The development of anticipation in the fetus: a longitudinal account of human fetal mouth movements in reaction to and anticipation of touch

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Running title: **The development of anticipation in the fetus**

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Abstract

Background: Research suggests that fetuses open or close their mouth in relation to directed movements (e.g. Myowa-Yamakoshi & Takeshita, 2006) but it is unclear whether mouth opening anticipates the touch or is a reaction to touch, as there has been no analysis so far of 1) the facial area of touch and 2) the sequential ordering of touch and mouth movements. If there is prenatal development of touch we would expect the frequency of fetal mouth opening immediately preceding the arriving hand at the mouth area to increase with fetal age.

Participants: Fifteen healthy fetuses, 8 girls and 7 boys, underwent four additional 4-D scans at 24, 28, 32 and 36 weeks gestation.

Results: Changes in the frequency of touch for different facial regions indicated a significant decline in touch upper and side part of the face and a significant increase in touching lower and perioral regions of the face with increasing gestational age. Results supporting the hypothesis showed a significant increase in the proportion of anticipatory mouth movements before touching increasing by around 8% with each week of gestational age. Additionally there was a decrease in the proportion of reactive mouth movements decreasing by around 3% for each week of gestational age.

Key words: human fetus, development of anticipation of touch, fetal mouth movements, comparison of reactive and anticipatory touch, 4-D scans

INTRODUCTION

Human neonates are able to move their hands to bring them in contact with their mouths immediately after birth (e.g., Blass, Fillion, Rochat, Hoffmeyer, & Metzger, 1989; Rochat, Blass, & Hoffmeyer, 1988; Takaya, Konishi, Bos, & Einspieler, 2003). A number of researchers have suggested that touching the mouth with a hand might be related to the functional development of the infant who can, through touch, explore features, abilities and limitations of their bodies (e.g., Kravitz, Goldenberg, & Neyhus, 1978), such as movements necessary for feeding (Miller, Sonies, & Macedonia, 2003; Reissland, Mason, Schaal & Lincoln, 2012) and environmental stimuli such as the difference between smooth and textured surfaces (e.g., Meltzoff & Borton, 1979). Others suggest 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. More cognitive explanations have been offered by Butterworth and Hopkins (1988), who suggest that self-touch, and specifically the touch of mouth with the hand, would be evidence for goal directed behaviour and the development of intention. This interpretation is supported by research which demonstrates that in neonates, directed hand-to-mouth touch occurs only when the infants were able to taste a drop of sweet solution but not when receiving a drop of water (Blass, Fillion, Rochat, Hoffmeyer, & Metzger, 1989). Given the observations by a number of researchers (e.g., de Vries, Visser, & Prechtl, 1982; Hepper, Shahidullah, & White, 1991; Kurjak, Azumendi, Vecek, Kupesic, Solak, Varga & Chervenak, 2003; Piontelli, 2010) of fetal ability to introduce a finger, part of the arm or umbilical cord into the mouth, it has been suggested that ability to coordinate movements develops prenatally. Such prenatal development has been shown in other areas. For example, in terms of the coordination of facial muscle movements to form expressions, research shows that this coordination of facial muscle movements can be observed to develop from 24-36 weeks gestation (Reissland, Francis, Mason & Lincoln, 2011; Reissland, Francis & Mason, 2012).

Regarding the coordination of touch and mouth movements, we do not know whether this development occurs in all fetuses at a similar time or whether there are individual differences, with some fetuses demonstrating the behaviour earlier than others. Myowa-Yamakoshi and Takeshita (2006) suggested in a cross sectional study of 27 fetuses divided into a younger group ranging in gestational age from 19-27 weeks (mean age: 24.6 weeks) and an older group ranging in age from 28-35 weeks (mean age: 31.6 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 30% of their observed fetuses did not show any directional movements of the hand to the mouth. They analysed whether the mouth of the fetus was open or closed before the hand had moved toward the mouth and found that the highest proportion of occurrences of fetal hand touching the perioral region was an observation of the mouth closed and then open.

If there is prenatal development of perioral tactile sensation with an eventual result of a finger, thumb or part of a hand being inserted into the mouth, we would expect the frequency of fetal mouth opening preceding the arriving hand at the mouth area to increase with fetal age. Research suggests that fetuses open their mouth or close their mouth in relation to directed movements (e.g., Myowa-Yamakoshi & Takeshita, 2006), but it is unclear whether mouth opening anticipates the hand-mouth contact event or is a reaction to it, as there has been no analysis so far of 1) the facial areas of hand contact, in terms of upper, side, lower part and perioral region of the face and 2) specifically the sequential ordering of hand-perioral contact and mouth movements. In the present longitudinal study, we investigate the ordering of touching the face and mouth movements to gain insight as to whether mouth movement is reactive happening when hand-mouth contact occurs, or whether mouth opening is anticipatory, occurring before a touch event. Reactive touch can be 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. In contrast the other two types of stimulation – namely, touch of the face without any mouth movements, and touch of the face and mouth movements happening at the same time are not expected to change over fetal age.

In order to establish whether fetuses show anticipatory movements, we coded in detail the sequence of opening and closing the mouth when the fetus touched the upper face area, side face area, lower face area and the perioral region (see Fig 1). We argue that if fetal movements develop from random to anticipatory touch, hand and mouth movements would become increasingly co-ordinated with age, we would expect to observe mouth movements to occur before the fetus touches the perioral or lower region of the face. In contrast, at earlier prenatal ages we would expect more mouth movements to occur in *reaction* to touch such that mouth movements would then be observed after the fetus had touched his/her face. Additionally, we wish to investigate whether the results of a cross sectional sample in which fetuses showed similar relative frequencies of hand to mouth contact irrespective of fetal age (Myowa and Takeshita, 2006) hold in the context of a longitudinal study. If hand to mouth contact is shown to increase, this would suggest a developmental progression of coordination of movements from the second to third trimester. This would contrast with the findings of fetuses in the first to second trimester by Kurjak et al (2003) who in their analysis of 15 fetuses ranging in age from 13 to 16 weeks gestational age, found that hand and mouth contact *decreased* over the age range with the oldest five fetuses observed at 16 weeks not showing any hand and mouth contact. In summary, the principal objective of this study was to investigate longitudinally whether fetuses increasingly touch the perioral region of the face. Secondly, we additionally hypothesize that as the fetuses mature from second to third trimester of pregnancy, they develop from a sequence of mouth opening following touch, to mouth opening occurring before touch which would suggest a development from reaction to anticipation. Thirdly, we investigate gender differences in these developmental changes.

METHODS

Participants

Fifteen healthy fetuses, 8 girls and 7 boys, were scanned in the second and third trimester. The fetuses were observed four times in the mornings in the radiography department where mothers underwent their 12 and 20 week medical scans lying in a darkened room on their back or on their side depending on the position of the fetus and how comfortable mothers were. The first research scan was performed at a mean age of 24.20 weeks (range 23.9-24.5 weeks); the second at 28 weeks (range 27.8-28.2 weeks); the third at 32.1 weeks (range 31.8-32.4 weeks); the fourth at 36.1 weeks (range 36.0- 36.4 weeks). All participants were first time mothers with mean age 27 years (range 19 - 40 years), specifically recruited through the midwives of the antenatal unit of the James Cook University Hospital, Middlesbrough, UK. All fetuses (mean: 40 weeks with range 37 -42 weeks gestational age) were assessed by a paediatrician and found to be healthy after birth, with mean weight 3283 grams (2380-4160grams). Apgar scores were measured at 1 minute (range 9-10) and 5 minutes (range: 9-10).

Ethics

Ethical permission for the study was granted by the County Durham and Tees Valley 2 Research Ethics Committee (REC Ref: 08/H0908/31) and the research and development department of James Cook University Hospital, as well as the Durham University (Department of Psychology ethics committee). All mothers gave informed written consent.

Procedure

Mothers were approached after they had completed normal 20-week anomaly scans, seeking consent to participate in the study. All participating mothers received four additional scans at the same time early in the morning. The start of the recording of the scan was determined by an active and visible fetus, and lasted for approximately 20 minutes. We defined that the fetus was "active" when we could observe muscle movements, such as any of the 11 types of mouth movements as well as movements in the eye region (see Reissland, Francis, Mason & Lincoln, 2011) or arm, hand or finger movements. Maternal prandial state was not recorded. During consent and before each procedure mothers were made aware that these additional scans were for research purposes and not routine medical scans. Mothers were provided with a DVD copy of their scans. The fetal face and upper torso were visualized both by means of 4-D colour full frontal or facial profile ultrasound recordings, as well as sequences of traditional monochrome 2-D images and both recorded for off line analysis with a GE 8 Expert Ultrasound System using a GE RAB4–8L Macro 4D Convex Array Transducer. Only touch of the head region was coded. We did not record the trajectory of the touch given that we were interested in analysing touch of the face in relation to mouth movements.

Because at times the fetal face could not be observed we accumulated 600 seconds of scan for each observation period, starting from the first moment the fetal face was codable. If the part of the face of interest was not visible for a time the coding was stopped and started as soon as the face became visible For 5 out of the 58 scans a total accumulation of 600 seconds could not be achieved, and, for these, the total accumulated time ranged from 236 seconds to 543 seconds. This has been taken account of in our statistical analyses No stimulation was applied in these observation periods.

Method of Coding

Mouth movements were coded using an adaptation of the Facial Action Coding System (Ekman & Friesen, 1978) used in previous studies (Reissland, Francis, Mason & Lincoln, 2011). For the purpose of the present study, we identified the following 11 types of mouth movements: upper lip raiser, lip pull, lip corner depressor , lower lip depressor, lip pucker, tongue show, lip stretch, lip pressor, lips parting, mouth stretch and lip suck (see Table 1), which we could be observed in fetuses and reliably coded from fetal 4 D scans. Because of variations in these movements with some occurring rarely in the analysis, we did not distinguish between these mouth movements and coded them as generic mouth movements.

Insert Table 1 here

Touch of the face was coded by dividing areas of the fetal face into the upper part of the face, side of the face, lower part of the face and perioral (mouth) regions (see Fig 1). Side touch was defined to be in line with the outer side of the eyebrow including the ear. Upper touch was defined to be touch of the forehead, eye region and nose and cheeks. Lower touch was defined to be in line with the philtrum and below, reaching the lower part of the chin and under the chin but excluding the perioral region. Touch to the perioral region was defined to be the mouth area up to the philtrum and outer edges of the lips and upper part of the chin.

Insert Figure 1 here

Combinations of touch movement and type of mouth movement were coded as follows. We examined all face-touch events in the scan, and determined the start and end times of the events. For each touch event, we recorded one or more of the following forms of mouth behaviour assessing the sequence of the movements: 1) touch only, including any touch of the face happening without mouth movement; 2) mouth movement up to 5 seconds before the start touch of the face (anticipation); 3) mouth movement and touch of the face starting at the same time or mouth movement starting after the start of the touch event lasting while the touch occurred and 4) mouth movements which started within five seconds after touch of the face had ended (reaction).

Reliability

We assessed reliability of the coding by independently re-coding 21% of recordings for touch behaviours and 50% of mouth movements recordings. Using Cohen's Kappa, reliability was established for these scans, which were coded independently by coders trained in the coding system. Reliability for 4 touch behaviours, namely upper touch, lower touch, side touch, touch of the perioral region was carried out on 12 scans (20.689% of all scans used). Cohen's Kappa for touch behaviours was 0.87, range for types of touch 0.67 to 0.97.

11 types of mouth movements were coded and reliability was performed on 29 scans (50% of all scans used). Cohen's Kappa for types of mouth movements was 0.86, range for types of mouth movements 0.8 to 1.

Statistical methods

a) Frequency of touch of upper, side, lower and perioral region of the face by age (24-36 weeks gestation) :

We used a Poisson log-linear mixed effects analysis (Pinheiro and Bates, 2000) to assess developmental change in the rate of different areas of face touches over gestational age and gender. This analysis models the number of events as a count variable adjusted by the length of scan as an offset, with a fixed effect of age, and a random individual-fetus effect. Formally, the main effects model is written as

$$\log_e(y_{it}) = \log_e(s_{it}) + \beta_0 + u_i + \beta_1\,\text{age}_{it} + \beta_2\,\text{gender}_i$$

where, for fetus i at age t, y_{it} is the observed number of counts of a specific touch type (upper, side, lower or perioral) s_{it} is the accumulated length of coded scan(usually 600 seconds), u_i is the individual fetus random effect, which is assumed to be normally distributed with mean 0 and variance σ^2, and β_0 and β_1 are unknown parameters representing the intercept and age slope.

The model accounts both for the skewness of the data and also allows for individual variability between fetuses in their propensity to the event, accounting for the base activity level of each fetus. The mixed effects modelling was carried out using the *glmer* function in the *lme4* package of the statistical package R. (Bates and Maechler, 2011) Significance of the affect of age was assessed by fitting two models – one with linear age and the second without linear age, and testing the difference between the two models using a likelihood ratio test (LRT). LRT tests were also used to assess the significance of gender and the gender by age interaction.

b) Sequence of touch and mouth movements

We primarily focused on two sequences: mouth movement before touch of the face, and mouth movement after touch of the face, which were types 2 and 4 in the coding scheme, and which corresponded to the anticipatory and reactive oral behaviour. For each of these two sequences we used a *binomial* logistic mixed effects analysis using *glmer*(Pinheiro and Bates, 2000) to assess developmental change in the relative proportion of these sequences by gestational age, taking the response variable to be the number of face touch events F_{it} following a specific sequence out of the total number of face touch events N_{it} in the accumulated scan period. Using the previous notation, the main effects binomial logistic mixed effects model can be written as

$$\text{logit}(p_{it}) = \beta_0 + u_i + \beta_1\ \text{age}_{it} + \beta_2\ \text{gender}_i \qquad F_{it} \sim \text{Binomial}(p_{it}, N_{it})$$

where p_{it} is the proportion of touch-mouth movements of a specific type out of all touch-mouth movements for fetus *i* at age *t*.

As in the earlier analysis, we took account of the repeated measures nature of the data by including an individual random effects term for the fetus. As before, significance was assessed by likelihood ratio tests.

RESULTS

Descriptive analysis

Over the 58 scans observed, we observed a total of 604 face touches and 519 touch-mouth movement combinations. The mean number of touches per fetal scan was 10.4 (1-30) and the mean number of touch-mouth combinations was 8.95 (range 1-27). Table 2 shows summary descriptive information on the data collected by gestational age. The first part of the table shows the mean number of facial touches by gestational age, for each of the four regions of the face. We can observe that upper and side face touches are declining by age, whereas lower and mouth area touches are increasing. The second part of the table shows touch-mouth events. Here, we can see that the mean number of mouth movements before touch are increasing with gestational age, whereas all other touch –face events are declining. The standard deviations are in general large, indicating considerable inter-fetus variability, and which is taken account of in the mixed effects analyses reported below.

Insert Table 2 here

Touch in relation to facial region

Table 3 shows the parameter estimates for the Poisson log-linear mixed effects models, giving the changes in the frequency of touch over age for different facial regions. The quantity exp(β) gives the multiplicative effect on the frequency of touch events for each week of age, and the quantity σ^2 gives the estimate of the variability between fetuses.

Insert Table 3 here

An analysis of touches on the upper face area showed a significant linear age effect (LRT χ^2=45.42 on 1 df, ; p<0.001). The value of exp(β) is estimated to be 0.908 with the rate of touch declining with age by around 9% for each week of gestational age. There was no gender by age interaction (χ^2= 0.1305 on 1 df, ; p=0.72). Gender as a main effect was also not significant (χ^2= 0.109 on 1 df,; p=0.87).

There was a significant linear age effect of touch of the side of the face (LRT χ^2=18.94 on 1 df, p<0.001), with the rate of touch decreasing with age by around 10% for each week of gestational age. There was no gender by age interaction χ^2= 0.917 on 1 df, ; p=0.34), and gender as a main effect was also not significant (χ^2= 0.41 on 1 df, ; p=0.52).

When touches of the lower part of the face were analysed , age was again significant (LRT χ^2 =4.55 on 1df, p=0.03), with the rate of touch increasing with age by around 4% for each week of gestational age. Again, there was no gender by age interaction χ^2= 1.865 on 1 df, ; p=0.17). Gender as a main effect was again not significant (χ^2= 0.06 on 1 df, ; p=0.81).

Finally, fetal touch of the perioral region of the face showed a significant age effect (LRT χ^2 =7.81 on 1 df, p=0.005), with the rate of touch increasing with age by around 7% for each week of gestational age. There was no gender by age interaction χ^2= 1.803 on 1 df, ; p=0.18). Gender as a main effect was also not significant (χ^2= 1.70 on 1 df, ;p=0.19).

Figure 2 shows the result of these mixed Poisson regression models in graphical form. The left panel shows the mean observed counts standardised for a 600 second observation period, and the right panel shows the fitted curves for an average fetus estimated for a 600 second observation period for the changing rates of touch of the face. The general trends can clearly be seen, with upper and side face touches declining, and lower face and mouth area touches increasing with gestational age. In none of the four analyses was gender significant, either as a main effect or as an interaction with age.

Insert Figure 2 here

Fetal mouth movements in relation to touch

An analysis of the changes in the proportions of different sequences of touch events by age showed an increasing trend in the trajectory in anticipated touch, namely mouth movement before touch occurred and a decreasing trend in reactive mouth movements, namely mouth movement following touch. Figure 3 shows the changing observed proportions of all of the touch-mouth sequences by gestational age. The upper frame shows the proportion of i) mouth movement followed by touch – an anticipatory sequence- and ii) touch followed by mouth movement - a reactive sequence. The lower frame shows the other two touch mouth sequences.

Insert Figure 3 here

Table 4 shows the results of the binomial mixed effects analyses used to test whether these trend slopes are significant. First, there was a strongly significant increase in the proportion of anticipatory mouth movements before touching with gestational age (LRT χ^2=10.83 on 1 df, p=0.001). The parameter estimate of the gestational age parameter is 0.0738, with the odds ratio estimated by exp(0.00738)= 1.077, suggesting that the odds of mouth movement before touch increases by around 8% for each week of gestational age. Second, there was a marginally significant decrease in the proportion of reactive mouth movements after touching with gestational age (LRT χ^2=2.74 on 1 df, p=0.098). The parameter estimate of the age parameter is -0.034, with the odds ratio estimated by exp(-0.034)= 0.967, suggesting that the odds of mouth movement in reaction to touch *decreases* by around 3% for each week of gestational age. Third, touch of the face without mouth movement was not significant (LRT χ^2 =0.82 on 1 df, p=0.365). Similarly, the effect of gestational age on mouth movement during touch was also not significant (LRT χ^2=0.73 on 1 df , p=0.394).

Gender effects were again tested but no significant differences between males and females were shown either as main effects or as interactions with age either for anticipatory or reactive touch. For anticipatory mouth movements before touching the LRT for the gender by age interaction was 0.124 on 1 df (p=0.72) and the LRT for the main effect of gender was 0.017 on 1df (p=0.89). For reactive touch followed by mouth movement, the LRT for the gender by age interaction was 0.076 on 1 df (p=0.78) and the LRT for the main effect of gender was 1.65 on 1 df (p=0.20).

Insert Table 4 here

DISCUSSION

Results showed that the frequency of touch of different facial regions, namely upper, side lower and perioral region of the face, vary over gestational age with a significant decline in the touch of upper and side part of the face and a significant increase in touch of the lower and perioral regions of the face with increasing gestational age. Furthermore we found a significant increase in the proportion of anticipatory mouth movements before touching occurred, which increased by around 8% with each week of gestational age. Additionally, as hypothesised, there was a decrease in the proportion of reactive mouth movements decreasing by around 3% for each week of gestational age.

The results indicate that fetuses, as they develop from 24-36 weeks gestation, increasingly touch their mouth region and lower part of their face. This contrasts with findings by Myowa-Yamakoshi & Takeshita (2006) who, when comparing two groups of fetuses aged 24 and 31 weeks, observed that although approximately half of the arm movements resulted in hands touching the mouth no developmental differences in frequency of touch between the two age groups were noted. In the present study, we compared developmental trends for touching various areas of the face and found that frequency of touching upper and side areas of the face declined over age, whereas frequency of touching the lower part and mouth areas of the face increased with age.

Although Hepper, Dornan & Lynch (2012) found that male and female fetuses at 33 weeks gestational age habituated to sounds at different rates they did not find any differences between male and female fetuses in terms of spontaneous motor behaviours. In common with other studies (e.g. de Vries,Visser & Prechtl, 1988) we did not find any gender differences in the present study.

Furthermore, fetal facial touch does not seem impeded with increasing gestational age given that research indicates that fetuses at 24 weeks gestational age have their elbows flexed 93% of the time observed (Ververs, Van Gelder-Hasker , De Vries, Hopkins, Van Geijn ,1998), increasing further at 36 weeks. Hence, elbow flexion which might be considered to be conducive to face touch is not related to fetal age. Moreover, a study examining fetal manual head contact from 12 to 38 weeks gestation found, when comparing manual contact at 24 weeks gestation with 36 weeks gestation, that at 24 weeks, fetuses ranged in frequency from 1-28 touches and at 36 weeks the range in frequency observed was 2- 24 touches (de Vries, Wimmer, Ververs, Hopkins, Savelsbergh, & van Geijn, 2001). Hence fetuses as they develop from 24 to 36 weeks gestation seem not to vary in their frequency of touching their head.

In our repeated measures analysis of 15 fetuses observed from 24-36 weeks, we found an increase in touching the lower part of the face as well as the immediate mouth area. Hence it seems that in the second and third trimester of pregnancy touch of these sensitive areas of the face increases and could be linked with maturation of the fetal cortex (Kostovic & Judas, 2010). Arguably, this maturation might be preparatory for feeding post-birth. The increasing sensitivity to somatosensory stimuli has been illustrated by studies examining cortical reactivity to somatosensory stimulation in early preterm, late preterm and full term infants (Vanhatalo & Lauronen, 2006). Thus research suggests that between ages of 29 and 32 post-conceptional weeks sensorial-driven functionality is established, and this could explain the findings in the current study in terms of the timing of reactive mouth behaviour and anticipatory mouth behaviour (Kostovic & Judas, 2010).

In summary, the fetal central nervous system matures over time as shown by studies investigating fetal responses to sound and vibration with fetal response to sound starting around 24 weeks gestational age (Gerhardt & Abrams, 2000). This brain maturation might be the reason for our results, which showed that with increasing gestational age, fetuses progressively behaved as if they were anticipating touch of their face more frequently by moving their mouth before touch occurred rather than reacting to a touch. Our use of the term "anticipation" in the title of this paper refers to implicit or behavioural anticipation as defined by Pezzulo and Castelfranchi (2007), consisting of anticipatory conduct without anticipatory representation. Although our analysis is based purely on the sequential ordering of behaviours, we argue with Zoia et al (2007) that this anticipatory behaviour is neurologically more complex than reactive touch, necessitating an increased level of motor control and arguably the development of mapping of this area in the fetal somato-sensori cortex. Future research needs to examine whether in growth retarded or other compromised fetuses, such development is delayed.

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Table 1. Definition of the 11 mouth movements.

The 11 mouth movements	**Description of the Mouth Movements**
Upper Lip Raiser	Raising of the upper lip with the upper lip pulled in a straight line towards the cheek.
Lip Pull	Pulling of the corners of the mouth in an upward direction in a slight ‘U’ shape.
Lip Corner Depressor	Pulling of the corners of the mouth in a downward direction causing ‘bulges’ in the corners of the mouth.
Lower Lip Depressor	Pulling of the bottom lip in a downward and horizontal direction.
Lip Pucker	Puckering of the lips with lips protruding forward.
Tongue Show	Tongue is visible.
Lip Stretch	Lips are pulled horizontally elongating the mouth.
Lip Pressor	Pressing of the bottom and top lips together without producing wrinkling of the chin.
Lips Parting	Slight opening of the mouth so that a gap is visible between the lips.
Mouth Stretch	Opening of the mouth with the jaw dropping.
Lip Suck	Sucking of either the top of bottom lip into the mouth cavity.

Note: mouth movements are adapted from FACS - see Reissland et al (2011) for further details

Table 2. Descriptive summary information on facial touches and mouth movements.

	Gestational age of fetus			
	24 weeks	28 weeks	32 weeks	36 weeks
(a) Facial touches	Mean number of facial touches (std. dev.)			
upper face touches	6.93 (5.84)	5.93 (6.87)	3.60 (3.98)	2.00 (2.41)
side face touches	3.50 (2.74)	0.53 (0.92)	2.07 (2.63)	0.71 (1.49)
lower face touches	2.07 (1.73)	2.00 (1.60)	2.73 (2.69)	3.07 (2.30)
mouth area touches	1.07 (1.64)	1.13 (1.92)	2.80 (4.75)	2.14 (3.46)
Total facial touches	13.57 (6.74)	9.60 (8.48)	11.20 (9.63)	7.93 (4.95)
(b) Touch–mouth movement sequencing –	Mean number of events (std. dev.)			
Mouth movement before touch of the face	2.50 (1.70)	2.20 (2.68)	3.07 (4.37)	2.93 (1.73)
Touch before mouth movement	5.00 (3.01)	3.53 (3.41)	3.67 (3.33)	2.36 (2.40)
Touch of the face without mouth movement	2.29 (2.79)	1.60 (2.23)	1.73 (2.02)	0.79 (0.97)
Mouth movement during touch of the face	3.79 (2.72)	2.20 (1.65)	2.73 (2.84)	1.86 (1.61)
(c) Fetal scans				
Number of scans	14	15	15	14

Table 3. Results of the analyses of the changing frequency of face-touch events by gestational age.

	Estimate β	**s.e.**	**Exp(β)**	**LRT**	**σ^2**
Upper face area					
β_1 (Age)	-0.097	0.015	0.908	45.42 on 1 df $p<0.001$	0.212
Side face area					
β_1 (Age)	-0.103	0.025	0.902	18.94 on 1 df $p<0.001$	0.539
Lower face area					
β_1 (Age)	0.041	0.020	1.042	4.55 on 1 df $p=0.03$	0.147
Mouth area					
β_1 (Age)	0.067	0.024	1.069	7.81 on 1 df $p=0.005$	1.009

Table 4. Results of the analyses of the changing proportion of face-touch events in relation to mouth movement by gestational age.

	Estimate β	**s.e.**	**Exp(β)**	**LRT**	**σ^2**
Mouth movement before touch of the face					
β_1 (Age)	0.0738	0.022	1.077	10.83 on 1 df p=0.001	0.174
Touch before mouth movement					
β_1 (Age)	-0.034	0.020	0.967	2.74 on 1 df p=0.098	0.182
Touch of the face without mouth movement					
β_1 (Age)	-0.024	0.027	0.976	0.82 on 1 df p=0.365	0.375
Mouth movement during touch of the face					
β_1 (Age)	-0.018	0.021	0.981	0.73 on 1 df p=0.394	3.05×10^{-9}

Figure legends

Figure 1. Coded areas of the fetal face: upper, side, lower and mouth areas

Figure 2. Number of fetal face touches of four facial areas by gestational age

Figure 3. Changing percentages of touch-mouth sequences

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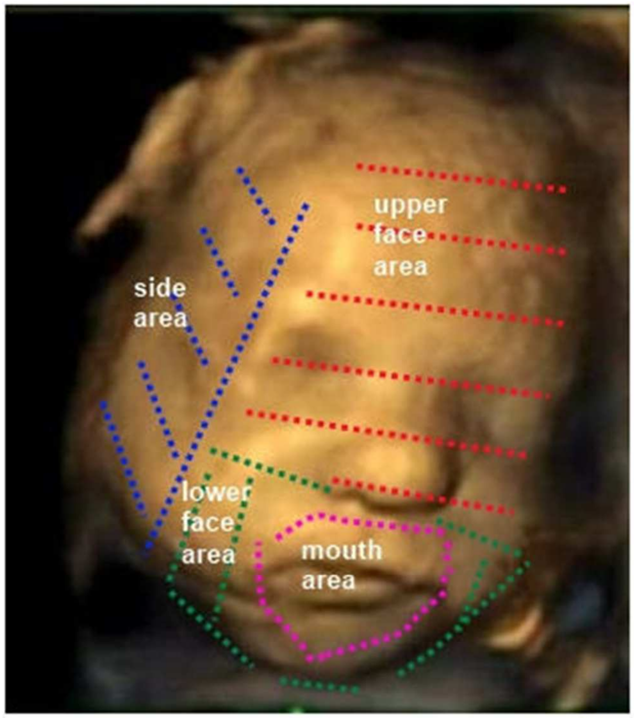
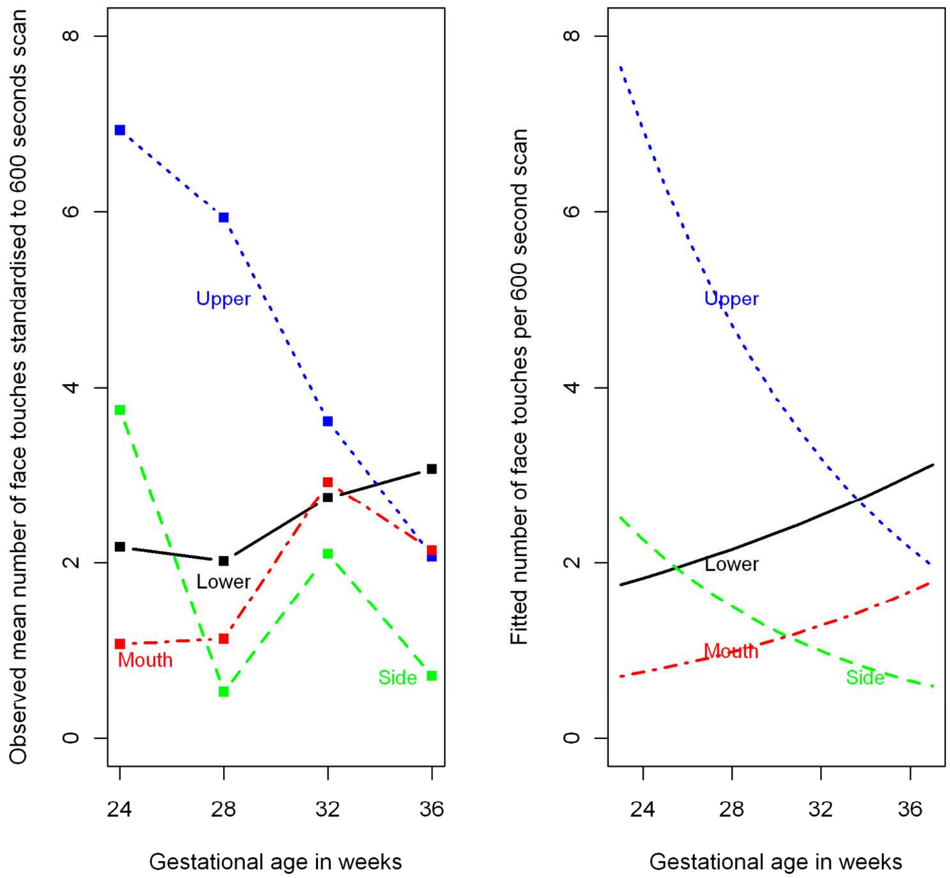
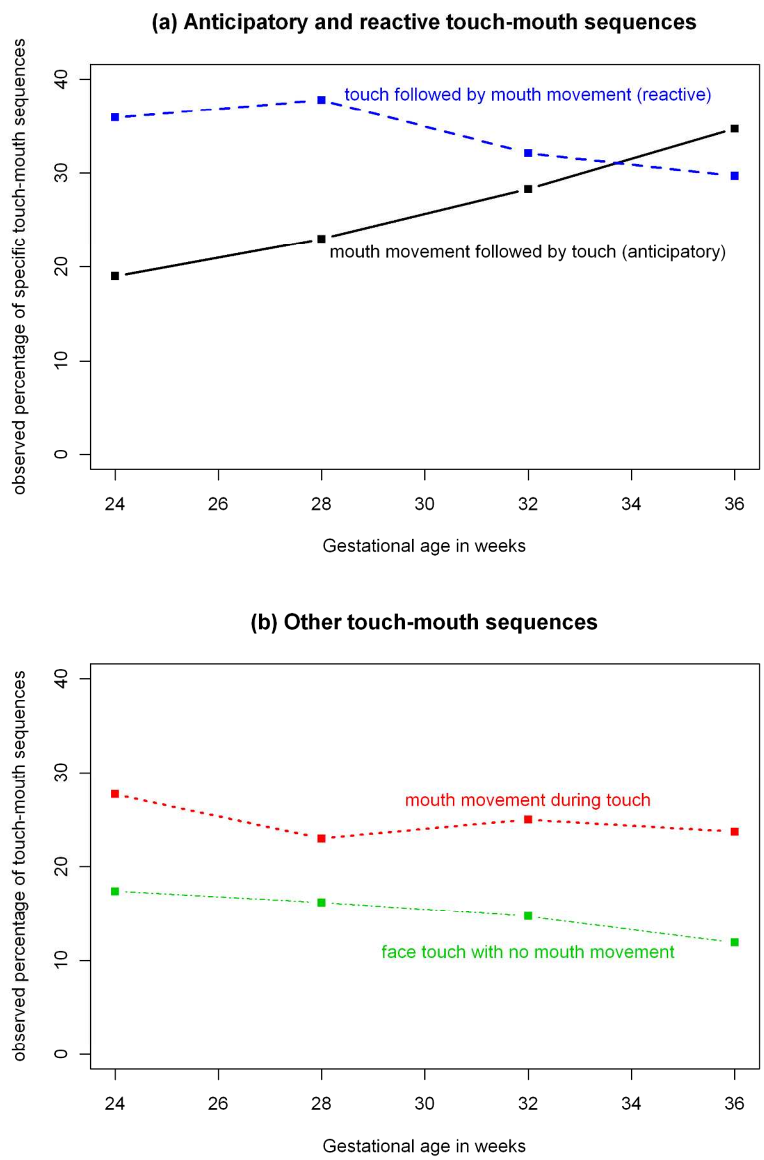


Figure 1. Coded areas of the fetal face: upper, side, lower and mouth areas.
111x126mm (72 x 72 DPI)



Number of fetal face touches of four facial areas by gestational age
173x173mm (300 x 300 DPI)



Changing percentages of touch-mouth sequences
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