenic motoneurons in the cervical region seem to possess sufficient synapse contacts to produce hiccup by as early as 8 weeks (de Vries et al. 1982). Fetal breathing movements typically follow 2–4 weeks later (de Vries et al. 1982), although they can sometimes even be observed as soon as 8–9 weeks (Lüchinger et al. 2008).

The developmental trends of both motor patterns are quite different, with fetal hiccups being the predominant type of diaphragmatic movements up until 26–30 weeks and fetal breathing movements predominating thereafter (Pillai and James 1990). The observation that hiccups decrease with advancing gestational age suggests that brain development may have an inhibitory effect on the hiccup. This assumption is corroborated by the finding that growth retarded or otherwise compromised fetuses hiccup more often than normally growing fetuses (Bots et al. 1978; James et al. 1995).

5.1 Hiccups

Pregnant women do usually notice fetal hiccups, which are forceful and jerky diaphragmatic contractions characterized by a sudden and abrupt displacement of the thorax and abdomen (de Vries et al. 1982; Zheng et al. 1998). Hiccups are often followed by passive limb or head movements, sometimes by both. Typically, hiccups occur episodically, in regular succession, at an interval of 2–3 s. Such hiccup spells can last up to 10 min (van Woerden et al. 1989). During fetal hiccups, the umbilical artery flow can be transiently reduced or even reversed (Levi et al. 2000), but this is not associated with an adverse fetal outcome (Mueller and Sipes 1993).

5.2 Breathing Movements

Fetal breathing movements emerge at 8–12 weeks (de Vries et al. 1982; Lüchinger et al. 2008). They are paradoxical in nature: inspiratory movements consist of fluent movements of the diaphragm in caudal direction, making the anterior chest move inward and the abdominal wall move outward (de Vries et al. 1982; Maršál et al. 1984). The displacement of the diaphragm in the caudal direction varies in amplitude and lasts no longer than 1 s. In normal fetuses, chest wall movements are generally 2–5 mm in amplitude, abdominal wall movements 3–8 mm (Patrick et al. 1978).

Breathing movements vary from superficial and rapid to deep and slow (Roodenburg et al. 1991). Such rapid and irregular ones (both in rate and amplitude) account for more than 90% of all breathing movements, while slow, deep inspiratory movements like sighs or gasps, or respiratory efforts that resemble grunting, coughing, or panting, are less frequent (Cosmi et al. 2001). Yet another type is shallow fetal breathing movements (Piontelli 2006), a form of superficial and regular breathing movements characterized by low synergistic outward excursions of the thorax and the abdomen. Shallow fetal breathing movements are noticed from 12 weeks onward; they increase until 16 weeks and then level off.

Lung development depends on normal fetal breathing movements. Surgical procedures that prevent breathing movements in fetal lambs cause severe lung hypoplasia (Wigglesworth and Desai 1982). Aside from lung growth, fetal breathing movements are also required for lung maturation. If they are abnormal, surfactant-active material is only partially released into the alveolar or amniotic fluid (Dornan et al. 1984). Moreover, fetal breathing movements appear to be required for the accomplishment of the morphological differentiation of type I and type II pneumocytes (Inanlou et al. 2005).

There are a number of (patho)physiological conditions that affect fetal breathing movements (Table 2). Among them, a high maternal plasma glucose concentration causes an increase of fetal breathing movements (Harper et al. 1987). Even around term, when fetal breathing movements are usually almost absent, they can increase by 25% after intravenous administration of glucose to the mother (Divon et al. 1985). Also, fetuses of diabetic mothers show more breathing movements than normal fetuses (Mulder and Visser 1991).

Table 2 Physiological reasons and pathophysiological conditions that result in an increase or decrease of fetal breathing movements

	Increase	Decrease
Physiological reasons	Glucose intake	Labor
	Diurnal variation: early morning	Diurnal variation: late evening
		Maternal fasting
Pathological conditions	Maternal diabetes	Smoking
	Maternal hypercapnia	Alcohol
		Methadone
		Maternal hyperventilation
		Severe fetal hypoxia
		Preterm rupture of the membranes

6 Specific Motor Patterns of the Head

Side-to-side movements of the head set in at 10–11 weeks' gestation (de Vries et al. 1982). They are usually characterized by slow speed and may cover a range of approximately 160°. At times, such head movements come along with hand-to-face contact. Quite often, side-to-side movements succeed each other, incidentally reaching a rhythmical pattern over a longer period. Prechtl (1989) regards these rhythmical side-to-side movements, which are slightly irregular in nature, as the basis of rooting. In the newborn, rooting gradually comes under tactile control and develops into an oriented turning response of the head and mouth toward the eliciting stimulus (Prechtl 1958).

Retroflexion of the head is usually carried out at a slow pace, but can sometimes also be quick and jerky, resembling a twitch. The displacement of the head varies in amplitude; wide displacement may cause overextension of the fetal spine. The head may remain retroflexed from a few seconds to more than a minute. Sometimes, retroflexion of the head is part of a stretch or yawn. It emerges at 10–11 weeks (Table 1) and can occur up to 12 times per hour, especially during the second half of pregnancy (de Vries et al. 1982; Roodenburg et al. 1991).

Anteflexion of the head is carried out at a slow pace and sometimes occurs along with hand-to-mouth contact. After birth at term, it takes 4–5 months for the anteflexion of the head to reoccur, so the movement in utero appears to be due to the buoyancy effect in the amniotic fluid (Prechtl 2001).

6.1 Movements of the Jaw

Spontaneous jaw movements emerge at 10–11 weeks' gestation (van Dongen and Goudie 1980). At this age, the masseter muscle is still mainly composed of irregularly arranged myotubes, and the motor endplate is as yet simple and undeveloped (Ezure 1996). Until up to 15 weeks' gestation, single wide opening of the jaw is more common than later (de Vries et al. 1982).

Rhythmical mouthing shows a developmental trend diametrically opposed to that of general movements. Its incidence increases progressively during the last 10 weeks of gestation (D'Elia et al. 2001). By now, the myotubes in the masseter muscle have disappeared and the muscle is composed solely of muscle fibers (Ezure 1996). Once fetal behavioral states are established, clusters of regular mouthing occur – in the absence of other motor activities – during behavioral state 1F, or quiet sleep (D'Elia et al. 2001). Rhythmical mouthing movements like sucking can entrain a sinusoidal-like fetal heart rate pattern that coincides with the oscillation frequency of the mouthing cluster. This might deceive the clinician, since a sinusoidal fetal heart rate can also reflect an underlying pathology like fetal anemia or acute blood loss (Nijhuis 2003).

At 13–14 weeks' gestation, mouth opening with tongue protrusion may occur (Ianniruberto and Tajani 1981). It is known from experiments on mice that tongue movements are required for a normal development of the palate (Walker and Quarles 1962). In the human fetus, tongue expulsion, tongue thrust, or tongue click can occasionally be observed during the second half of pregnancy (Roodenburg et al. 1991; Yigiter and Kavak 2006). Most of the tongue protrusions can be observed during behavioral state 2F, or active sleep (van Woerden et al. 1988).

By means of 3D-ultrasound, various facial expressions can be distinguished, such as smiling movements (Campbell 2002), full extension of the lips in a pout or scowling (Yan et al. 2006). Usually, 3D-recordings are carried out during the last trimester, which is why the early ontogeny of these facial expressions is not yet known.

6.2 *Eye Movements*

By means of transabdominal ultrasound scanning, the fetal lens can be seen at 14 weeks' gestation (de Elejalde and Elejalde 1985). Displacement of the lenses indicates (1) slow, rolling eye movements, or (2) rapid, more regular eye movements (Prechtl and Nijhuis 1983). Eye movements begin to consolidate at about 24 weeks – a tendency that becomes more distinct henceforth as the consolidation grows into a long-term cluster of rapid eye movements from around 30 weeks onward (Bots et al. 1981; Koyanagi et al. 1993). Bear in mind, however, that it is extremely difficult – and sometimes impossible – to assess eye movements while the fetus is performing general movements or head rotations.

From 23 to 26 weeks onward, opening and closing of the eyelids can be observed (Campbell 2002). Repeated blinking is associated with the central dopaminergic system (Karson 1982). It occurs during the last weeks of pregnancy at a frequency of 6 ± 2 blinks per hour (Petrikovsky et al. 2003).

7 Stretches and Yawns: Life-Long Motor Patterns

One striking phenomenon in fetal motor development is the early emergence of stretches and yawns. They both can be observed from 12 weeks onward (de Vries et al. 1982), but even more interesting is the fact that they continue to exist throughout life with virtually no change in form or pattern.

A stretch consists of the following components: marked extension of the trunk, retroflexion of the head, and elevation of the arms in outward rotation. The pattern lasts for several seconds and only occurs in the form of isolated events. Sometimes a stretch is accompanied by a short-lasting heart rate deceleration.

Yawning is a phylogenetically old, stereotyped event in humans and animals (Darwin 1872). It is considered to be indicative of fatigue, drowsiness, or boredom, although research has found no support of these popular hypotheses. In fact, neither elevated carbon dioxide nor a depressed oxygen level in the blood increases yawning; and, reversely, breathing pure oxygen does not decrease yawning either (Provine et al. 1987). As for the fetus, yawning is not associated with fetal hypoxia (Sepulveda and Mangiamarchi 1995). The most curious, if least understood, aspect of human yawning is its contagiousness: people who witness or even just think about yawning cannot help but yawn themselves, which is not so much a case of imitation – since the mirror-neuron system is not involved – as an automatically released behavioral act (Schürmann et al. 2005).

A fetal yawn starts with a slow, usually wide and prolonged opening of the jaw and a simultaneous downward moving of the tongue as well as a retroflexion of the head, sometimes accompanied by limb stretching. After reaching its maximum opening, the mouth remains open for a few seconds. The third part of the complex yawning movement consists in shutting the mouth quickly and returning to the initial position. Once a yawn is under way, there seems to be no way back. Fetal yawning is accompanied by a flow of fluid between the amniotic cavity and the fetal airway (Masuzaki et al. 1996).

The physiological function of yawning is still a subject of speculation. Some consider it to be a protective mechanism that prevents alveolar collapse (Sepulveda and Mangiamarchi 1995). Others regard it as a spreading activation of facial motor patterning (Giganti et al. 2002). The powerful muscular contraction caused by yawning could also release arousal by activation of the locus coeruleus, to which the cranial nerves send retro-projections (Saper et al. 2001). Still others consider yawning a mechanism for thermoregulation, providing compensatory cooling when other provisions fail to operate favorably (Gallup and Gallup 2008).

8 Sucking and Swallowing

We know from ultrasound recordings that from 14 weeks onward (Table 1), rhythmical bursts of regular jaw opening and closing at a rate of about 1–2 per second can be followed by swallowing movements, which indicates that the fetus is drinking amniotic fluid (de Vries et al. 1982). Sucking and swallowing increase as pregnancy progresses. By 34 weeks, most healthy fetuses can suck and swallow well enough to sustain nutritional needs via the oral route, if born at this early age (da Costa et al. 2008). During the final weeks of life, sucking increases, as does the amount of amniotic fluid swallowed: starting from 2 to 7 mL per day, the fetus swallows 450–500 mL per day by the end of pregnancy (Bosma 1986).

Swallowing is both preparatory and functional. It is preparatory in the sense that the neonate must be capable of ingesting food actively; and it is functional in that fetal swallowing – along with urine flow and intramembraneous resorption of fluids – is one of the main regulators of the amniotic fluid volume (Bacchi Modena and Fieni 2004). Moreover, swallowing is considered to enhance the growth and development of the mandibula (Sherer et al. 1995) as well as the gastrointestinal tract (Grassi et al. 2005).

9 Diurnal Variations of Fetal Activities

As early as by 20–22 weeks' gestation, fetal activity shows a diurnal variation with peaks of activity in the late evening (Patrick et al. 1982; de Vries et al. 1987; de Vries and Fong 2006). It is, above all, the increase in breathing movements during the afternoon that accounts for this diurnal variation. Head retroflexion and jaw opening also occur more often in the afternoon and in the evening than in the morning. Since the percentage of general movements per hour basically remains constant throughout the day, general movements account for 50% of the total activity during the morning hours, but only for 30% during the evening hours.

At midgestation, diurnal variation of the basal fetal heart rate, which is closely related to the maternal heart rate variation, sets in as well (de Vries et al. 1987). The underlying mechanism of this biological clock is poorly understood and caution is required in determining causal links. The suprachiasmatic nuclei in the anterior hypothalamus also seem to play an essential role in generating diurnal rhythms in early development (Lunshof et al. 1997). Furthermore, maternal factors – especially maternal glucocorticoid levels – may play an important role, since heart rates of anencephalic fetuses with an aplasia rostral of the medulla oblongata show diurnal oscillations (Muro et al. 1998).

10 Continuity of Motor Patterns from Prenatal to Postnatal Life

While birth is an environmental discontinuity *par excellence,* the motor repertoire displays an impressive continuity from intrauterine to extrauterine life (Prechtl 1984). The comparison of a third-trimester-fetus with a preterm infant of the same age reveals that their movements are pretty much the same in spite of the fact that the respective environmental influences are quite different in terms of gravity, spatial constriction, and perceptual information. Neither preterm infants nor preterm fetuses change their motor repertoire in a way that would indicate functional reorganization around term age (Prechtl 1985).

Some movements like stretches or yawns maintain their pattern throughout life, whereas other patterns such as general movements or sucking change at the end of the second month postterm (Hopkins and Prechtl 1984; Iwayama and Eishima 1997; Einspieler et al. 2004). Anteflexion of the head and upward extension of the legs disappear temporarily after birth, only to reappear 15–18 weeks later.

A set of endogenously generated motor patterns gradually comes under afferent control after birth (Prechtl 1984, 2001). Rooting is an outstanding example: a rhythmical side-to-side head movement in the fetus, it aligns with the stimulated perioral area in the young infant. While, in the fetus, sucking movements are endogenously generated, they need to be triggered after birth in the actual feeding situation. Hence, it is a matter of vital biological adaptation that rooting and sucking are elicited in the proper feeding situation, which now is initiated by the caregiver. Other examples of endogenously generated motor patterns that need to come under sensory control are breathing movements and smiling movements.

11 Why Does the Fetus Move in the First Place?

There is more and more evidence that embryonic and fetal movements are necessary for the proper development of the skeletal, muscular, and neural systems, or vice versa, that normal fetal development requires adequate fetal activity. Function is an integral part of normal development, and the prenatal use of an (albeit immature) structure is necessary for the continuing and normal development of the very structure.

If the neuromuscular activity underlying the movement is silenced pharmacologically or by disease, the population of the spinal motoneurons, the distribution of neurotransmitter receptors on the muscle fibers, and the pattern of neuromuscular synaptic contacts develop abnormally (Pena and Shokeir 1974; Oppenheim 1981; Moessinger 1983).

The number of motoneurons undergoing genetically determined cell death (apoptosis) is closely related to muscle activity. Chick embryos immobilized by means of neuromuscular blocking agents show an increase of motoneurons in the brachial and lumbar lateral motor columns that would otherwise degenerate. When administration of the immobilizing agents is stopped, allowing the embryo's motility to return to control level, the excess neurons undergo a delayed cell death and the total cell number falls below control level (Oppenheim et al. 2003). On the other hand, there is a delay in the disappearance of early multiple motor endplates when muscle activity is reduced by means of tenotomy in young rats (Benoit and Changeux 1975). Conversely, this disappearance is accelerated when muscle activity is increased by way of electrical stimulation of the corresponding nerve (O'Brien et al. 1978).

In the context of the human fetal akinesia deformation sequence, it has been reported that, in one and the same fetus, a partial absence of movements results in contractures or hypoplasia in the respective regions (e.g., upper limbs, part of the face, thorax), while the active regions (e.g., lower limbs) develop normally (Tongsong et al. 2000).

In addition to common genetic regulatory programs required for organogenesis, mechanical forces generated in the embryo or fetus also have an influence on how the differentiating tissues respond to gene instructions. Lack or impairment of such physical forces changes the state of the organs (Inanlou et al. 2005).

Fetal movements continuously change the position of the fetus – when, for example, the trunk follows a rotation of the head, or when the fetus somersaults backward with the help of alternating leg movements. These active – and frequent – changes of the intrauterine position prevent adhesions and local stasis of the blood, especially in the early fetus, whose skin is very fragile (Visser and Prechtl 1988).

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