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The emergence of fetal behaviour. I. Qualitative aspects

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Summary

The emergence of spontaneous fetal motility during the first 20 weeks of gestation was studied longitudinally in 11 healthy nulliparae, using real-time ultrasound. The aim of this investigation was to study the onset and developmental course of spontaneously generated specific fetal movement patterns. 60-min observations were repeated weekly from 7 to 15 weeks and at 16/17 and 18/19 weeks. The qualitative aspects of fetal motility and posture were analyzed during video recording. Sixteen distinct movement patterns (just discernible movements; startle; general movements; hiccup; breathing; isolated arm or leg movements; isolated retroflexion/rotation and anteflexion of the head; jaw movements; sucking and swallowing; hand-face-contact; stretch; yawn; rotation), closely resembling those observed in preterm and fullterm newborn infants, could be distinguished and a detailed description is presented. The first movements were observed at 7.5 weeks postmenstrual age. A scatter of two weeks was found for the ages at which frequently occurring movement patterns could be observed for the first time. By the age of 15 weeks all 16 movement patterns could be observed. There were no major changes between 8 and 20 weeks in the appearance of the different movements, which meant that they were easy to recognize at all ages studied. A systematic assessment of position and posture showed a preference for the supine position before 16 weeks, and for the lateral position after 16 weeks. There was no consistent intra-individual preference for position or posture. Two specific motor patterns could be identified as causing either somersault or rotation around the longitudinal axis. The number of changes in fetal position increases from 10 weeks onwards, reaches a peak at 13–15 weeks and decreases after 17 weeks.

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fetal movement patterns; real-time ultrasound; first half of gestation; normal pregnancy

Introduction

Spontaneously generated motility as an expression of early neural activity is common to all vertebrate embryos and fetuses. Although interest in this phenomenon dates back to antiquity, systematic studies were not undertaken till the end of the 19th century.

In mammals, including the human, systematic observations on embryonic (and fetal) spontaneous and evoked movements have been carried out in operatively aborted fetuses [3,6,7,11,15,20]. In addition, spontaneous motility of the human fetus has been recorded with transducer devices through the abdominal wall of the mother. Both techniques suffer from limitations which were only recently overcome by the introduction of modern real-time ultrasound scanning of the intrauterine fetus. This non-invasive technique not only provides direct visualization of fetal activity, but also makes it possible to do repeated and prolonged observations in a systematic manner throughout the course of pregnancy.

Thus, we now have a tool to investigate longitudinally the emergence and differentiation of an individual's prenatal movement repertoire. Methodologically this is very close to the approach in developmental neurology in which the observation of quality and quantity of movement patterns serves as a basis for the investigation of neural development and for assessment of the condition of the nervous system. Moreover, the modern scanning technique enables us to make a critical evaluation of the earlier findings obtained from the exteriorized fetus. Our present knowledge of prenatal development of neural functions is almost exclusively based on the results of such experiments involving fetuses who were in a terminal condition.

Besides these more basic issues, the assessment of the fetal neurological condition can be expected to become a practical intra-uterine diagnostic procedure for clinical purposes. However, designing such a procedure only becomes meaningful once a sound knowledge of normal development has been achieved.

With these goals in mind we try in the present study to answer the following questions, at least for the first 20 weeks of gestation:

1) How should fetal movement patterns be classified exhaustively in the age range from 7 to 20 weeks?
2) At what age does each of these movement patterns appear for the first time?
3) Do these movement patterns change their quality during intrauterine development?
4) Are there age related preferences in fetal position?
5) Are specific motor patterns responsible for changes in the fetal position?

The study is restricted to the first 20 weeks for purely technical reasons. With the presently available equipment, the older fetus cannot be visualised as completely as can the younger fetus. When the fetus grows larger only parts of the body can be seen and thus, at the present time, it is not possible to differentiate movement patterns with the same reliability after 20 weeks.

Subjects and Method

Eleven healthy nulliparae volunteered after a detailed explanation of the aim of the investigation. They were selected when they came for the first out-patient visit at 7 or 8 weeks of gestation. All women had a clean history and continued to have an uneventful course of pregnancy. The duration of gestation was calculated from the first day of the last menstrual period and checked by repeated measurements of crown–rump length. In two cases fetal age was adjusted according to this growth parameter. All individual growth curves stayed at all ages within $\pm$ 2 S.D. of the Robinson curve [31].

Continuous real-time ultrasound observations of 60 min duration each, were repeated weekly from 8 to 15 weeks and then at 16 or 17 and 18 or 19 weeks. Although observations continued until the end of pregnancy these additional observations will not be reported here for reasons already mentioned.

All recordings were performed between 16.00 and 18.00 hours, the women lying on a bed in a comfortable semi-recumbent position. The transducer of a linear array real-time scanner (Searle Model 2300, probe 3.5 MHz, display field 11.4 cm wide) was fixed to the maternal abdomen in the appropriate position by a specially constructed mechanical holder. The fetuses were usually visualized in the mid- or para-sagittal longitudinal section. If the fetus changed position the transducer was adjusted accordingly. A graphic notation of every new position of the transducer was made in order to document the fetal position in relation to the maternal abdomen.

For an adequate analysis of fetal motility a sufficiently long observational period is necessary. We felt it was safe to expose fetuses for 1 h to the particular type of ultrasound we employed, following the statement of the Committee on Bio-effects of the American Institute of Ultrasound in Medicine made in 1976 [1]: "In the low MHz frequency range there have been, as of this date, no demonstrated significant biological effects in mammalian tissues exposed to intensities below 100 mW/cm^2. Furthermore, for ultrasonic exposure times less than 500 s and greater than 1 s, such effects have not been demonstrated even at higher intensities, when the product of intensity and exposure time is less than 50 J/cm^2" (p. 351). In the present studies the spatial peak temporal average was 0.2 mW/cm^2. Exposure time exceeded 500 s but the product of intensity and exposure time was far less than 50 J/cm^2 (viz.: $0.2 \times 10^{-3} \times 3600 = 0.7$ J/cm^2).

The scanning images of each session were recorded on video tape together with the output of a digital clock in order to locate each observed event at a precise moment in time.

Analysis of fetal motility was carried out only during playback of the video recordings. The incidence and duration of different movements was marked on an event recorder (Hewlett-Packard, 7754A) employing hand-held push buttons. Movements of the head, trunk and extremities respectively were scored separately during three playback sessions. In a fourth playback the fetal positions and postures were analyzed.

During a pilot study a scheme for the classification of the different movement patterns of the fetus was designed. To this end 21 1-h recordings of nine fetuses, ranging in age from 7 to 20 weeks, were used. To ensure a detailed observation, the video tapes were run repeatedly. Recognition of the different movement patterns of the fetus was facilitated by previous research on preterm and fullterm infants [26,27].

Inter-observer training was carried out until a high degree of agreement was reached in the recognition and differentiation of the various movement patterns (viz. above 90%). During the course of the present study a few details were added to the classification obtained during the pilot study. For these refinements the agreement between different observers was also satisfactory.

Results

As a result of the observations made during the pilot study and the eleven cases of the present investigation, we arrived at the following classification of sixteen distinct movement patterns.

Classification of movement patterns

(1) Just discernible movements

Between 7 and 8.5 weeks postmenstrual age a slow and small shifting of the fetal contours is seen lasting from half a second to two seconds, which usually occurs as a single event. The small size of the fetus (about 2 cm) and the limited resolution of contemporary scanning equipment has so far impeded a more detailed analysis of this type of movement.

(2) Startle (Fig. 1)

A startle is a quick generalized movement, always initiated in the limbs and sometimes spreading to neck and trunk. Flexion or extension of the limbs is usually of large amplitude, but can also be small or just discernible. The movement lasts about one second. Startles frequently occur as single events but may sometimes follow each other in rapid succession with a few seconds interval. Startles can appear superimposed on a general movement, or may be followed by a general movement within ten seconds.

(3) General movements

This category is applicable if the whole body is moved but no distinctive patterning or sequencing of the body parts can be recognized. When they first appear at 8 and 9 weeks, they are slow and of limited amplitude. At 10–12 weeks general movements become forceful. Movements of the limbs, trunk and head are

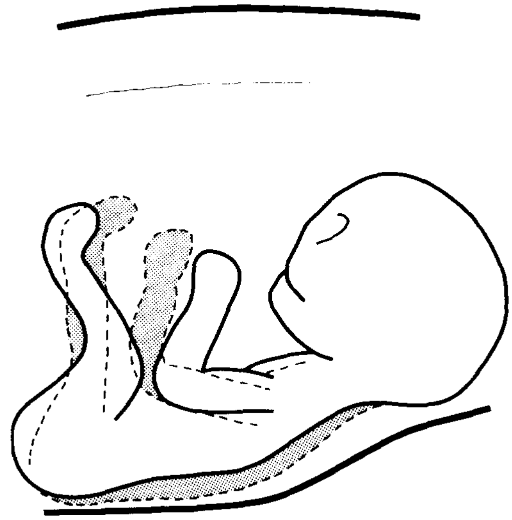

Fig. 1. Startle: Drawing from video monitor. Initial position and end position (grey) of movement.

rapid but smooth in appearance. The movements are of large amplitude and therefore frequently cause a shift in fetal position during this age period.

After 12 weeks general movements become more variable in speed and amplitude. They may last from about 1 to 4 min but wax and wane during this period. However variable these movements are, they are always graceful in character.

(4) Hiccup

A hiccup consists of a jerky contraction of the diaphragm. An abrupt displacement of diaphragm, thorax and abdomen can be seen on the scanning image. It lasts less than 1 s. Hiccups frequently follow each other in regular succession, but infrequently may occur as single events. They are often followed by passive limb and/or head movements. There is a clear difference between startles and hiccups: startles are initiated in the limbs, whereas a hiccup begins with a jerky diaphragmatic movement which may be followed by displacement of the limbs.

(5) Breathing

Fetal breathing movements in utero are paradoxical in nature, i.e. 'inspirations' consisting of fluent simultaneous movement of the diaphragm (caudal direction), leading to movements of the thorax (inwards) and abdomen (outwards). Each displacement of the diaphragm lasts less than 1 s and can be either small or large. Usually, breathing occurs episodically and can be either regular or irregular. The earliest breathing movements tend to have a regular pattern.

Although breathing frequently occurs alone, it is sometimes seen in combination with jaw opening and/or swallowing, as well as with general movements. A single

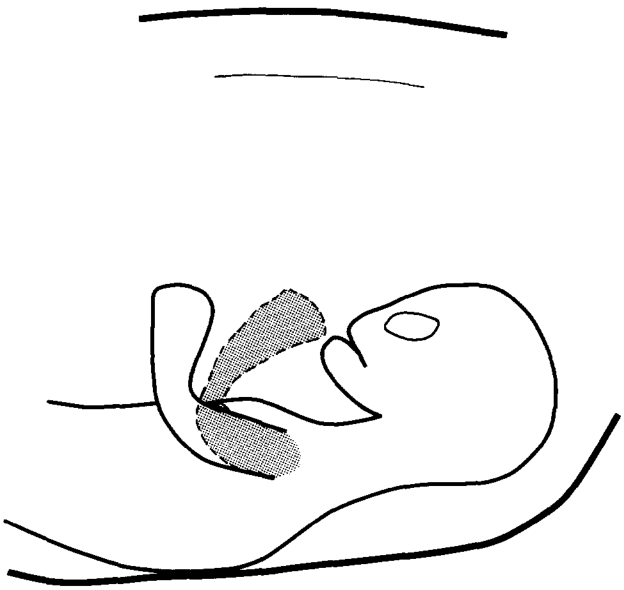

Fig. 2. Isolated arm movement. Initial position and end position (grey).

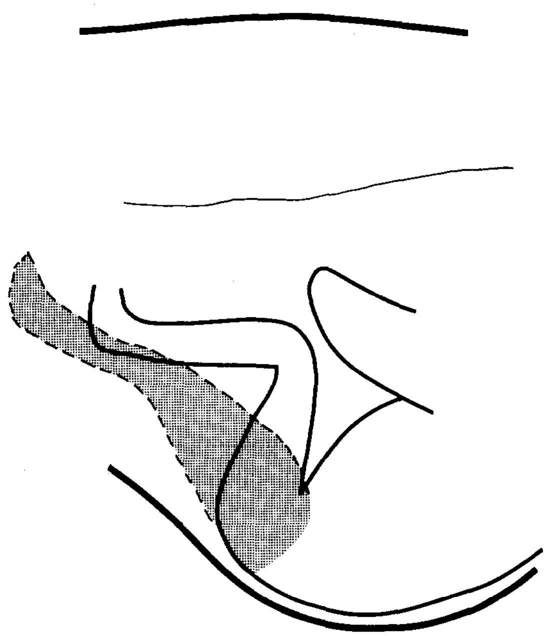

Fig. 3. Isolated leg movement. Initial position and end position (grey).

breathing movement with a large displacement of the diaphragm may resemble a sigh.

(6/7) Isolated arm or leg movement (Figs. 2 and 3)

These may be rapid or slow movements, and may involve extension, flexion, external and internal rotation or abduction and adduction of an extremity, without movements in other body parts. The amplitude can vary from small to very large. Extension of an arm is frequently accompanied by extension of fingers at least after 12 weeks. Slow arm movements often occur unaccompanied by other movements. Slow leg movements are rarely seen. Fast and jerky movements of the arm or leg can occur either as a single event (twitch) or as rhythmical movements at a rate of about three to four per second (clonus). The latter only occurs after 14 weeks and is rare even then. Twitches and cloni occur not only as isolated phenomena but may also be superimposed on general movements or may precede them.

(8) Isolated retroflexion of the head (Fig. 4)

Retroflexions of the head are usually carried out slowly, but can also be fast and jerky. The displacement of the head can be small or large. The latter may cause over-extension of the spine of the fetus. The head may remain in retroflexion for 1 s to more than 1 min. Although most often seen as a single isolated event, repetitive jerky retroflexion of the head also occurs. Slow retroflexion of the head may be accompanied by a wide opening of the jaws and rotation of the head.

(9) Isolated rotation of the head (Fig. 5)

Rotation of the head is carried out at a slow velocity and only exceptionally at a

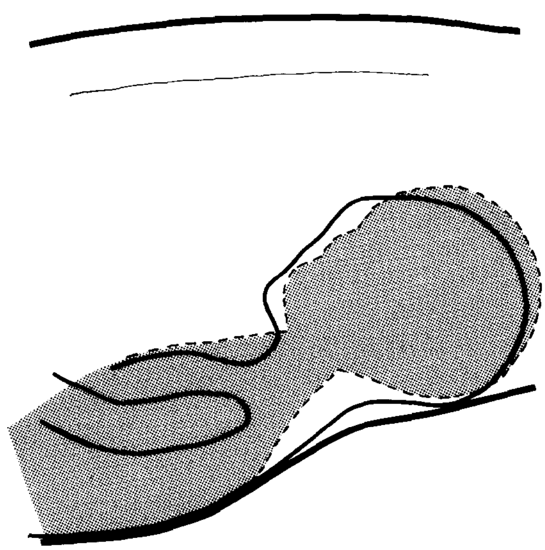

Fig. 4. Retroflexion of the head. Initial position and end position (grey).

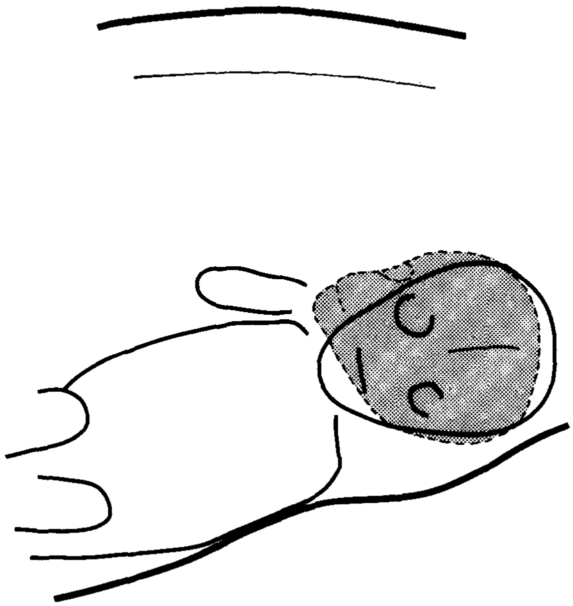

Fig. 5. Rotation of the head. Initial position and end position (grey).

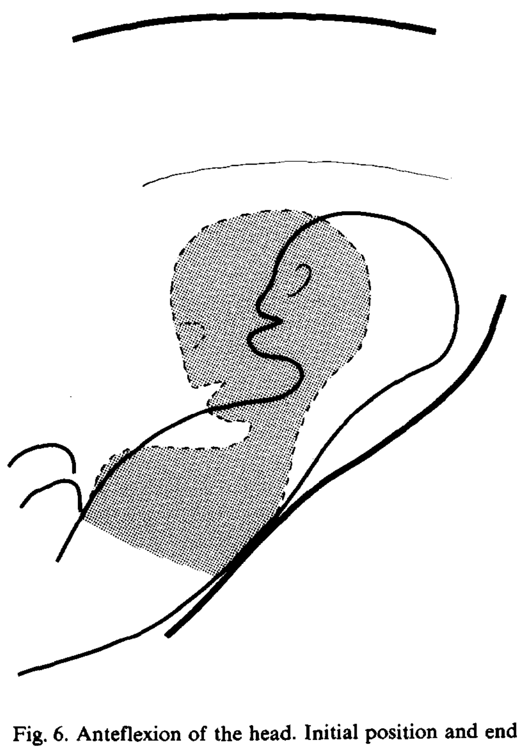

Fig. 6. Anteflexion of the head. Initial position and end position (grey).

higher speed. The head may turn from a midline position to one side and back. The duration of the movement is mostly longer than one second. The movement frequently occurs as a single event, but if repeated is never rhythmical. Rotation of the head is often associated with hand-face-contact.

(10) Isolated anteflexion of the head (Fig. 6)

Anteflexion of the head is only carried out at a slow velocity. The displacement of the head is small. The duration is about 1 s. Anteflexion can occur alone and singly, but it also happens rhythmically together with hand-face-contact, when sucking can be observed.

(11) Jaw movements

Jaw opening may be either slow or quick. The extent of jaw opening is variable. The duration of opening varies from less than 1 s to 5 s. The movement may occur once or be repeated. Up to 15 weeks a single wide opening of the jaws is more common than at later age; irregularly repeated movements occur more often after 15 weeks than before. Jaw opening may occur alone or during general movements, with hiccups (probably passive) and with isolated head movements. Movements of the tongue are also incidentally observed.

(12) Sucking and swallowing

Rhythmical bursts of regular jaw opening and closing at a rate of about one per second may be followed by swallowing, indicating that the fetus is drinking amniotic fluid. Swallowing consists of displacements of tongue and/or larynx.

(13) Hand-face-contact

In this pattern of movement the hand slowly touches the face, the fingers frequently extend and flex. Insertion of fingers into the mouth can only very rarely be seen accurately. Hand-face-contact continues for a period of time exceeding 1 s. It either occurs alone or as a part of a general movement.

(14) Stretch (Fig. 7)

A stretch is a complex motor pattern, which is always carried out at a slow speed and consists of the following components: forceful extension of the back, retroflexion of head, and external rotation and elevation of the arms. This pattern always lasts several seconds, and only occurs singly.

(15) Yawn (Fig. 8)

This movement is similar to the yawn observed after birth: prolonged wide opening of the jaws followed by quick closure often with retroflexion of the head and sometimes elevation of the arms. This movement pattern is non-repetitive.

(16) Rotation of the fetus

Rotation of the fetus occurs around the sagittal or transverse axis. A complete change in position around the transverse axis, usually with a backwards somersault,

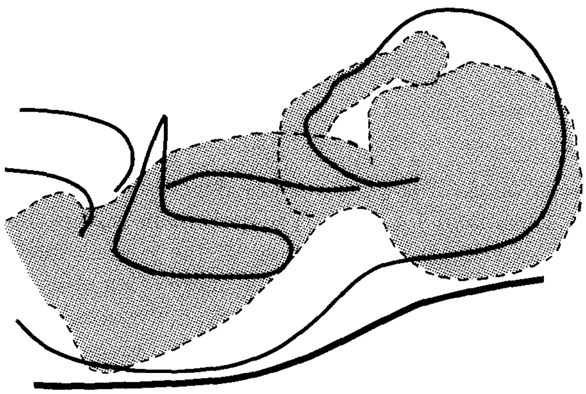

Fig. 7. Stretch. Initial position and end position (grey).

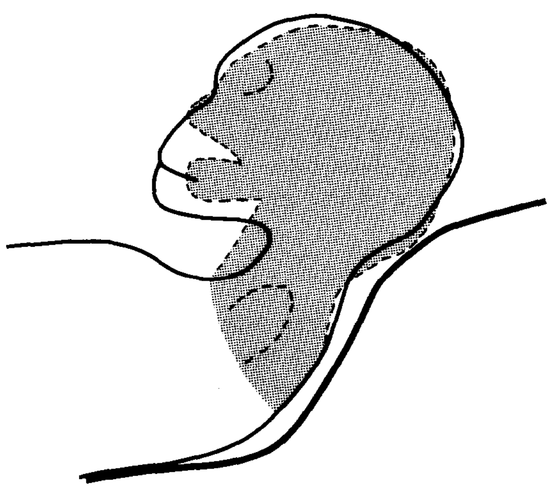

Fig. 8. Yawn. Initial position and end position (grey).

is achieved by a complex general movement, including alternating leg movements which resemble neonatal stepping. Rotation around the longitudinal axis can either be the result of leg movements with hip rotation, or result from rotation of the head, followed by trunk rotation. A total change in fetal position can be achieved in as little as 2 s, but may take more time.

Developmental onset of specific fetal movement patterns

The first just discernible movements of the fetus occur at 7 weeks and a few days in two out of five observations, the rest follows at 8 weeks postmenstrual age. These movements are at the limit of the resolution of our equipment. After 9 weeks these kinds of movements are no longer observed. All other previously mentioned movement patterns, once observed, remain present during the observation period until 20 weeks, and many of them can also be observed in preterm and fullterm infants.

Although eye movements had been observed incidentally from 18 to 20 weeks, we did not pay special attention to them, as they are difficult to observe without special scanning procedure.

When the different movement patterns are rank-ordered according to their first appearance in the group of eleven fetuses (Fig. 9), all fetuses follow a specific sequence or developmental profile. A certain scatter exists in the ages at which each of the individual patterns are observed for the first time over the group of fetuses. This scatter is partly produced by the 1-week intervals between the observations (resolution).

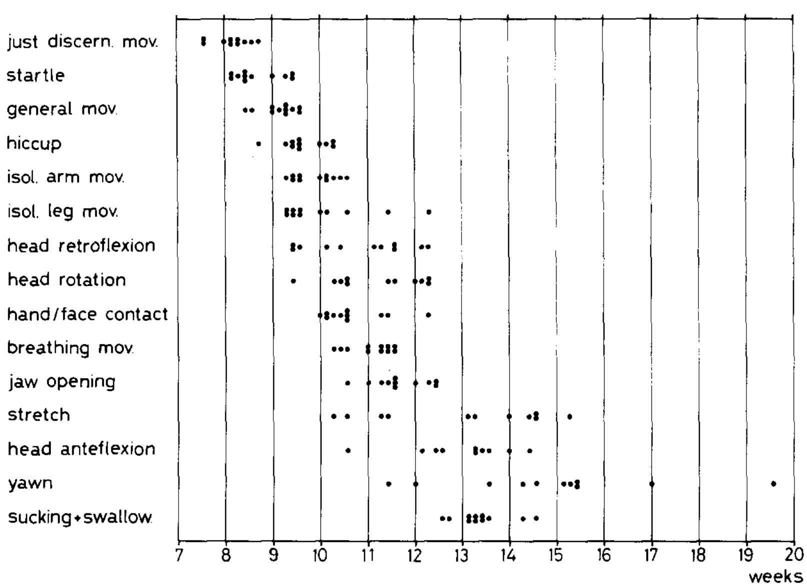

Fig. 9. First occurrence of specific fetal movement patterns. Each dot represents an individual. Ages at observations are given in full weeks and days.

The 2-weeks range found for startles, general movements, hiccups, isolated arm movements (more frequently occurring than isolated leg movements) and breathing movements may be also due to the scatter of conception in relation to the first day of the last menstrual period. When we plotted the onset of patterns in relation to crown–rump length, the ranges gave an identical picture.

Another possible reason for the wide scatter observed in some of the items (e.g., stretch, head anteflexion, isolated leg movements and sucking–swallowing) is their infrequent occurrence. Thus, they may not be seen during a particular hour of observation (see Fig. 11).

Periodicity of activity

Fetal motility in its various components develops early a temporal patterning. The distribution and duration of general movements, for example, changes with age (Fig. 10). At 8 weeks, these movements are scattered irregularly over the record, whereas they occur grouped in bursts of several minutes during the following weeks. The occurrence of such bursts becomes obscured after 14 weeks and is replaced by much longer epochs of fluctuating activity. Periods in which general movements or other gross movements are absent, usually have a duration of about 5 min but pauses of up to 14 min have been observed.

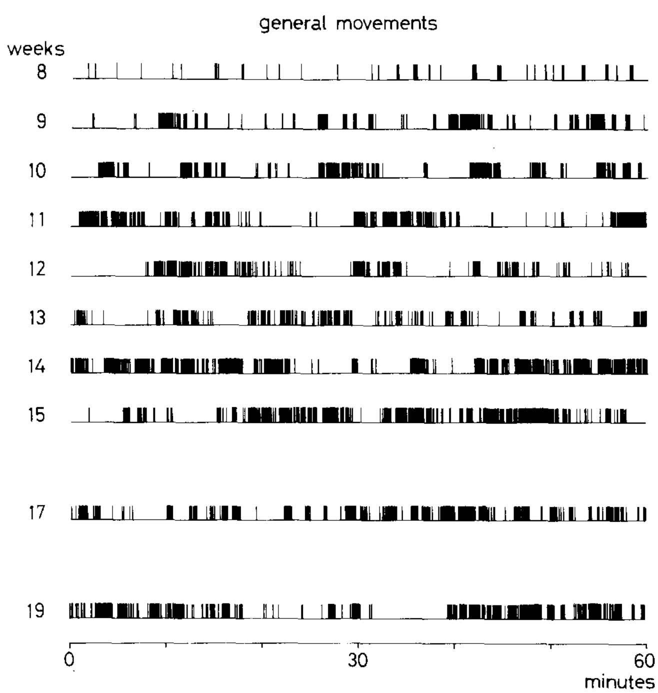

Fig. 10. Representative example of the rate of general movements. Each upward deflection indicates an observed general movement.

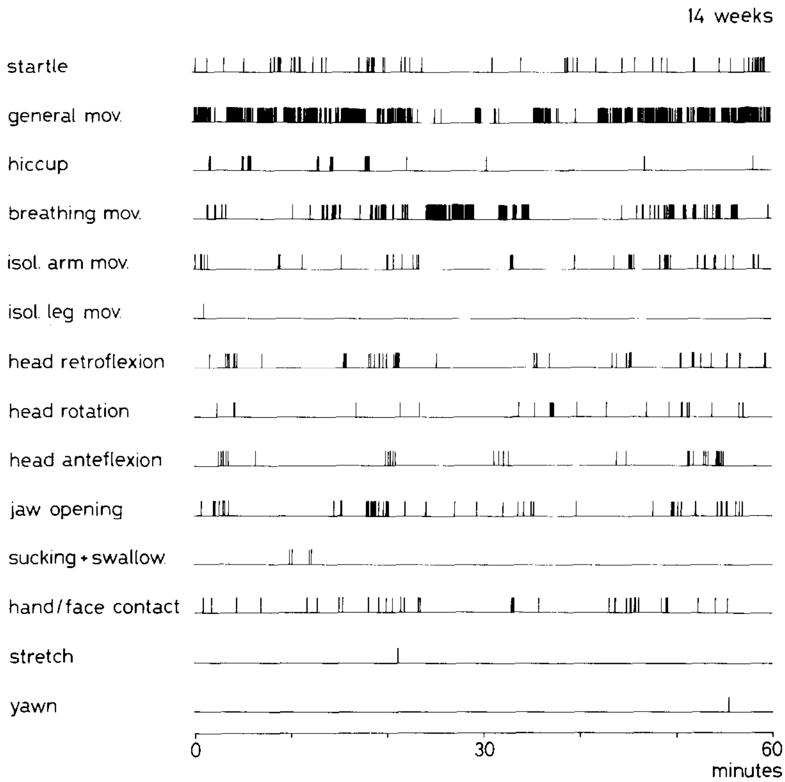

Fig. 11. Compiled actogram of one hour observation of a fetus at 14 weeks. Note the different periodicities and the multitude of specific movement patterns.

The periodicity is not restricted to general movements. In a representative example of a 1-h recording at 14 weeks (Fig. 11), grouping of activities is evident in various movement patterns. In addition, the richness of the repertoire of specific fetal movements and their temporal pattern can be clearly seen.

Fetal position

(1) Orientation in the uterus

As all recordings were made with the transducer in a sagittal plane of the fetus, the position of the scan on the maternal abdomen was an indicator for orientation of the fetus within the uterus. Three possibilities can be distinguished: longitudinal, diagonal, transverse. The percentages of the total recording time in which each fetus is found in one of the three orientations are given in Fig. 12a, b and c, respectively. While the transverse orientation decreases from 12 to 20 weeks, the longitudinal orientation shows the reverse. Diagonal positions are more frequently seen between 11 and 17 weeks than before and after that age.

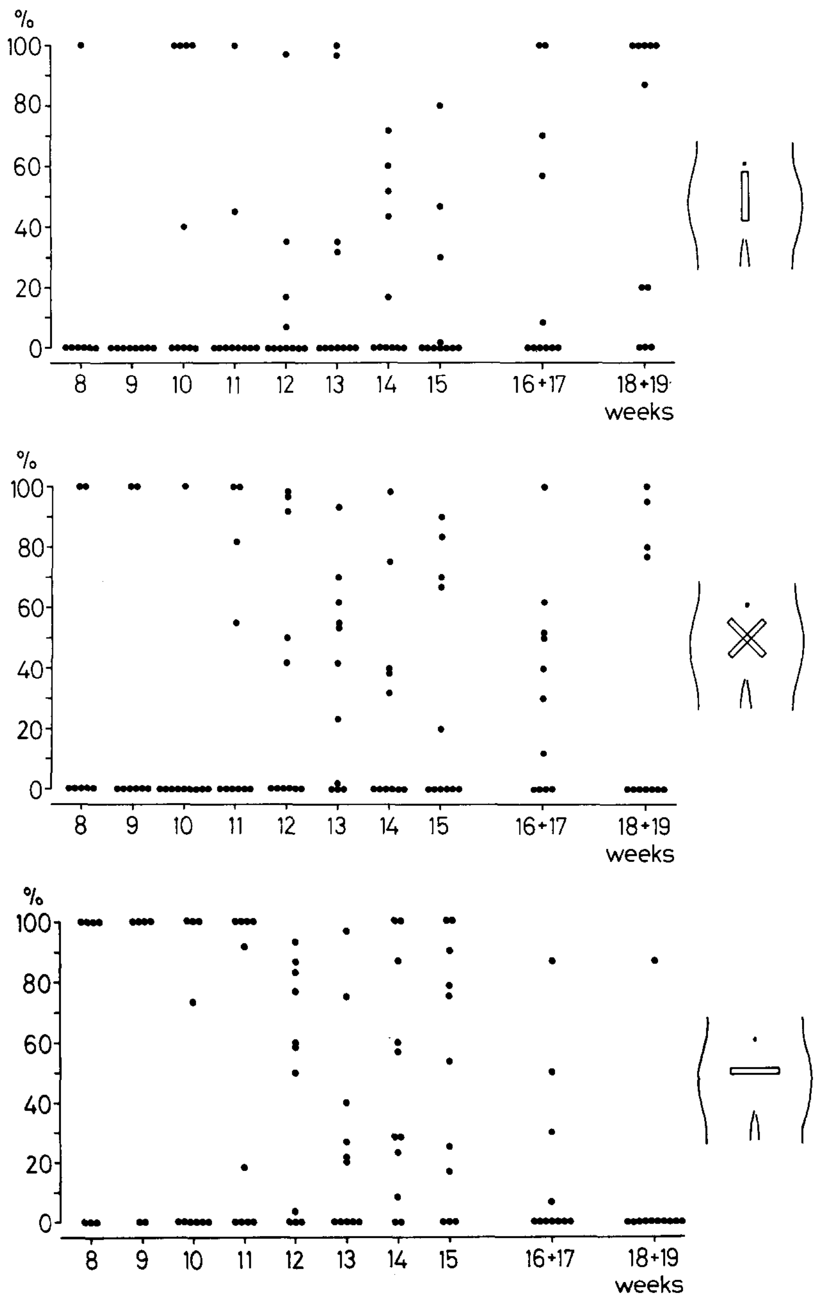

Fig. 12. (a) Percentage of recording time in which the transducer was placed in the longitudinal position over the uterus. Each dot represents an individual. Below eleven weeks, data are not available for all 11 cases. When fetal orientation was in the mother's anterior-posterior axis, recorded scan position is omitted. (b) Same as in (a) but transducer in diagonal position. (c) Same as in (a) but transducer in transverse position.

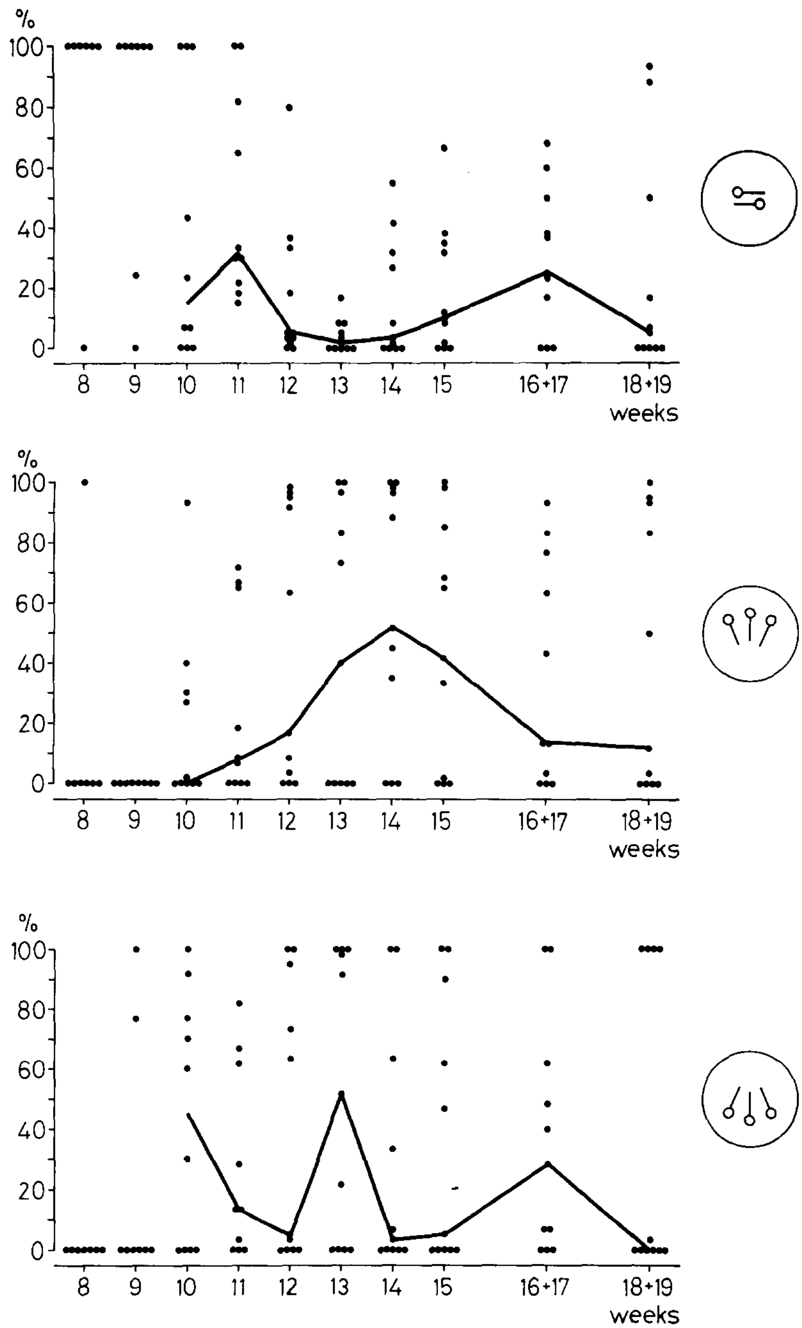

Fig. 13. (a) Percentage of recording time in which the fetus was in horizontal orientation in the scan plane (see right hand indication). Dots represent individuals. Solid line gives median values per week. (b) Same as in (a) but fetus with head up and rump below. (c) Same as in (a) but fetus with head below and rump up.

(2) Orientation within the field of gravity

The standardized supine position of the mothers during the recordings insured that the plane of scanning was always parallel to the force of gravity. Therefore, the orientation of the fetus' head and trunk within the scanning plane indicates his orientation in the field of gravity. The preferred position is horizontal (Fig. 13a) at 8 and 9 weeks, declining to a minimum at 13 weeks, followed by a mild increase. The upright position (Fig. 13b) is seen only in one case at 8 weeks, in none at 9 weeks, followed by an increase up to 14 weeks after which it again becomes less frequent. The upside down position (Fig. 13c) shows a more inconsistent pattern during the developmental course. The analysis per individual did not reveal an intra-individual week to week preference of a particular orientation within the field of gravity.

(3) Fetal posture

The fetus' posture in relation to the surface he is resting on can be supine, prone, lateral, sitting/standing upright or on his head. Again, these fetal postures show clear developmental trends. The data from 8 to 10 weeks are incomplete, because it was not possible to determine the fetal position in all cases during the whole hour. The supine position exceeds all other positions from 11 to 15 weeks, is equally frequent as the lateral position at 16–17 weeks, but decreases remarkably at 18–19 weeks (Fig. 14). The inverse picture is shown by the frequency curve of the lateral position. Both the supine and lateral position curves have a dip at 13 and 14 weeks, which can be explained by the more frequently occurring prone and vertical

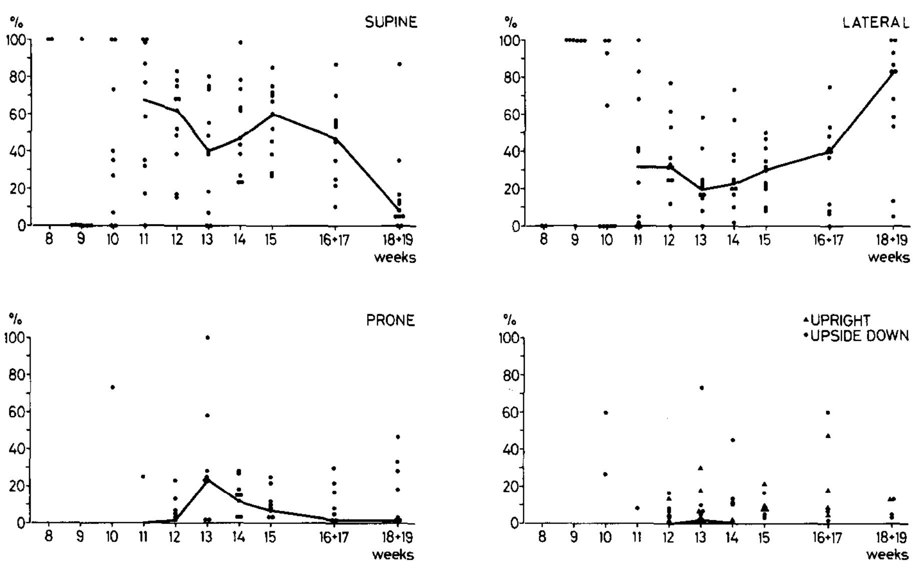

Fig. 14. Percentage of recording time in which fetal posture was supine, lateral, prone, upside down or upright. Solid line indicates median values per week. In both illustrations at the bottom, zero values are not indicated.

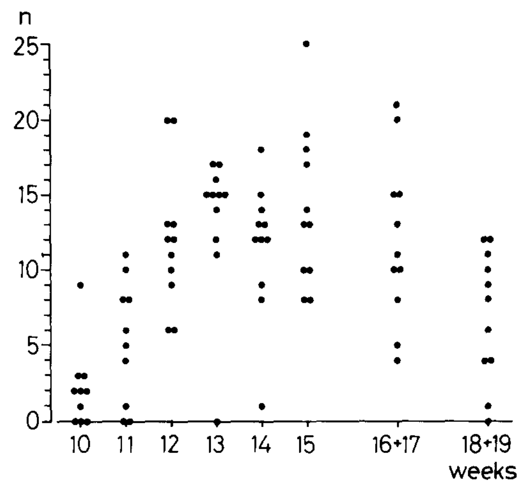

Fig. 15. Number of positional changes during each recording of 1 h. Each dot represents an individual. Younger ages are omitted, because recognition was insufficiently reliable.

positions respectively. No intra-individual preference position, stable over time, can be detected.

(4) Rate of changes in the fetal position

As indicated above, the fetus may rotate or otherwise change position in relation to the uterus as well as to the force of gravity. The number of such displacements was counted per individual in each of the recordings. As expected the rate increases from 10 weeks onwards and reaches a climax at 13–15 weeks. Unexpectedly, it declines afterwards (Fig. 15). This decrease in the rate of changes is not due to a decrease in motor activity (as we have seen from the quantification of motility), but seems to be related to changes in the spatial condition in the uterus which make positional displacement increasingly more difficult to perform.

Discussion

Spontaneous movements of the human embryo and fetus seem to be a fundamental expression of early neural activity, but knowledge of their underlying morphological substrate and of their functional significance during prenatal life is still scanty. It is only in recent years that a slow change takes place in this situation.

Present concepts of prenatal neurological development are heavily biased by reflex studies on exteriorized fetuses. The classic studies by Minkowski [20] and Hooker and Humphrey [11,15] led to the impression that early fetal behaviour consists merely of reflexes rather than of spontaneously generated movement patterns, despite incidental observations of spontaneous movements in the operatively removed young fetus and the non-induced 'quickening' felt by mothers after 16–18 weeks of pregnancy. Ironically the spontaneously moving young fetus had to be 're-discovered' with the advent of ultrasound scanning. Thanks to the pioneering investigations by Reinold [29,30] it not only became clear that the fetus of 8–10 weeks (postmenstrual age) moves spontaneously in utero under perfectly normal conditions but also that different kinds of movements are discernible. "..., it became apparent that these movements sometimes followed one and the same pattern, while at other times different patterns were present. Beyond that, variations were also noted in the frequency of movements made during unit time and the density of movements, i.e. the number of immediately consecutive movements followed by an interval without spontaneous motor activity. These intervals were found to be of variable duration" [30, p. 116]. He categorized spontaneous movements into two classes: (1) strong and brisk movements involving the entire body, and (2) slow and sluggish movements confined to fetal parts.

With the increased quality of resolution and dynamics of modern ultrasound equipment, a more refined distinction of fetal movements became possible, which though perhaps clinically less attractive, is certainly closer to reality. Instead of looking at the overall quality of movements, Birnholz et al. [4] suggested a classification of spontaneous movement patterns which are said to be based on reflex patterns reported by Hooker and Humphrey. Nine such patterns were distinguished (twitch, independent limb, isolated head, combination, quasi-startle, limb-joint, hand-face, isolated diaphragm and respiratory). As they observed only for very short periods (30 s to 5 min) it is not surprising that they did not see, for example, hand-face contact before 16 weeks and respiratory movements before 29 weeks. In addition, eye movements were described by Birnholz [5] at 16 weeks. In contrast to the later occurring types, these early eye movements were single, transient linear deviations from a midposition.

Van Dongen and Goudie [9] made continuous observations of 10–15 min duration in 46 patients between 6 and 12 weeks postmenstrual age. The first movements were seen at 8 weeks (18–22 cm CR) and were called "rippling movements". At 9 weeks, the whole fetus moved "in a rather convulsive manner". Between 10 and 12 weeks, four patterns were seen: (1) a resting or 'sleeping' phase, (2) extensions, flexions and rotations of the head, waving of the arms and kicking of the legs; one fetus moved the jaw up and down, (3) sporadic kicks against the sac wall, (4) regular strong pulsed movements of the fetal trunk, resembling hiccoughing.

The most recent and comprehensive study of the quality of fetal movement patterns was that by Ianniruberto and Tajani [16]. Based on 2000 cases, recorded once or repeatedly between 8 and 41 weeks of gestation, these authors provided a time-table of spontaneous or elicited movement patterns. The duration of observations varied between a few minutes and 30 min. Unfortunately, the descriptions of patterns according to Milani-Comparetti's motoscopy [18] were often very brief and global without specifying what the fetus was really doing (e.g., vermicular movements, creeping, climbing, hands 'exploring' uterine wall, etc.). To the extent that their observed patterns are comparable with our classification, their dates of first occurrence are mostly later than in our observations. This is probably due to their shorter observation time and to the fact that they did not have the advantage of observing from video recordings. Nevertheless, their observations contain a wealth of information.

A word of warning must be given concerning responses of the fetus to mechanical stimulations through the maternal abdominal wall. The above mentioned authors [4,16,30] reported fetal movements which they assumed they had elicited. As the base-rate of spontaneous fetal movements is very high, it is extremely difficult to prove that a movement following a stimulus is indeed elicited and not a spontaneous movement which would have occurred even without stimulation. With short recordings of a few minutes such a proof is plainly impossible.

It is interesting to compare the time-tables for the onset of new responses provided by the investigations of Hooker and Humphrey [11,15] with our findings on the emergence of new spontaneous movement patterns, given in Fig. 9. It should be kept in mind that the aborted fetuses were in a terminal condition, as can be appreciated in comparing the film recordings of Hooker [12] with ultrasound scans of fetuses moving under normal intrauterine conditions. The nervous system of the experimental fetuses was probably already in a depressed state and spontaneous activity had ceased, even though responses could still be produced by stimulation. Nevertheless, there is a remarkable similarity in the ages at which reflexes and spontaneous movements occur. At 7.5 weeks the first responses, a contra-lateral flexion of the neck, could be elicited by peri-oral (trigeminal) tactile stimulation [13]. The first observed, "just discernible movements" occurred at the same age. At 8.5 weeks the trunk and arms also became involved in the response, the same age at which general movements occur spontaneously [15]. Startles have not been described by Hooker and Humphrey *. Arm or leg movements following hand or foot stimulation were seen at 10.5–11 weeks, while isolated spontaneous movements of the limbs were observed about 1 week earlier in utero with ultrasound. Elicited retroflexion of the head was seen at 9.5 weeks, the same age as we observed such movements to occur spontaneously; a rotation of the head was seen in the stimulation experiments at 10–11 weeks, which is also in agreement with our findings. Opening of the jaws after stimulation happened earlier (8.5–9 weeks) than the spontaneous movement (10.5–11 weeks); however, for the former the movement was part of retroflexion of the head and trunk extension, while the latter occurred unaccompanied by other movements. Swallowing was reported by Hooker [11] to occur at 12.5 weeks, which coincides exactly with our findings.

This striking similarity in the data from the two approaches provides good evidence against the opinion that reflexes occur ontogenetically earlier than the homologous spontaneous movements. On the other hand we have no evidence from our findings that the spontaneous movement patterns precede the corresponding reflex patterns.

A more difficult problem arises when we try to relate our data to what is known about maturation of neural and muscular structures. Studies on the ultrastructure of

* One of us (H.F.R.P.) was told by Dr. Humphrey that startles had been observed by them.

the nervous system and of the muscles of the young fetus are still scarce. In a series of elegant studies Okado [21–24] has shown that synapse formation in the cervical spinal cord starts at 8 weeks postmenstrual age. Axodendritic synapses precede axosomatic synapses in the motor column by a week. These early synapses are formed between interneurons and motoneurons, followed later by connections formed by afferent fibres and interneurons. Axodendritic synapses in the lateral motor column show a large increase in number from 8 to 9 weeks (from 1.4 synapses per 200 μm^2 to 10 synapses per 200 μm^2). This increase corresponds with our observations that arm movements and hiccups start to occur at this age. Unfortunately, similar detailed morphological studies do not seem to be available for the cranical nerves in the brain stem and for the lumbar spinal cord.

As regards muscle development, the diaphragm is formed by 8 weeks and completed by 10 weeks [2,32], providing the anatomical substrate for the hiccups observed at this early age. If motoneurons need a critical number of functional synapses in order to discharge spontaneously, then the phrenic motoneurons in the cervical region seem to possess sufficient contacts to produce hiccups. The development of limb muscles has been studied in quadriceps muscles. The first myotubes with contractile elements were found at 9 weeks postmenstrual age [10,19]. We do not yet know much about innervation of these muscles and the development of the ultrastructure of motor endplates. Older light microscopic studies indicate, for example, that at 7–8 weeks there are endplates in the intercostal muscles [17], and in the biceps by 11 weeks [8]; for more detail see Humphrey [13]. Whether polyneuronal innervation is a feature in early stages in the human as it is in various mammals [28], is unknown.

Concluding remarks

On the basis of our results and their discussion, we can provide answers to the five questions raised in the Introduction.

(1) In the present study we attempted to provide an exhaustive list of fetal movement patterns observed during the first 20 weeks of gestation. The terminology is consistent with previous descriptions of movement patterns in preterm infants [27], neonates and young infants [25,26]. The intimate familiarity with these postnatal patterns has definitely facilitated the recognition of strikingly similar and, therefore, most likely homologous movement patterns in the fetus. With the exception of the transient class of 'just discernible movements' whose nature is still obscure, all described patterns can also be observed after birth. The reduced effect of the force of gravity in utero makes many movements more fluent and elegant than after birth. Moreover, a sudden relaxation does not produce a rapid drop of elevated limbs. It may also take 12–15 weeks after birth at term until an anteflexion of the head or a rotation of the body is possible with an infant in supine position. Even if these differences are taken into account, there were no movements recognized in the fetus which we could not classify as belonging to the one or the other category we have described.

(2) The ages at which specific movement patterns occur for the first time in ontogeny are consistent within 2 weeks for all the individuals studied, provided the rate of occurrence is sufficiently high (e.g., 10–30 times during 1 h recording). The spread is much larger only for those movements with a low rate of occurrence (e.g., yawn, stretch, etc.).

(3) Though there are some changes in the appearance of fetal movements between 8 and 20 weeks, most notably in general movements and jaw opening, these changes are unimpressive compared with the consistency of their "Gestalt", which makes them similar enough to be recognized again at various ages.

(4) If one neglects the early fetal positions on the bottom of the amniotic sac until the age of 10–11 weeks, the orientation of the fetus in the uterus can vary with only slight preferences typifying the total group, but without any consistency from week to week in the individual.

(5) The fetus does possess two specific movement patterns for rotations and somersaults which produce changes in his orientation in relation both to shape of the uterus and direction of the force of gravity. They may also change the fetal position from prone to supine or lateral and vice versa.

The fact that movements, even of the young fetus, appear not to be uncoordinated and random but are specific and recognizable patterns makes them candidates for diagnostic purposes in the compromised fetus. There are strong indications from preliminary observations that under abnormal conditions changes in the quality of fetal movements precede changes in the quantitative output of motility.

The quantitative aspects of the fetal movement patterns reported here will be dealt with in a following publication.

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