Fetal reactions to face-like and non-face-like light stimuli controlling for maternal mental health: a study with reference to research methodologies

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Abstract

This research report builds upon existing research on the topic of fetal behavioural responses to light stimuli (Reid et al., 2017, Reissland et al., 2020). This report includes a background of fetal behavioural responses to visual stimuli, including a discussion on fetal behaviour coding techniques in comparison to emerging AI technologies. In this hypothesis-generating study, five fetuses were exposed to a range of face-like and non-face-like light stimuli. The Fetal Observable Movement System (FOMS) was used to code eye movement and head turn behaviours observed on 4D ultrasound videos using Observer 12. The statistical analysis controls for the impact of maternal mental health (stress and depression) on fetal behavioural responses. The study generated no statistically significant findings, however, some of the statistical trends observed and methodological conclusions drawn warrant further research.

Introduction

Since the introduction of 4D ultrasound scans in the mid-1990s, the field of fetal behavioural research has been transformed as clearer, sharper visualisation of the developing fetus can be viewed in both real-time and offline (Campbell, 2024). Consequently, the potential for research into fetal behaviour has grown, and it is within this research field that my 6-week Laidlaw project lies.

Firstly, this report provides a background overview of research papers relevant to fetal responses to light stimuli, and the effect of maternal mental health on fetal behaviour.

Secondly, this report provides an overview of the current landscape of fetal facial behaviour research methodologies, with a particular focus on the relative benefits and drawbacks of manual human ultrasound coding, in comparison to Artificial Intelligence (AI) coding. As AI becomes increasingly dominant in healthcare research (Davenport & Kalakota, 2019), this report aims to understand how AI technologies may specifically impact fetal facial behaviour research.

The rest of this research report focusses on the lab-based research I conducted this summer, specifically focussing upon the effect of face-like and non-face-like light stimuli on fetuses at average 32-week and 36-week gestation, and the impact of maternal mental health upon this. To do this, my analysis of results focussed upon answering several research sub-questions, which are found in the Analysis section.

Due to the 6-week timescale allowed for the research, only a small number of participants were used. Therefore, this research study can be characterised as 'hypothesis-generating' – the findings can be used as a starting point for future research within the field.

Background: fetal behavioural responses to light stimulation

Reid et al. (2017) conducted a study which specifically focussed upon fetal responses to face-like stimuli using 3 points as stimulus, which concluded that there was a statistically significant difference between fetal head turning behaviour towards 'top-heavy' face-like stimuli (with two points on top and one at the bottom) in comparison to inverted 'bottom heavy' stimulus. However, questions relating to the methodology of the study have casted doubt upon the validity of the results. As Scheel et al. (2018) note in their critique of the Reid et al. study, the absence of a control non-face-like stimuli limits the ability to draw reliable conclusions about fetal preference for top-heavy face-like patterns. Furthermore, concerns were noted on whether the fetus could differentiate between the top-heavy and bottom-heavy light stimuli due to light scattering through the mother's abdomen, therefore again bringing into question whether fetuses were differentially responding to the stimuli.

Reissland et al. (2018; 2020) also conducted studies extending knowledge on fetal behavioural responses to stimuli, with a particular focus on including maternal mental health as a variable with the potential to impact results. In their 2018 study focussing upon the impact of maternal anxiety and depression on fetal eye-blink rate, Reissland et al. found statistically significant differences in the rate of eye blinking in fetuses with anxious (20% increased eye blink rate, per unit increase in anxiety) or depressed (21% decreased eye blink rate, per unit increase in depression) mothers, in comparison to non-anxious and non-depressed mothers. Furthermore, exposing the fetus to sound stimuli also significantly affected fetal blink rate, a finding which again has important implications for understanding the development of fetal sensory systems across the gestational period.

In 2020, Reissland et al. extended these findings to consider whether fetuses differentially turned their heads in reaction to face-like light stimuli in comparison to a control non-face-like stimulus, controlling for maternal mental health. Both the face-like and non-face-like stimuli used had the same number of LED lights (12 red 3 mm LED bulbs (3 W each) with a centre wavelength of 640 nm), which was more than the 3 used by Reid et al. (2017). The study found that there was a statistically significant difference between relative head turns when exposed to face-like (both top-heavy and bottom-heavy) stimuli in comparison to the control stimulus. Additionally, the study reported significant correlations between maternal anxiety and depression and fetal reactivity to the stimuli. These findings indicate that maternal mental health factors impact fetal behavioural reactions, thereby supporting the importance of controlling for maternal mental health in fetal developmental research.

Taking the literature together, gaps in the existing research to address in fetal vision research include:

- Control light stimuli: In the current research, several configurations of control non-face-like light stimuli are used alongside the RU and UD face-like stimuli.
- Eye blink rate in relation to face-like stimuli: whilst the Reissland et al. (2020) study found significant differences in head movement responses to face-like vs control stimuli, the current study considers whether similar results are found for eye blink responses.
- Scattering of light stimuli are modelled for the current study to ensure each stimulus is distinguishable for the fetus (see Appendix 1).

Coding systems and AI in fetal ultrasound research

This discussion seeks to evaluate the relative benefits and limitations of various fetal movement coding methodologies.

Fetal ultrasound movement coding can be done manually using a range of approaches, from qualitative description of general movements (Reissland, 2014), to recognised coding systems including Kurjak's Antenatal Neurodevelopmental Test (KANET), and the Fetal Observable Movement System (FOMS) (Reissland, 2015). As Reissland notes in her 2014 paper, the former method of fetal facial movement coding is limited by the use of 'emotionally charged language', which can be subjectively interpreted and thus risks creating coding discrepancies between individual labs/coders. For example, research that classifies fetal facial expressions as 'smiling' (eg Hata, Dai & Marumo, 2010) or 'grimacing' (eg Kurjak et al., 2003) - without defining the anatomical muscle movements that constitute this - both implies an emotional intent in the fetus that has yet to be confirmed, and increases the chance of coding differences between individual coders.

Therefore, established anatomically based coding systems can offer a more objective methodology to analyse fetal movements. Whilst systems such as KANET focus on fetal movements in several areas of the body and include other physiological measurements for clinical use (Neto, 2015), the coding scheme used for the current study (FOMS) focusses specifically on fetal facial movements and self-touches. The FOMS scheme (based on the established FACS scheme (Friesen and Ekman, 1978)) characterises 17 facial movements that can be observed on 4D ultrasound videos and occur independently (Reissland et al., 2016), with each movement defined anatomically by the muscles used to create the movement. As with other manual coding schemes, the potential for human error in coding movements incorrectly or 'over-coding' could weaken the strength of this methodology, however conducting reliability checks with other trained FOMS coders can mitigate this issue. Therefore, whilst the FOMS system is labour intensive, it offers a more fine-grained and objective system through which to analyse fetal movement (Reissland et al., 2015).

In recent years, fetal movement research has been impacted by the emergence of AI methodologies as an alternative to manual coding. Whilst much of the existing literature surrounding AI methodologies and ultrasound coding is based upon clinical applications (eg Miskeen et al., 2025), for example to identify fetal facial anomalies, the potential benefits and limitations of such technologies also have relevance for fetal research. Currently, a range of AI technologies have been developed to code human movements, including 'FaceReader' for adult humans. More commonly for fetal ultrasound research, AI deep-learning algorithms such as: Convolutional Neural Networks (CNN), Recurrent Neural Networks (RNN), and Long Short-Term Memory networks (LSTM) (Sriraam et al., 2025) can be used. The potential benefits of such technology for fetal facial coding have been discussed by Miyagi et al. (2021) who analyse an original deep learning AI movement classifier software, specifically for its potential for fetal facial movement coding and ultrasound image enhancement. Whilst Miyagi et al. make some valid points on the potential of AI to reduce the time cost of manual human coding techniques and reduce the risk of human error in coding, the results of the paper are weakened by the large confidence score standard deviations on the ability of AI to accurately code fetal facial movements. For example, Miyagi et al. present a confidence interval surrounding the ability of AI to correctly identify eye blink movements of $0.175<x<0.9$, suggesting there is between a 17.5%-90% chance that the AI output is reliable (Hazra, 2017). Similar large confidence interval ranges were reported for 'scowling' and 'face without any expression' categories, however Miyagi et al. note that using more fetal ultrasound videos to 'train' the AI software may reduce confidence intervals and improve accuracy in the future. Furthermore, the paper reports that the AI system used could only recognise 7 facial movements, and of these several comprised unspecific terms such as 'mouthing' and 'scowling'. This contrasts with the manual coding system FOMS described above, which anatomically defines 17 facial movements. Using Miyagi's paper as an example of current literature surrounding AI in fetal movement research illustrates potential issues with AI based fetal coding, and raises questions over whether AI coding technologies currently offer the same reliability as manual coding.

Finally, the use of AI to enhance 4D ultrasound image quality (Bachnas et al., 2024) is also considered one of the benefits brought by AI technology. In enhancing ultrasound video sharpness, AI could tackle issues with image resolution which currently pose an issue to manual coders. However, Bachnas et al. (2024) also acknowledge that using algorithms to modify 4D ultrasound images risks uneven application across different fetal ethnicities and appearances, thus risking research not being generalizable across different research groups. Nevertheless, using AI to improve image quality of 4D ultrasound images, if reliably applied, could enhance and potentially augment manual coding techniques to improve confidence in facial coding results.

Methodology of the current study

For this study, 4D ultrasound videos of fetal reactions to light stimuli were coded, and behavioural responses were analysed controlling for maternal mental health factors.

Sample in this study:

For the current study, ultrasound videos of five mothers were coded: for two mothers, only the ~32-week scan was available; for three mothers both the ~32-week and ~36-week scans were available. These five mothers met a set of inclusion criteria (see Appendix 2), and Durham University ethics committee approved the study. The mean gestational age at the two scan points was 32.2 weeks and 36.3 weeks respectively.

Each fetus at each scan point was exposed to 6 different stationary light stimuli (see Appendix 3), as presented in the table below. Each stimulus was presented between 3-4 times to the fetus, for an average duration of 20 seconds at a time. The stimuli was delivered by a custom designed probe, which was placed touching the mother's abdomen by the experimenter while a trained sonographer recorded fetal reactions using GE Healthcare Voluson 8.

Face-like stimuli	Non-face-like stimuli
RU – right side up (top-heavy) 'smiley face' UD – upside down (bottom-heavy) 'smiley face'	DS – diagonal stripes ES – extended stripes VS – vertical stripes SQ – square

As well as each stimulus being presented to the fetus when stationary, each stimulus was also presented 'moving' by the experimenter moving the probe over the mother's abdomen. Although this was done for each of the six stimuli, because of time constraints in the current study, only responses to the moving RU and UD stimuli were analysed.

Maternal mental health studies

Before each of the scans, mothers were asked to complete mental health questionnaires. These included questions on their attachment, their stress levels, and whether they were experiencing symptoms of anxiety or depression. The anonymised mental health of the mothers used in my study are presented in Appendix 5.

Coding of 4D ultrasound scans

To code the archived ultrasound videos, the FOMS coding scheme was used on Observer 12. Specifically, eyes open/closed (see Appendix 4) and head turns (left/right/up/down) were coded for.

Overall, 56 videos were coded, including 48 ‘stationary stimuli’ videos of length ~69-93 seconds, and 8 longer ~198 second ‘moving stimuli’ videos.

Methodology analysis factors to be considered

- Small sample size – only having five participants decreases the reliability of results.
- Ultrasound videos – some videos had large sections where no facial behaviour could be coded (see Appendix 6), reducing the time in which a relative frequency of movement could be calculated.

Analysis and Discussion

The relative frequency of fetal eye and head turn movements was first calculated using Observer 12 to generate tables noting:

- The exact start/stop and behavioural movement durations
- The number of each behavioural response within the codable duration.

This data was then exported to Excel, where further statistical analysis was conducted. Finally, some statistical analysis was conducted using SPSS.

What is the effect of maternal mental health on fetal responses to presented light stimuli?

Appendix 7 shows a regression analysis of maternal mental health as correlated with each type of light stimuli (x-axis). From this regression analysis, key observations include:

- ES and UD stimuli appear to have relatively stronger associations with stress and depression.
- VS stimulus has a moderately stronger correlation with stress and anxiety.

However, there are no statistically significant findings. This may be attributed to the small dataset, as five participants is too small for reliable regression modelling. This leads to:

- **Perfect R^2 values (1.000)** — indicating 'overfitting', meaning that the analysis trends are too tightly tailored to the study data and therefore could not be generalised to new data points.
- **NaN p-values and standard errors** — meaning variability in results cannot be tested due to insufficient number of data points/degrees of freedom.

Using the Friedman Test (non-parametric repeated-measures ANOVA) on the regression analysis also confirms non-significance of results.

$\chi^2(5) = 5.47$
$p = 0.361$ (exceeds statistically significant benchmark $p<0.05$)

What is the effect of maternal mental health on specific behavioural responses at specific gestational ages?

No statistically significant correlations between maternal mental health and specific behavioural responses were found. However, as shown in Appendix 8, a positive trend between anxiety and stress with eye movements at ~36 weeks was observed. This aligns with the findings of Reissland et al. (2018) on increasing rate of fetal movement associated with anxiety/stress, however considering the current study only has three data points at ~36-weeks, this can only be considered as a trend shown in the data.

Is there a difference between the behaviour of individual fetuses at 32-weeks vs 36-weeks?

For the fetuses where there were scans available at both ~32 and ~36 weeks, two-tailed paired t-tests on average rate of both eye movements and head turns were conducted. The only statistically significant result ($p<0.05$) was in mother LABA93, where there was a statistically significant change in frequency of eye movements between ~32 and ~36 weeks (see Appendix 9).

Is there an overall difference in eye movement and head turn behaviour ~32 vs ~36 weeks?

Analysis of the average relative frequency of movement across all mothers at ~32-weeks and ~36-weeks, as shown in Appendix 10, demonstrates no consistent pattern.

Is there a difference in average rate of movement when exposed to face-like (RU, UD) in comparison to non-face-like (SQ, ES, DS, VS) light stimuli?

Although there are differences in average rate of movement for different stimuli, as presented in Appendix 10, there appears to be no consistent relationship between frequency of movement and type of light stimulus. Nevertheless, including different non-face-like light stimuli in a larger study may be valuable in trying to determine whether it is the face-like properties of the RU and UD stimuli that have elsewhere been shown to elicit preferential response (Reissland, 2020), rather than other features of stimuli such as lines of symmetry.

Is there a difference in fetal response to moving stimuli in comparison to non-moving light stimuli?

To analyse whether moving the light stimuli across the mother's abdomen impacts upon rate of movement, paired two-tailed t-tests were conducted on behavioural responses to UD and RU static and moving light stimuli. Again, no statistically significant findings were observed (see Appendix 11).

Overall, there were no statistically significant findings from this study. This perhaps could be attributed to the small sample size and the methodological challenges noted above.

Nevertheless, this study could be used as 'hypothesis-generating' for further research - including more participants - to build upon.

Conclusions and Implications

In conclusion, several research papers have previously focussed upon fetal behavioural reactions to light stimuli, including Reid et al. (2017), and Reissland et al. (2018, 2020). Additionally, the Reissland et al. papers confirm the importance of recognising maternal mental health as a variable which can impact upon fetal behaviour.

Through considering evidence on the relative benefits and limitations of different fetal facial coding methodologies, it can be concluded that whilst manual coding still brings advantages regarding interpretation of a wider range of more complex facial movements, there may be a role for AI in augmenting manual coding practises to improve 4D ultrasound video clarity. However, AI methodologies, if continually introduced into fetal clinical settings and research, need to be managed ethically and reliably in order to ensure positive outcomes.

Finally, I found no statistically significant results regarding the relationship between fetal eye movement and head turn responses to various face-like and non-face-like light stimuli, controlling for maternal mental health. However, despite this, trends supported by previous research were observed:

- Correlation between average (across all participants) rate of eye movement and stress/anxiety at 36 weeks, corroborating the effect of anxiety on fetal behaviour (Reissland et al., 2018)
- Significant difference between rate of eye movement at ~32 and ~36 weeks for LABA93 participant, corroborating finding of changing behaviour over gestation (Reissland et al., 2011)

Overall, despite its small size, the study could be used as hypothesis-generating for future research. If this were the case, the areas that could be explored further in a larger study include:

- Building on differences between relative rate of movement and stimuli type, is there a significant difference between responses to different control stimuli (VS, ES, DS, SQ), and, if so, can it be hypothesised what factors affect this? For example, does the symmetry of the light stimuli impact fetal behaviour, and if so, what does this mean for the creation of new face-like and non-face-like stimuli?
- Building on the trend observed at 36-week eye movement, is there a significant correlation between movement frequency in response to light stimuli across gestation, controlling for maternal mental health?

Research into fetal behaviour towards light stimuli could have implications not only for fetal research but also expecting families and the public more broadly. For example, further research into why a fetus responds differentially to different stimuli may be valuable in gaining an insight into fetal brain and visual development and, in the long term, could perhaps be used as an indicator of healthy fetal development across gestation. Furthermore, findings on the reliability and use of AI in fetal research could hold significance in guiding the trajectory of fetal research techniques, as well as potentially the use of AI to code ultrasound videos to identify fetal anomalies in a clinical setting.

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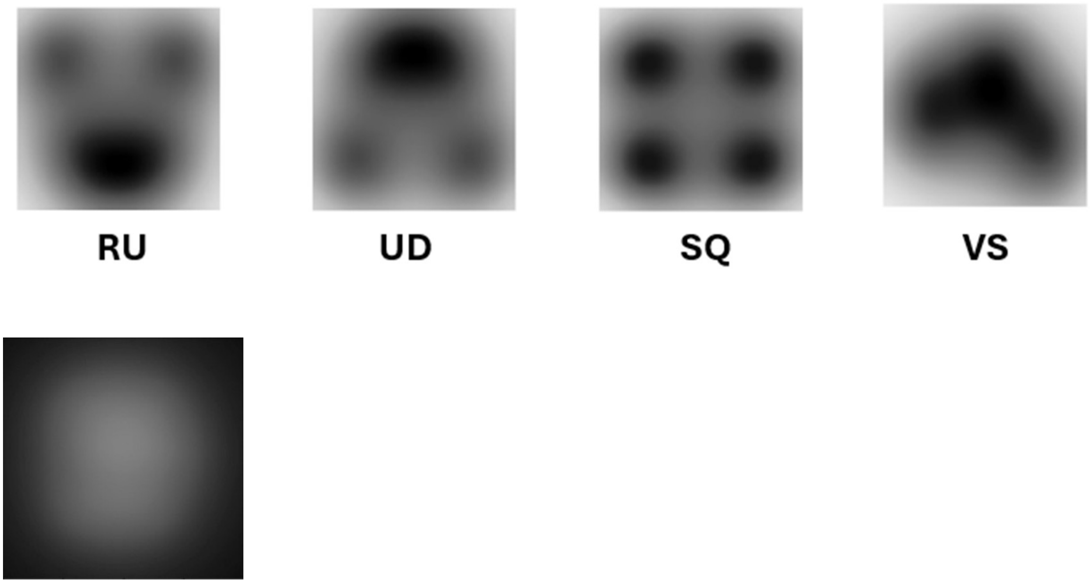
Appendices

Appendix 1 – modelling (by Durham University Department of Physics) of how light stimuli appears to the fetus in utero



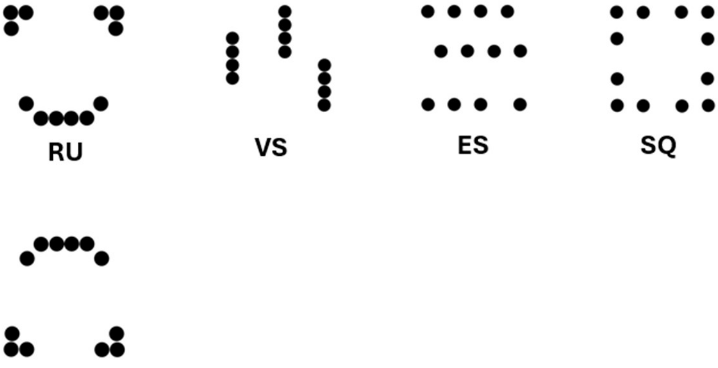
RU UD SQ VS

ES

Appendix 2 – inclusion criteria for vision study participants

- Healthy 20-week anomaly scan
- No medical history
- No alcohol consumption during pregnancy
- No smoking during pregnancy

Appendix 3 – light stimuli used for the study



RU VS ES SQ

UD

Appendix 4 – example of 4D ultrasound ‘eyes open’

Appendix 5 – anonymised maternal mental health information

CHOO00 32w:

- High Attachment
- Medium stress
- No anxiety or depression

KAWA87 32w:

- High attachment
- Medium stress
- No anxiety or depression

KAWA87 37w:

- No attachment score
- Medium stress
- No anxiety or depression

LABA93 32w:

- High attachment
- Low stress
- No anxiety or depression

LABA93 35w:

- High attachment
- Low stress
- No anxiety or depression

MERO95 34w:

- High attachment
- Medium stress (though higher medium than before)
- No anxiety or depression

MERO95 37w:

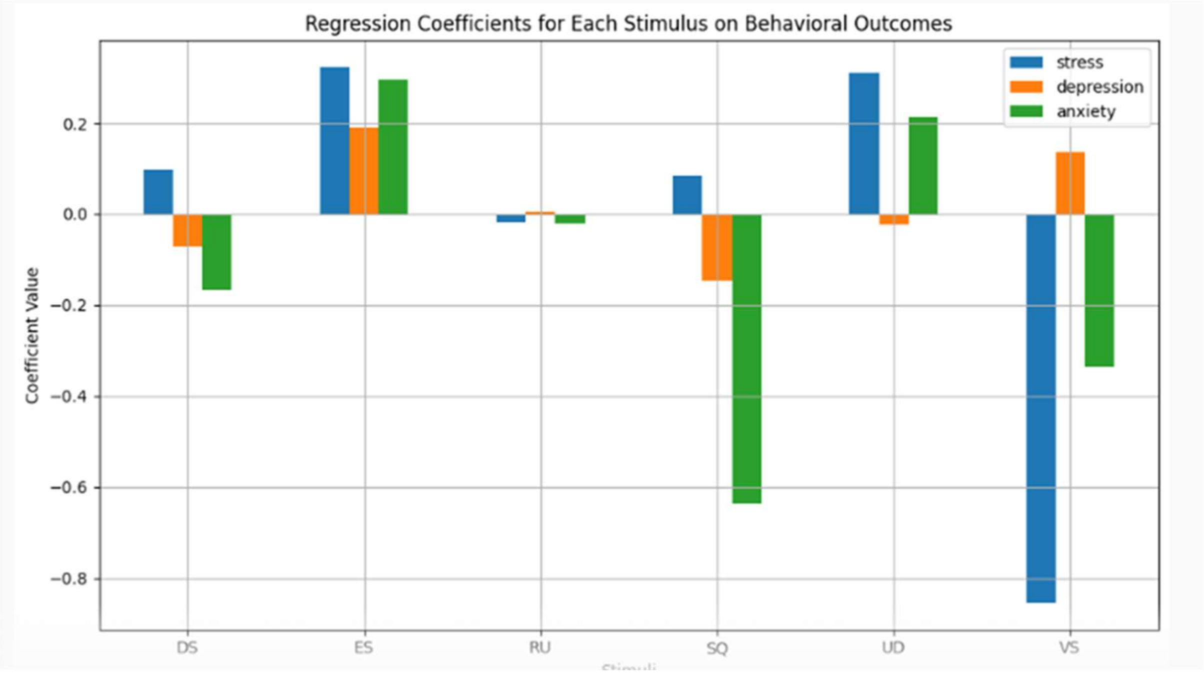
- High attachment
- Medium stress (though higher medium than before)
- No anxiety
- Depression - abnormal

ELPO31W 31w:

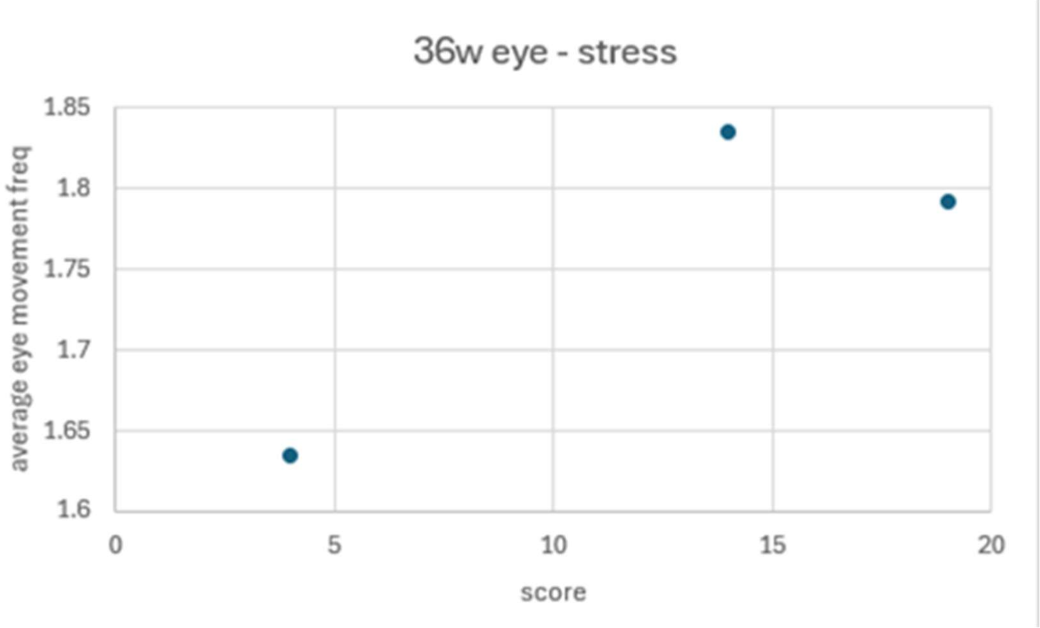
- High attachment (just)
- Medium stress (highest medium)
- Anxiety – abnormal
- No depression

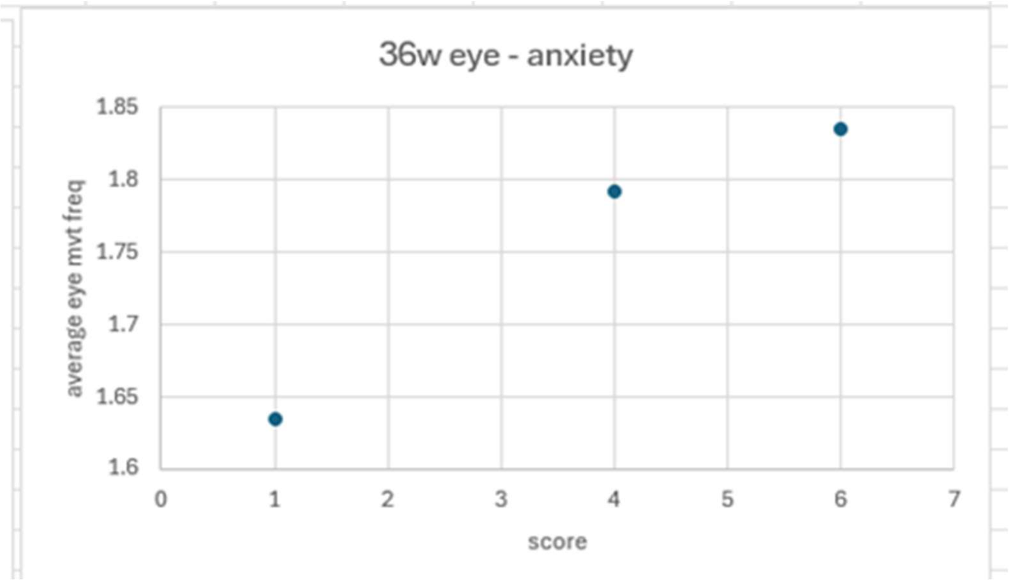
Appendix 6 – examples of none codable ultrasound images

Appendix 7 – regression analysis of maternal mental health to eye blink behaviours



Appendix 8 – 36-week eye movement with regard to maternal stress/anxiety



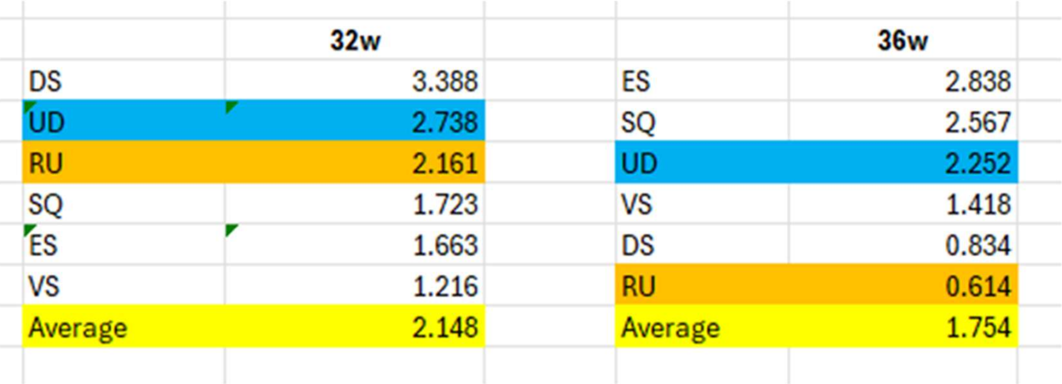


Appendix 9 – T-tests of differences between fetal behaviour at ~32-weeks and ~36-weeks

Mother	T-test p-value between 32w and 36w eye mvts average	T-test p-value between 32w and 36w head turns	Statistical significance
KAWA87	0.109	0.426	No
LABA93	0.011	0.095	Yes – but only for eyes.
MERO95	0.072	0.128	No

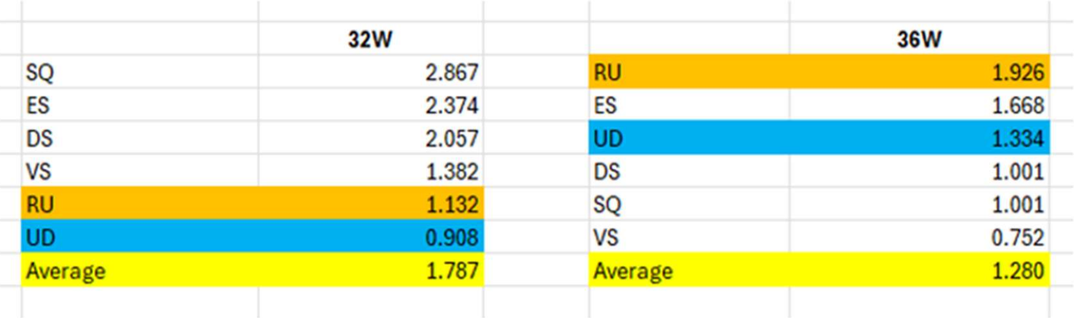
Appendix 10 – average rate of fetal movement (movement/minute) in response to different light stimuli at ~32-week and ~36-week. Orange and blue indicate the face-like stimuli.

Eye movement



	32w		36w
DS	3.388	ES	2.838
UD	2.738	SQ	2.567
RU	2.161	UD	2.252
SQ	1.723	VS	1.418
ES	1.663	DS	0.834
VS	1.216	RU	0.614
Average	2.148	Average	1.754

Head turn



	32W		36W
SQ	2.867	RU	1.926
ES	2.374	ES	1.668
DS	2.057	UD	1.334
VS	1.382	DS	1.001
RU	1.132	SQ	1.001
UD	0.908	VS	0.752
Average	1.787	Average	1.280

Appendix 11 – t-test results of average rate of fetal movement in response to moving vs static RU and UD stimuli.

Stimulus	Behavioural response	P-value after conducting t-test between static and moving stimuli relative frequency (3dp)	Statistical significance?
UD	Eye movement	0.234	No
UD	Head turn	0.133	No
RU	Eye movement	0.557	No
RU	Head turn	0.910	No