

**Goal directed behaviours: the development of pre-natal touch behaviours**

**\*Nadja Reissland**

**Joe Austen**

**Correspondence to:**

**\*Associate Professor**

**Department of Psychology**

**Durham University, UK**

## **Abstract**

Through their general movements in the womb, human fetuses will touch various aspects of their environment. This might include their own bodies, the body of a twin, the uterine wall, and the umbilical cord. Somatosensory responses can be observed as early as 8 weeks gestational age. (e.g., Bradley & Mistretta, 1975). Sparling and Wilhelm (1993) indicated that during the later gestational periods, the hands of the fetuses begin to be directed to, and manipulate, other parts of the body, such as feet or the other hand, and explore parts of the external environment in the womb, such as the umbilical cord. Castiello et al (2010) observed that by 14 weeks gestation not only movements directed at the self but also movements directed to a co-twin can be observed in the womb.

The effects of experiencing touch might be wide reaching in terms of fetal development and preparation for life outside of the womb. Touch behaviours will be discussed in terms of the fetal sensitivity to touch, the effects of touch on body movement, cross cultural differences in fetal touch behaviour and general movement, fetal action planning and goal directed action, and visually guided fetal touch. The chapter concludes with a discussion of prenatal touch behaviours and later development.

## **Introduction**

Studies indicate that the sensory system becomes functional in a specific and invariant order with tactile sensing abilities to develop first (e.g. Lickliter & Bahrick, 2016). The face becomes sensitive to touch by around 7 week's gestational age (Hooker, 1952; Humphrey, 1972) and the hands by around 10 weeks gestational age (Hooker, 1952; Humphrey, 1972). Hence, tactile stimulation is the first stimulation a fetus will be exposed to. Research suggests that touch behaviours are intentional and possibly planned from an early age onward in that neonates and infants move their hands toward their mouths either directly or indirectly by initially making contact with the perioral region of the face and opening their mouths in anticipation of the arrival of their hands (e.g., Butterworth & Hopkins, 1988; Blass, Fillion, Rochat, Hoffmeyer, & Metzger, 1989; Rochat, Blass, & Hoffmeyer, 1988; Takaya, Konishi, Bos, & Einspieler, 2003). Similar claims have been made for fetuses (e.g. Reissland et al., 2014).

Prenatally, the functional significance of touch could be that it affords fetuses the first opportunity to learn about the areas and variations of sensitivity of their body as well as define their body limit in relation to the intrauterine environment (Kravitz, Goldenberg, & Neyhus, 1978) and potentially the extra-uterine environment as suggested by Marx & Nagy (2015). Through touch fetuses might learn a sense of self by differentiating between their own body and others, including the external environment and other bodies. This suggestion is based on studies indicating that somatic sensation allows the animal or person through their touch to generate information necessary to identify or differentiate between objects and physical stimuli that come into contact with their body. Khazipov, et. al. (2004) found that sensory feedback from spontaneous fetal movements in rats played an important role in establishing a mental representation of the body in the somatosensory cortex. Yamada, et. al.

(2016) developed this research further by developing a robot model based on an integrated system of brain-body and environmental interactions which the researchers based on human anatomical and physiological data. They tested their model under human intra-uterine conditions and suggest that intra-uterine stimulation through touch could provide the foundations for cortical learning of body representations which are hypothesized to provide foundations for postnatal visual-somatosensory integration.

After birth the fetus will seek out the nipple by rooting, namely crawling towards the nipple, which is a behaviour related to their neurobehavioral maturity (Radzysinski, 2005). Hence one potential functional development is related to feeding abilities in general and specifically to their ability to initiate breastfeeding successfully. Others argue that the reason for self-exploration of their bodies leading for example to thumb sucking (Feldman & Brody, 1978) or general self-touch (Rock, Trainor & Addison, 1999) could have the function of arousal regulation. Weiss (2005) suggests that, if prenatally there is insufficient experience with touch sensations, neurosensory organization could be compromised.

More cognitive explanations have been offered by Butterworth and Hopkins (1988), who propose that self-touch and specifically hand-mouth touch is evidence for goal directed behaviour and the development of intention. This suggestion is supported by research with neonates, which demonstrates that new-born infants perform hand-mouth touch action only when they can taste a drop of sweet solution but not when receiving a drop of water. Casual observations by a number of researchers (e.g. de Vries, Visser, & Prechtl, 1982; Hepper, Shahidullah, & White, 1991; Kurjak, et. al., 2003; Hata, et. al., 2010) of fetal ultrasound images indicating fetal ability to introduce a finger, part of the arm or umbilical cord into the mouth, suggest that ability to coordinate movements develops prenatally.

## **Fetal Sensitivity to touch and the effects of touch on body movement**

Although historically fetuses were said to live in a sensory deprived environment (Windle, 1940), Bradley & Mistretta (1975) argued that, even though they are to some extent buffered by amniotic fluid, fetuses experience tactile stimulation through their own, as well as maternal, movements. In fact, research indicates that tactile stimulation is essential for healthy development (e.g. Ardiel & Rankin, 2010). For example, Kuniyoshi & Sangawa (2006) developed self-organizing neural robot models of the human body, which were able to learn through movements the sensory and motor structure of normal human infant motor development. In studies examining tactile functions, Mori & Kuniyoshi (2010) simulated self-organizing behaviours of movements in the human fetus. They argued that tactile stimulation is the dominant sensory experience because tactile stimulation can be elicited through self-stimulation in response to fetal movement. Hence, they suggest that the fetus learns tactile-motor contingencies. Based on this assumption they developed a simulation of fetal motor development induced by tactile sensations. Yamada et al (2016) found that the intra-uterine environment which is spatially restricted exerts pressure which leads to tactile sensory feedback correlated across body parts. They argue that these physical restrictions may be beneficial and enable the development of a cortical map of the body. The development of a cortical map is essential for normal human development (Dazan, et. al., 2006). Without such cortical maps the infant might not be able to direct touch intentionally to their own body or reach other bodies (e.g. hands) or objects. Additionally, the area which the fetus touches, such as the mouth region, corresponds to developmental sensitivity of the skin as fetuses mature. Sensitivity of various areas of the body has been tested in humans and can be seen in Fig 1, with the more sensitive areas show more sensibly spaced nerve endings.



Fig 1. Tactile points of the robotic simulation of sensitivity of the skin developed by Mori & Kuniyoshi (2010).

Yamada et. al. (2016, see Fig.1), tested the intrauterine sensorimotor experiences necessary for learning mechanisms guiding development using a robot model integrating interactions between the brain, body and environment, which they called ‘embodied interactions’. Using this model, they were able to show the mechanistic link between sensorimotor experiences via embodied interactions and the cortical learning of body representation. They demonstrated with their model that intrauterine movements provide specific organisational patterns relating to the body parts based on both proprioception and tactile sensory feedback which resulted in the learning of body representations. This is the basis then on which we can argue that as fetuses move they will learn about their bodies.

### **Cross cultural differences in fetal touch behaviour and general movement**

Cross cultural studies have concentrated on gait, such as crawling, standing, walking or sitting (Karasik, et. al., 2010) and found that infant massage with vigorous movements such as stretching and tossing the infant up in the air, such as used in India and Nepal (Reissland & Burghart, 1987), results in sitting and walking at earlier ages than infants not exposed to such

movements (Hopkins & Westra, 1988). However other types of movements are rarely studied cross-culturally in prenatal populations.

Reissland et al (2015) analysed fetal self-touch behaviours comparing 4 low birth weight (<2500 grams) Japanese fetuses with 3 low birth weight English fetuses and found an indication of differences in touch, with Japanese fetuses seemingly showing more touch compared with English fetuses. The reasons for the observed differences are unclear.

However, clues to the differences in behaviour might relate to maternal factors. Lai, et. al. (2016) suggest that the key determinant of fetal healthy development relates to adequate perfusion and oxygen transfer which is dependent on a well-functioning placenta which results in a full term fetus with healthy weight as assessed by Apgar scores. Apgar scores indicate healthy development, through a rating of colour, heart rate, muscle tone, etc. of the new-born at 1 and 5 minutes after birth, with a maximum score of 10 indicating optimal health of the new-born. Hanaoka, et. al. (2016), testing fetal movements in Japanese and Croatian fetuses using Kurjak's antenatal neurodevelopmental test (KANET, Kurjak, et. al., 2008), found that although the KANET score was in the normal range in both populations, there was a significant difference in total KANET scores between Japanese (median, 14; range, 10–16) and Croatian fetuses (median, 12; range, 10–15). These authors also recorded maternal factors and infant outcome at birth. There were significant differences in the Japanese and Croatian groups in terms of maternal age, parity, infant birth weight, as well as infant Apgar scores at 1 and 5 min recorded for Japanese and Croatian offspring, which all might be factors contributing to the cultural differences observed. Di Pietro, et. al. (2004) studied fetal general movements using a fetal actocardiograph rather than analysing fetal movements in ultrasound as was the case in the studies by Reissland et al (2015) and Hanaoka et al. (2016). They recorded fetal general movements with the actocardiograph from

20 to 38 weeks gestation. In their analysis of fetal general movements they found significant differences between fetuses observed in Lima (Peru) and Baltimore, Maryland (USA) with the fetuses from Baltimore moving more compared with fetuses in Lima but with a similar trend of a decrease in general movements from 20-38 weeks gestation. Again, as in previous studies, there were differences in maternal factors in the two groups with women from the US having a heavier pre-pregnancy weight of 68.2 kg compared with 54.8 kg in Lima. The infants' weights also differed, with US infants being slightly heavier at a mean of 3,520 grams compared with infants from Lima with a mean weight of 3,214 grams at birth. In sum, the results on cross cultural studies are uncertain and need to be examined in more detail using the same coding system of fetal movements and controlling for maternal factors.

### **Fetal action planning and goal directed action**

In a kinematic study Zoia, et. al. (2007) examined whether fetal hand movements were planned. They performed a kinematic analysis of hand movements directed towards the mouth and eyes by 8 fetuses observed at 14, 18, and 22 weeks of gestation. They found that by 22 weeks, kinematic patterns of fetal movements varied depending on the goal of the action. Specifically the speed with which fetuses either moved their hands toward either the eye or the mouth varied, being slower for movements directed toward the eye compared with movements directed towards the mouth.

One might surmise that fetal facial touch is constrained by gestational age with fetuses at later gestational ages being able to touch fewer areas of the head and face. However, research indicates that fetuses are able to flex their elbows; necessary for touching various parts of the head, face and mouth. For example, Ververs, et. al. (1998) reported that 10 fetuses, which they observed longitudinally, were able to flex their elbows at 24 weeks 93% of the time observed increasing by 3% to 96% of the time of observed at 36 weeks. In a study by



Reissland, et. al. (2013) the development of fetal touch behaviours was observed in terms of region of touch, either top of the head, side of the face, lower face or mouth and timing of touch in relation to mouth opening. (see, Fig 2)

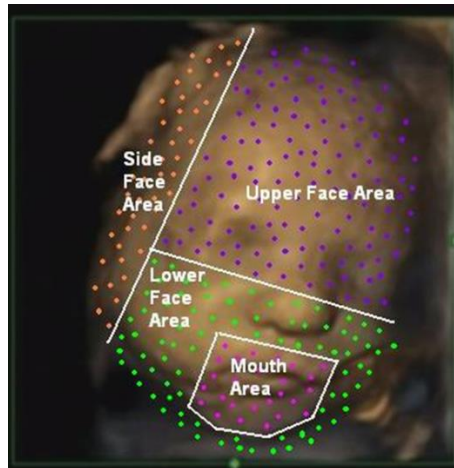


Fig. 2. Regions of touch, upper, side, lower and mouth areas, coded in the fetal face.

From 24- 36 weeks of gestation fetuses in this study touched the upper part of their head less as they developed with rate of touch declining by around 9% of each week of gestational age. The rate of decrease of the side of the face (see Fig. 3 as an example of side of the face touch) was around 10% for each week of gestational age.



Fig. 3 Fetus touching side of the face.

In contrast touches of the lower part of the face increased with age by around 4% for each week of gestational age but the most significant increase was touch of the perioral region of the face with the rate of touch increasing by around 7 % for each week of gestational age (see Fig. 4). Hence, it is suggested that fetuses move their hands and explore the region of the face of prime important for postnatal life such as getting ready to feed from breast or bottle after birth.



Fig. 4 Fetus touching perioral region of the face

Some researchers report that fetal hand-to-face movements, although possible, appear to occur less frequently than those observed in neonates. According to Butterworth and Hopkins (1988), human neonates showed arm movements toward the face 3.48 times on average per minute observation. On the other hand, fetal arm movements observed in 2D scans occurred 0.2 times on an average per minute of observation Sparling et al. (1999) also counted the frequencies of “hand to/at/near mouth” movements in 1-day-old neonates in addition to those of the fetuses observed in 2D scans. They reported that although the frequencies of hand to face movements decreased in fetuses from 26 weeks to 37 weeks gestation to approximately

0.2 hand to face movements per minute observed at 37 weeks, when observed after birth at the age of one day, neonatal arm movements increased to 1.2 movements per minute.

Nevertheless, prenatal practice of hand-face contacts may be responsible for highly organized inter-sensorimotor patterns observed immediately after birth (Butterworth & Hopkins, 1988). Indeed, prenatal practice starts early in life with reactive touch being observed from the first trimester of fetal life (e.g., Piontelli, 2010). However, the coordination of anticipated touch is neurologically more complex than reactive touch necessitating an increased level of motor control (Zoia, et, al., 2007). This increased level of motor control implies some action planning (Zoia et al., 2007) and hence arguably cognitive maturation which would be expected to occur later in fetal development.

Regarding specific “intentional” goal directed behaviours, if neonates already have some knowledge of their own bodies, the well-coordinated movements between their hands and mouths might have developed in the uterus. Indeed, human fetal thumb (or other finger) sucking can be observed as early as 10 to 15 weeks of gestation (e.g., de Vries, Visser, & Prechtl, 1982; Hepper, Shahidullah, & White, 1991). Whether such fetal hand-mouth coordination might occur accidentally was investigated by Myowa-Yamakoshi & Takeshita (2006). If human fetuses were capable of coordinating hand and oral activities, then they would observe well-organized or controlled patterns in their hand-mouth coordination. They observed in a cross sectional study of 27 fetuses, divided into a younger group with a mean age of 24.6 weeks (range 19-27 weeks) and an older group with a mean age of 31.6 weeks (range 28-35 weeks), that approximately half of the observed arm movements resulted in hands touching the mouth with no developmental differences between the two groups. Additionally, they report that the results showed that a minority of 30% of the observed fetuses did not show any directional movements of the hand to the mouth. However, in this

study it was not clear if fetuses touched “intentionally” or “accidentally” the mouth region. This question was investigated in the following longitudinal study from 24-36 weeks gestation (Reissland et al., 2013). In this study fetuses were observed in 4D scans. Results indicated that fetuses increased significantly the proportion of anticipatory mouth movements. These fetuses opened their mouth before touch occurred, which was related to gestational age with an increase of around 8% with each week of gestational age. Additionally, there was a decrease in the proportion of reactive mouth movements, mouth movements which occurred in reaction to a touch. These reactive movements decreased by around 3% for each week of gestational age. Furthermore, fetuses increased the touch of the mouth area compared to the upper and side areas of the face with the rate of touch of the upper face area declining with age by around 9% for each week of gestational age and touch of the side area of the face decreasing with age by around 10% for each week of gestational age. These results indicate that fetuses, as they develop from 24 to 36 weeks gestation, do not only increasingly touch the sensitive part of their face, namely the mouth region and lower part of their face, but also they touch these sensitive areas more frequently compared to the relatively less sensitive areas of their head and face. Furthermore, fetuses seem not only to anticipate touch when the mouth is positioned on a clear trajectory to their hand. Rather as can be observed in Fig. 5 of a 32 week old fetus turning the head to suck on the thumb.



Fig. 5. 32 week old fetus turning the head toward hand and sucking a thumb.

According to Castiello et al (2010), twins provide a unique opportunity to investigate differences in touch behaviour in terms of self-touch, other human touch and touch of the uterine environment, such as uterine wall or placenta. Castiello, et. al. (2010) hypothesized that the kinematics for arm actions aimed at a social target which in adults have been found to differ from those aimed at a non-social objects (Becchio, et al 2010), would differ in twin fetuses. They found that movements toward the uterine wall at 14 and 18 weeks gestation did not differ. However, the proportion of self-directed movements was greater at 14 than 18 weeks gestation but movements directed toward the twin were greater at 18 than 14 weeks gestation. Hence, twin fetuses, as they grow older, seem to direct touch in preference to the other fetus rather than themselves. Kurjak, et. al. (2013) examined twin pregnancies in 4D in all three trimesters using the KANET scoring system found no statistically significant differences between singleton and twin pregnancies. However, they also reported increasingly complex touch behaviour as the pregnancy progressed. Hata, et. al., (e.g. 2011, 2012) published a series of 4-D ultrasound studies on inter-twin contact and reactions to touch during the first trimester of pregnancy. They found, comparing mono-chorionic di-amniotic (MD) and di-chorionic di-amniotic (DD) twins at 10–11 weeks gestational age, a significant difference in the total number of all types of contact. Based on these studies Hata, et. al. (2011, 2012) suggested that the frequency of the type of inter-twin contact at the earlier gestations from 10-13 weeks might be due to early fetal neuromuscular development and differentiation of the neuromuscular system. Arabin, et. al. (1996) analysed touch reactions of twins from 8 up to 16 weeks gestation using 2D scans. They report increasingly complex interactions from 8-16 weeks gestation with touch of the twin observed at 12 weeks not eliciting any reaction from the twin and complex touch which they called “embrace” being observed in diachronic twins at 16 weeks gestation. Such embrace can be seen in the figure

below of dizygotic twins (25 weeks 2 days old) where the girl fetus wraps her arm around the shoulder of her twin brother (see Fig 6).

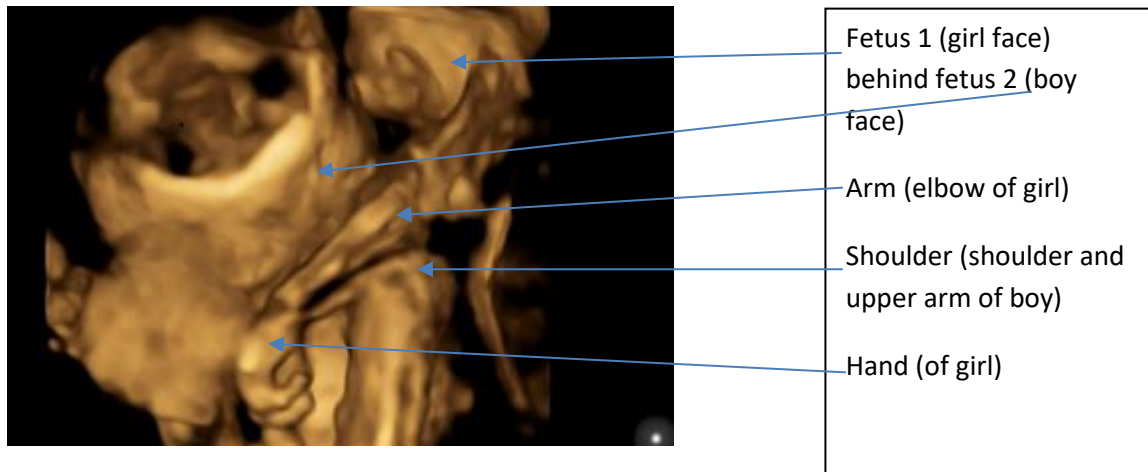


Fig. 6 Twins at 25 weeks 2 days old: sister fetus behind brother fetus with her left arm draped over the left should of her brother.

### **Visually guided touch**

Some suggest that prenatal hand to mouth coordination should occur without visual cues because even if the fetal eyes are actually open, there is little light in the uterus (Butterworth & Hopkins, 1988). In fact, more recent research has shown that there is enough light in the womb permitting the fetus to see his or her hands. Specifically eye blinking which can be observed in utero (see fig. 7), is an indication that fetuses might react to different light conditions (e.g. Del Giudice, 2011).



Fig 7. 32 week old fetuses with eyes open

Del Giudice (2011) analysed the amount of light entering the womb. He reports that fetuses will be exposed to ample light for optimal fetal vision of 50 lux intra-uterine illuminance when the mother with an abdominal thickness of 20 mm (measured as the distance between the abdominal surface and the anterior wall of the amniotic sac) stands indoors near a window or outdoors in shadow. Therefore it is likely that during the summer months fetuses can be predicted to develop in conditions allowing for ample visual experience before birth which could result in visually guided touch (see Fig 8.)



Fig 8. 32 week old fetus raising the left hand towards the eye during exposure to light.

In a 2D scan analysis of 18 fetuses, Petrikovsky, et. al. (2003) examined fetuses between 33 and 42 weeks' menstrual age and found that fetuses blinked with a mean frequency of 0.1 movements per minute of observation. This increased to 0.25 movements per minute

observation when fetuses received vibro-acoustic stimulation Hence touch and sound sensations affected amount of blinking.

## **Discussion**

This short chapter has provided the reader with an overview of prenatal touch in singleton and twin fetuses and illustrates how far we have come from the early days of fetal research when fetuses were seen to be as sensory deprived. Instead, we can now have a clearer understanding of fetal development and brain function through analysis of prenatal touch and movement.

As the first sense to develop, touch plays a critical role in the early stages of fetal development. The new research examining brain function in utero as well as different types of stimulation including not only vibro-acoustic, different types of sound and light stimulation indicate that fetuses are prepared for life outside of the womb.

Lickliter (2011) argued that the fetus is prepared for life post-birth in the constrained environment of the uterus. Not only is there the constraint of the womb limiting and regulating the type of stimulation but also the amniotic fluid buffers stimulation in terms of relative amount, type and timing. These patterns of pre-natal controlled stimulation are essential for healthy development and any alteration will have an impact on brain development, as can be seen in premature birth. For example, consequences of an abnormal touch environment provided in the Neonatal Intensive care unit has profound effects on the developing premature brain (e.g. Als, et. al 2003).



Castiello, et. al. (2010) go so far as to suggest that fetuses might plan actions and anticipate the consequences of their touch behaviours and thereby demonstrate “social actions” from the 14<sup>th</sup> week of gestation. Although I agree with Castiello et al (2010) in principle that fetuses show behaviour which can be interpreted as action planning, I would agree with Pezzulo & Castelfranchi (2007), that the observed behaviours do not include cognitive representations. Hence fetuses behave as if they planned an action, as a precursor to later development which includes the cognitive representation of that planned action.

Prenatal touch serves the function of mapping the self vis-a-vis the other, where “other” can be either another human being or the environment of the uterus. It is therefore one of the earliest instances of human engagement with the world and, as such, more research must be done in order to understand it better. A next stage in advancing this research would be to include compromised fetuses, such as fetuses restricted in their ability to feel, touch and move in order to establish whether they will be delayed in their action planning behaviours.

## References

- Als, H., Gilkerson, L., Duffy, F.H., McAnulty, G.B., Buehler, D.M., Vandenberg, K., Sweet, N., Self, E., Parad, R.B., Ringer, S.A., Butler, S.C., Blickman, J.G., & Jones, K.J. (2003). A three-center, randomized, controlled trial of individualized developmental care for very low birth weight preterm infants: medical, neurodevelopmental, parenting, and caregiving effects. *Journal of Behavioral Pediatrics*, 24, 399-408.
- Ardiel E.L., Rankin C.H. 2010. The importance of touch in development. *Journal of Paediatrics & Child Health*, 15, 153–156.
- Becchio, C., Sartori, L., & Umberto Castiello, U. (2010). Toward You: The Social Side of Actions. *Current Directions in Psychological Science*, 19, 183-188 DOI: 10.1177/0963721410370131
- Blass, E. M., Fillion, T. J., Rochat, P., Hoffmeyer, L. B., & Metzger, M. A. (1989). Sensorimotor and motivational determinations of hand–mouth coordination in 1-3-day-old human infants. *Developmental Psychology*, 25, 963–975.
- Bradley, R.M. & Mistretta, C.M. (1975). Fetal sensory receptors. *Physiological Review*, 55, 352–382.
- Butterworth, G., & Hopkins, B. (1988). Hand–mouth coordination in the new-born baby. *British Journal of Developmental Psychology*, 6, 303–314.
- Castiello, U., Becchio, C., Zoia, S., Nelini, C., Sartori, L., Blason, L., D'Ottavio, G., Bulgheroni, M., Gallese, V. & Rustichini, A. (2010). Wired to Be Social: The Ontogeny of Human Interaction, *PLoS ONE*, 5, <http://dx.doi.org/10.1371/journal.pone.0013199>
- Dazzan, P., Morgan, K.D., Chitnis, X., Suckling, J., Morgan, C., Fearon, P., McGuire, P.K., Jones, P.B., Leff, J., Murray R.M. (2006). The structural brain correlates of neurological soft signs in healthy individuals. *Cerebral Cortex*, 16 1225–1231.

- Del Giudice, M. (2011). Alone in the dark? Modeling the conditions for visual experience in human foetuses. *Developmental Psychobiology*, 53, 214-219.
- DiPietro, J. A., Caulfield, L. E., Costigan, K., Merialdi, M., Nguyen, R., Zavaleta, N., & Gurewitsch, E. (2004). Fetal neurobehavioral development: A tale of two cities. *Developmental Psychology*, 40, 445–456.
- Feldman, J. F., & Brody, N. (1978). Non-elicited newborn behaviors in relation to state and prandial condition. *Merrill-Palmer Quarterly*, 24, 79–84.
- Hanaoka, U., Hata, T., Kanenishi, K., AboEllail, M.A.M., Uematsu, R., Konishi, Y., Kusaka, T., Noguchi, J., Marumo, G., Vasilj, O., & Kurjak, A. (2016). Does ethnicity have an effect on fetal behavior? A comparison of Asian and Caucasian populations. *Journal of Perinatal Medicine*, 44, 217–221.
- Hata T, Kanenishi K, Sasaki M. (2010). Four-dimensional sonographic assessment of fetal movement in the late first trimester. *International Journal of Gynecology and Obstetrics*, 109, 190–193.
- Hata T, Kanenishi K, Sasaki M, Yanagihara T. (2011) Fetal reflex movement in twin pregnancies late in the first trimester: 4-D sonographic study. *Ultrasound Med Biol* 2011; 37: 1948–1951.
- Hata T, Sasaki M, Yanagihara T. (2012) . Difference in the frequency of types of inter-twin contact at 10-13 weeks' gestation: Preliminary four-dimensional sonographic study. *JMatern Fetal Neonatal Med.* 25: 226–230.
- Hata, T., Kanenishi, K., Hanaoka, U., Uematsu, R., Marumo, G.,(2016). HDlive in the assessment of twin pregnancy. IN Reissland & Kisivlesky Pp385-405
- Hepper, P. G., Shahidullah, S., & White, R. (1991). Handedness in the human fetuses. *Neuropsychologia*, 29, 1107–1111.

- Hooker D. (1952). *The Prenatal Origin of Behavior*. Lawrence, KS: University of Kansas Press.
- Hopkins, B. & Westra, T. (1988) Maternal handling and motor development: An intracultural study. *Genetic, Social and General Psychology Monographs* 114,379–408.
- Humphrey, T. (1972). Central representation of the oral and facial areas of human fetuses. In: *Third Symposium on Oral Sensation and Perception. The Mouth of the Infant*, (ed J. F. Bosma) Springfield, Ill. : Thomas, p. 98-136
- Karasik, L. B., Adolph, K. E., Tamis-LeMonda, C.S, Bornstein, M. H. (2010) WEIRD walking: Cross-cultural research on motor development. *Behavioral and Brain Sciences*, 33, 95-96.
- Khazipov, R. et al. (2004) Early motor activity drives spindle bursts in the developing somatosensory cortex. *Nature*, 432, 758–761.
- Kravitz, H., Goldenberg, D., & Neyhus, A. (1978). Tactual exploration by normal infants. *Developmental Medicine and Child Neurology*, 20, 720–726.
- Kuniyoshi, Y.(2006). “Emergence of embodied behavior: Coupled chaos system and fetal motor development,” *ALIFE X Workshop Proceedings*, pp. 195–196.
- Kuniyoshi, Y., Sangawa, S.(2006). Early motor development from partially ordered neural-body dynamics: experiments with a cortico-spinal-musculo-skeletal model. *Biological Cybernetics*, 95(6):589-605. Epub 2006 Nov 23
- Kurjak, A., Azumendi, G., Veccek, N., Kupesic, S., Solak, M., Varga, D., & Chervenak, F. (2003). Fetal hand movements and facial expression in normal pregnancy studied by four-dimensional sonography. *Journal of Perinatal Medicine*, 31, 496–508.

Kurjak A1, Talic A, Stanojevic M, Honemeyer U, Serra B, Prats P, Di Renzo GC. (2013).

The study of fetal neurobehavior in twins in all three trimesters of pregnancy. *J Matern Fetal Neonatal Med.* 26, 1186-95. doi: 10.3109/14767058.2013.773306.

Kurjak A, Miskovic B, Stanojevic M, Amiel-Tison C, Ahmed

B, Azumendi G, Vasilj O, Andonotopo W, Turudic T, Salihagic-Kadic A. (2008). New scoring system for fetal neurobehavior assessed by three- and four-dimensional sonography. *Journal of Perinatal Medicine*, 36, 73-81.

Lai, J., Nowlan, N. C., Vaidyanathan, R., Shaw, C.J. & Lees, C.C. (2016). Fetal movements as a predictor of health. *Acta Obstetrica Gynecologica Scandinavica*, 95, 968-975.

Lickliter, R. & Bahrick, L.E. (2016). Using an animal model to explore pre-natal origins of social behavior using animal models. In Reissland, N. & Kisilevsky, B. (eds). *Fetal Development: research on brain and behavior, environmental influences, and emerging technologies*. Springer., pp. 3-14.

Marx, V. & Nagy, E. (2015). Fetal behavioural responses to maternal voice and touch. *Plos One* 10(6)e0129118. Doi;10.1371/journal.pone.0129118

Mori, H. & Kuniyoshi, Y. (2010). A human fetus development simulation: self-organization of behaviors through tactile sensations. *IEEE9th International Conference on Development and Learning*, 82-87.

Myowa-Yamakoshi, M., & Takeshita, H. (2006). Do human fetuses anticipate self-oriented actions? A study by four dimensional (4D) ultrasonography. *Infancy*, 10, 289–301.

Petrikovsky, B.M., Kaplan, G., Holsten, N. (2003). Eyelid movements in normal human fetuses. *Journal of clinical ultrasound*, 31, 299-301.

Pezzulo, G. & Castelfranchi, C. (2007). The symbol detachment problem. *Cognitive Processes*, 8, 115-131.

- Piontelli, A. (2010) Development of normal fetal movements: The first 25 weeks of gestation. Milan, Italy: Springer.
- Radzyski, S. (2005). Neurobehavioral Functioning and Breastfeeding Behavior in the Newborn. *Journal of Obstetric, Gynecologic & Neonatal Nursing*, 34, 335-341
- Reissland, N. & Burghart, R. (1987). The role of massage in south asia: child health and development. *Social Science and Medicine*, 25, 231-239.
- Reissland, N., Francis, B., Aydin, E., Mason, J., & Schaal (2014). The development of anticipation in the fetus: a longitudinal account of fetal mouth movements *Developmental Psychobiology*, 56, 5, 955–963. DOI: 10.1002/dev.21172
- Reissland, N., Austen, J.M., Hanaoka, U., AboEllail, M.A.M., Uematsu, R., Hata, T. (2015). The potential use of the Fetal Observable Movement System in Clinical Practice. *Donald School Journal of Ultrasound and Obstetrics and Gynecology*, 9, 426-433.
- Rochat, P., Blass, E. M., & Hoffmeyer, L. B. (1988). Oropharyngeal control of hand–mouth coordination in newborn infants. *Developmental Psychology*, 24, 459–463.
- Rock, A. M. L., Trainor, L. J., & Addison, T. L. (1999). Distinctive messages in infant-directed lullabies and play songs. *Developmental Psychology*, 35, 527–534.
- Sparling, J. W., & Wilhelm, IJ (1993). Quantitative measurement of fetal movement: Fetal-Posture and Movement Assessment (F-PAM). *Physical and Occupational Therapy in Pediatrics*, 12, 97-114.
- Takaya, R., Konishi, Y., Bos, A. F., & Einspieler, C. (2003). Preterm to early post-term changes in the development of hand–mouth contact and other motor patterns. *Early Human Development*, 75, S193–S202.
- Ververs, I. A.P ; Van Gelder-Hasker, M. R ; De Vries, J. I.P ; Hopkins, B. ; Van Geijn, H. P. (1998). Prenatal development of arm posture. *Early Human Development*, 51,61-7
- Weiss, S.J. (2005) Haptic perception and the psychosocial functioning of preterm,

- low birth weight infants. *Infant Behavior & Development* 28, 329–359.
- Windle, W.F. (1940). *Physiology of the fetus: Origin and extent of function in prenatal life*. Philadelphia, PA, US: W B Saunders Co Physiology of the fetus: Origin and extent of function in prenatal life.(1940). xiii 249 pp. <http://dx.doi.org/10.1037/13600-000>
- de Vries, J. I. P., Visser, G. H. A., & Prechtl, H. F. R. (1982). The emergence of fetal behavior: I. Quantitative aspects. *Early Human Development*, 7, 301–322.
- Yamada, Y., Kanazawa, H., Iwasaki, S., Tsukahara, Y., Iwata, O., Yamada, S., & Kuniyoshi, Y. (2016). An Embodied Brain Model of the Human Foetus. *Scientific Reports*, 6:27893, DOI: 10.1038/srep27893
- Zoia, S., Blason, L., D'Ottavio, G., Bulgheroni, M., Pezzetta, E., Scabar, A., & Castiello, U. (2007). Evidence of early development of action planning in the human foetus: A kinematic study. *Experimental Brain Research*, 176, 217–226.

## **Acknowledgement**

I would like to thank Joe Austen and Emma Reames for comments on the chapter.