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Effect of maternal position on fetal behavioural state and heart rate variability in healthy late gestation pregnancy

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Key points:
Fetal behavioural state in healthy late gestation pregnancy is affected by maternal position.
Fetal state 1F is more likely to occur in maternal supine or right lateral positions.
Fetal state 4F is less likely to occur when the woman lies supine or semi recumbent.
Fetal state change is more likely when the woman is supine or semi recumbent.

Fetal heart rate variability is affected by maternal position with variability reduced in supine and semi recumbent positions.

Key words: Fetal behavioural state, fetal heart rate variability, maternal position, pregnancy, stillbirth
Abstract:

Background: Fetal behavioural states (FBS) are measures of fetal wellbeing. In acute hypoxemia, the human fetus adapts to a lower oxygen consuming state with changes in the cardiotocograph and reduced fetal activity. Recent studies of late gestation stillbirth described the importance of sleep position in the risk of intrauterine death. We designed this study to assess the effects of different maternal positions on FBS in healthy late gestation pregnancies under controlled conditions.

Method: Twenty nine healthy women had continuous fetal ECG recordings under standardized conditions in 4 randomly allocated positions, left lateral, right lateral, supine and semi-recumbent. Two blinded observers, assigned fetal states in 5 minute blocks. Measures of fetal heart rate variability were calculated from ECG beat to beat data.

Results: Compared to state 2F, state 4F was less likely to occur when women were semi-recumbent (OR=0.11 95%CI 0.02, 0.55), and supine (OR= 0.27 95%CI 0.07, 1.10).State 1F was more likely on the right (OR=2.36 95%CI 1.11, 5.04) or supine (OR=4.99 95%CI 2.41, 10.43) compared to the left.

State change was more likely when the mother was semi-recumbent (OR=2.17 95%CI 1.19, 3.95) or supine (OR=2.67 95%CI 1.46, 4.85).There was a significant association of maternal position to mean fetal heart rate. The measures of variability (SDNN and RMSSD) were reduced in both semi-recumbent and supine positions.

Conclusion: In healthy late gestation pregnancy, maternal position affects FBS and heart rate variability. These effects are likely fetal adaptations to positions which may produce a mild hypoxic stress.

List of Abbreviations

BMI body mass index
CI Confidence Interval
CTG cardiotocograph
ECG electrocardiograph
FBS fetal behavioural state
fECG fetal electrocardiograph
FHR fetal heart rate
FHRV fetal heart rate variability
GLM GLIMMIX
OR Odds Ratio
PaO2 Arterial oxygen tension
Introduction:

The presence of fetal behavioural states (FBS) has now been established for many years (Nijhuis et al. 1982; Arduini et al. 1986) and fetal heart rate (FHR) patterns have been used to deduce the fetal state (Timor-Tritsch et al. 1978; Pillai&James, 1990a), which is reliably determined by examination of the characteristics of the baseline fetal heart rate patterns alone (Pillai&James, 1990b). FBS and their transitions are measures of fetal wellbeing that reflect the neurological integrity of the fetus (Romanini&Rizzo, 1995) and the development of autonomic nervous control of heart rate (Brandle et al. 2015).

FBS may be defined as combinations of particular physiological variables which are stable over a period of time and recur (Martin, 2008). During the third trimester of pregnancy, fetal activities are cycle or state-dependent, so that prolonged, and often repeated recording of behaviour is necessary before any adverse conclusions can be drawn about fetal wellbeing (Pillai&James, 1990b). The development and stability of FBS is disturbed in adverse situations such as maternal diabetes and chronic fetal compromise such as growth restriction (van Vliet et al. 1985; Mulder et al. 1987). More acute compromise in a previously healthy fetus leads to suppression of fetal activity which may adapt over time in the absence of metabolic acidemia (Martin, 2008). In acute hypoxemia, the fetus makes adaptations to a lower oxygen consuming state, with effects on electrocortical activity shown in sheep (Boddy et al. 1974; Richardson et al. 1985; Bocking& Harding, 1986). The human fetus also makes adaptive changes to hypoxia (Martin, 2008) with changes in the cardiotocograph (CTG) and in reduced fetal activity (Bocking, 2003; Froen et al. 2008).

Behavioural state transitions have also been found to be different in length of time and characteristics in the growth restricted compared with the normally grown fetus (Arduini et al. 1989). Measures of fetal habituation and behavioural state transitions have been proposed as methods of assessing fetal wellbeing and predicting neonatal outcome (Krasnegor et al. 1998).

Recent developments in transabdominal fetal electrocardiography (fECG) have permitted ambulatory recording of the beat to beat fetal heart rate (Narayan et al 2015). A conventional cardiotocograph (CTG) may be derived from this and fetal behavioral state determined.

Fetal heart rate variability (FHRV) calculated from beat to beat heart rate intervals is an established marker of fetal wellbeing as it reflects the development and function of the fetal autonomic nervous system in both health and in stress such as hypoxia (Dawes et al. 1994; Schneider et al. 2008). Reduction in FHRV is known to precede fetal distress and alterations in the inter beat interval may occur before any noticeable change in the heart rate itself is detected (Dalton et al. 1983). The changes in fetal behavioural state may be associated with changes in FHRV (Romanini & Rizzo, 1995).
A recent study of factors associated with late (third trimester) stillbirth described the importance of maternal sleep position where non left sided sleeping, particularly supine, was found to be associated with an increased risk of stillbirth (Stacey et al. 2011). Two further studies have confirmed adverse effects of supine sleeping (Owusu et al. 2013; Gordon et al. 2015). The mechanisms by which a normally formed fetus in a healthy pregnancy should be at risk of stillbirth remain unclear as does the reason why maternal position should be of importance. A triple risk model has been proposed as a method of understanding the pathogenesis of late stillbirth involving the interplay of maternal factors, a vulnerable fetus and the imposition of a stressor which then produces a lethal combination (Warland & Mitchell 2014). An aim of our studies was to investigate the effects of maternal position in healthy late gestation prior to examining vulnerable pregnancies such as those in the obese woman or with fetal growth restriction. Vulnerable groups at increased risk of late stillbirth have been identified as a priority area for research in high-income countries (Flenady et al. 2011).

Therefore as part of ongoing studies of stillbirth, we designed this study to assess the effects of different maternal positions in healthy late gestation pregnancies under controlled conditions on FBS as a marker of fetal wellbeing. We hypothesised that FBS would be affected by maternal position.

Method:

Ethical Approval:

This study was approved by the Northern Regional Human Ethics Committee. (NTX/11/09/084). All subjects gave written informed consent. All studies approved by the Northern Regional Human Ethics Committee conform to the Declaration of Helsinki.

Subjects:

Twenty nine healthy women aged ≥ 18 years with a normal singleton pregnancy, late in the third trimester (35-38 weeks gestation), were recruited from low risk midwifery care at National Women’s Hospital, Auckland, New Zealand.

Maternal exclusion criteria included: multiple pregnancy, current smoking or alcohol use, early pregnancy body mass index (BMI) >30, any medical or obstetric complications (e.g., preeclampsia, any known cardiovascular including hypertension or use of antihypertensive treatments, respiratory or renal disorders, all forms of diabetes), not regularly attending scheduled obstetric appointments, any orthopaedic or musculoskeletal conditions which would make adopting different maternal positions difficult and inadequate English speaking to give consent. Fetal exclusion criteria included: abnormal biometry for the gestation, reduced amniotic fluid volume and abnormal umbilical arterial Doppler measurements.

A maternal echocardiogram was performed immediately prior to study to ensure normal maternal cardiac anatomy and function.

Fetal biometry using customized centile charts (McCowan et al 2004) and fetal Doppler measures of the umbilical and middle cerebral arteries were also recorded using standard methodologies. Fetal biometry <10th centile was considered abnormal and was an exclusion
factor. Pulsatility indices in the umbilical arterial <95th centile, and in the middle cerebral arterial >5th centile and a cerebroplacental pulsatility index ratio >5th centile on reference charts (Ebbing et al 2007) were considered normal and were required for inclusion in the study. In addition, a measurement of the single deepest pool of amniotic fluid was performed; all assessments being performed to ensure normal fetal wellbeing. Birth outcome data were collected to confirm the health status of the mother and neonate.

Procedures:

Participants were told to abstain from alcohol, caffeine, chocolate and strenuous exercise on the day of the assessment, and not eat within two hours of the assessment. All assessments were performed in the afternoon between 2 and 5 pm.

Four maternal positions, supine, semi-recumbent, left lateral and right lateral were studied. In supine the women lay on her back with one pillow. The semi-recumbent position was defined as having the woman supine with the cephalad end of the examination couch raised to a measured 30 degrees from the horizontal and one pillow was provided. The lateral positions involved the women being placed at least 30 degrees from supine, with the head of the couch flat and one or two pillows provided.

On arrival in the laboratory, the participants were randomised to the order of maternal positions from a computer-generated list created in MS Excel. Each woman was monitored for 30 minutes in each position. The participant would move directly from one position to the next unless she needed to use the bathroom. Assessments were all performed in the same room, by the same investigators (PS, JM).

A continuous fetal ECG, electrohysterogram and maternal heart rate were recorded using the Monica™ AN24 ambulatory transabdominal fetal ECG device (Monica Healthcare, Nottingham, UK). Skin preparation, electrode placement and impedance testing were performed as per the manufacturer's instructions. This device enabled monitoring of the fetus without need to reposition bulky transducers when the mothers moved between each position. In addition, in contrast to conventional cardiotocography, the device recorded a fetal ECG with true beat to beat intervals being recorded in one minute epochs without autocorrelation as used in commercial CTG machines.

Data processing:

The data from the Monica™ device were uploaded to a PC computer with the Monica (VS) analysis software. The Monica VS software uses beat to beat data to construct a fetal cardiograph, which when combined with the hysterogram produced a printout analogous to a standard CTG suitable for interpreting FBS.

The Monica™ has a built in proprietary algorithm to deal with signal loss (any epoch with >30 s signal loss in the 1 minute epochs used for the analysis of the raw ECG signal is disregarded and no result is given for that epoch). The manufacturer's analysis programme (Monica DK v1.9) was used to calculate FHRV. The mean FHR was assessed for each minute analysed, giving up to 30 samples (30 one min epochs) per position in each subject. Each epoch was quantified by the mean FHR, the standard deviation of RR intervals.
(SDNN) and the root mean square of successive RR intervals (RMSSD). The left lateral position was used as the referent from which the other positions were compared. For analysis of the relationship of these variables in relation to fetal state, the observations over each block of time were averaged to correspond with the block of time the fetal state had been determined.

The CTGs were scored independently by two obstetricians (PS, WB), blind to maternal position. Each block was scored for fetal state as either 1F, 2F, 4F, transition or indeterminate using the methods of Pillai and James (1990a). Consistent heart rate patterns were defined as a state when the duration was at least 3 minutes. Comparison of the scoring found a kappa of 0.68 which is considered substantial with complete agreement in 82% of observations. When the agreement analysis was limited to observations where a fetal state had been defined by both scorers kappa was 0.86 (considered almost perfect) and there was complete agreement for 95% of observations. For observations where there was disagreement, the scorers reviewed the observations together, blind to the original scoring and reached a consensus view. These observations are those used in the analysis.

**Statistical analyses:**

Odds ratios were determined to estimate the risk of the fetus being in state 1F and state 4F compared to the predominant state 2F by maternal position. This was carried out using repeated measures analyses (i.e. the repeated measures over the 30 minutes in each position of fetal state) in the GLIMMIX (GLM) procedure in SAS. The models used a binary outcome with a logit link and a random intercept term.

Differences in FHR and FHRV were assessed using the GLM procedure to compare differences in these measures when the fetus was in 1F or 4F compared to the referent 2F group. The analyses to compare FHR and FHRV by maternal position (with referent left position) for state 1F and 2F were carried out in the same manner. The sample size did not allow for this analysis to be carried out for data where the fetus was in state 4F (n=24).

All analyses were carried out in SAS for Windows v9.3 (SAS Institute, Cary, NC).

**Results:**

There were analysable data for 511 (88.1%) of the observations (blocks of time), data loss was due to loss of signal (8.3%), fetus in transition (1.7%) or indeterminable state (1.9%). Visual analysis of the FHR data showed that there were no decelerations at times of state change, nor periods of fetal bradycardia.

**Distribution of fetal state**

The distribution of FBS by maternal position is shown in table 1. As would be expected the primary FBS was 2F (74.0% of the time) followed by 1F (21.3%) and 4F (4.7%).

**Effect of maternal position on fetal state**

In table 2, the likelihood of being in a state other than 2F related to maternal position is shown. In comparing state 2F to 1F, those on the right (OR=2.36, 95%CI 1.11, 5.04) or supine (OR=4.99, 95%CI 2.41, 10.43) were significantly more likely to be in 1F compared to those on the left. Compared to state 2F, state 4F was less likely to occur when the women
were in the semi-recumbent position (OR=0.11, 95%CI=0.02, 0.55). In supine the likelihood of being in 4F was also reduced but did not reach statistical significance (OR=0.27, 95%CI 0.07, 1.10).

In comparison with the left lateral position, when mothers were placed semi-recumbent or supine, the fetus was significantly more likely to change behavioural state (OR=2.17, 95%CI 1.19, 3.95) and (OR=2.67, 95%CI 1.46, 4.85) respectively. There was no pattern as to what state change took place.

Effect of fetal state on measures of fetal heart rate variability

In table 3 the effect of fetal state on FHR and FHRV is shown. Compared with state 2F, in state 1F there is a significant reduction in FHR, SDNN and RMSSD. In state 4F the mean FHR is higher with significant reduction in RMSSD.

Association of maternal position with heart rate variability

Maternal position was significantly associated with mean FHR and variability. During state 1F, the FHR was higher when the mother was supine or semi recumbent compared with the left lateral position (table 4). The measures of variability (SDNN and RMSSD) were found to be reduced in both the semi-recumbent and supine positions compared to the left (table 4). There was no difference in the measures of variability between left and right during state 1F as shown in table 4. In state 2F, the effects were not as notable, with a decrease in FHR in the right compared to left, and a decrease in SDNN when semi-recumbent compared to left. The effect of maternal position on measures of HRV in state 1F is shown in Figure 1. There were no significant differences in measures of HRV when the fetus was in state 2F.

Discussion:

This study has shown that in healthy late gestation pregnancy, maternal position has a significant relationship with both fetal behavioural state and heart rate variability. Both the time the fetus spent in the particular state and the likelihood that a change of state would occur were significantly related to the maternal position. In the supine and semi-recumbent positions, the fetus was more likely to be in state 1F. When the maternal position was semi-recumbent or supine, the fetus was also more likely to change state.

State 1F is a condition of fetal quiescence and in the presence of a stressor such as reduced uteroplacental perfusion or hypoxia, a move to a low oxygen consuming state would be a protective reaction to an adverse stimulus. Non reactive non stress testing or prolonged periods in 1F are fetal responses to hypoxia. In the normal mature fetus, state 1F has a reported mean duration of 20 minutes with a range up to 38 minutes (Pillai& James, 1990a). The frequency of the state changes seen in this study would appear to exceed that found in observational studies where the mother maintained a constant semi recumbent position (Pillai& James, 1990a), further suggesting that maternal position and the position change had an effect on FBS and was a stressor.

Heart rate variability is a measure of cardiac autonomic control and in the fetus it is made up of sympathetic and parasympathetic nervous system activity as well as intrinsic pacemaker rhythms of the sino-atrial node (Jensen et al. 2009; Papaioannou et al. 2013). In addition,
there is some evidence that there are also non neural influences such as fetal body and breathing movements (Visser et al. 1982; Dalton et al. 1983). Sympathetic activity is important in the maintenance of fetal blood pressure for example in periods of repeated asphyxia (Galinsky et al. 2014; Lear et al. 2016). In this study both RMSSD and SDNN were decreased in the supine and semi-recumbent positions. This is highly likely to reflect the concomitant changes in FBS with the increased risk of being in state 1F. State 1F is associated with reduced fetal body movements, a key contributor of FHRV, while preclinical evidence strongly supports that changes in FBS are also associated with marked changes in autonomic activity (Schneider et al. 2008; Gustafson et al. 2012). Although decreased FHRV is accepted to predict fetal distress, decreased FHRV in the present study is unlikely to reflect the direct effect of the stressors associated with maternal supine and semi recumbent position. Acute hypoxia is in contrast associated with an increase in FHRV in both fetal sheep (Parer, 1980) and humans (Thaler et al. 1985) while more severe asphyxia is also associated with an initial increase in FHRV in fetal sheep (Westgate et al. 1999). Reduced uterine blood flow after fluoxetine infusion in an ovine model was found to cause transient, mild fetal hypoxemia and acidosis for 12 hours, which were associated with a small increase in fetal heart rate (Morrison et al 2002) though measures of HRV were not reported. The findings were consistent with the sustained adaptation to longer periods of mild to moderate hypoxia. In our study, we did not observe FHR decelerations suggesting that the observed changes in FBS and FHRV were not due to acute moderate to severe hypoxia but rather a much milder change in fetal oxygen tension, sufficient to trigger a change in fetal sleep state to a lower oxygen consuming state, but not the autonomic adaptive responses. In a study of women with preeclampsia markedly reduced fetal movements were associated with episodes of haemoglobin desaturation in sleep. Treatment with overnight continuous positive airways pressure improved fetal movements (Blyton et al 2013) with lends support to the concept that, the fetus adapts to hypoxia by switching to a low oxygen consumption state.

The explanations for our findings are speculative. No women in the study reported symptoms suggestive of supine hypotension whilst they were supine or semi recumbent. Continuous maternal brachial arterial blood pressure recording was undertaken and no hypotensive episodes were detected. In addition, there were no clinically nor statistically significant differences in maternal pulse rate between the 4 positions (data not shown). Notwithstanding that, there is evidence that the supine position can alter uterine blood flow in the third trimester of pregnancy (Jeffreys et al. 2006), though in that study fetal responses were not recorded. Studies of the effects of tilt positions in late pregnancy have shown reductions in leg blood flow on changing from the left lateral to supine positions, but without effects on Doppler measures of uterine arterial resistance nor changes in fetal Doppler or heart rate (Kinsella et al. 1990). A recent study of 10 singleton pregnant women using magnetic resonance imaging to investigate aortocaval compression did not confirm aortic but only caval compression which was relieved by 30 degree but not 15 degree tilt (Higuchi et al. 2015), suggesting that arterial blood flow may not be reduced by the supine position, at least in healthy non obese subjects. However, in a smaller study than ours, it has been suggested that the supine position in late pregnancy was associated with changes to the fetal middle cerebral arterial and umbilical arterial Doppler pulsatility indices suggesting a fetal response to the physiological stress of position change (Khatib et al. 2014).There do not appear to have been studies demonstrating changes in FBS with maternal position.
In addition to the consideration of blood flow changes with maternal position, body position may affect oxygenation. Changes in maternal PaO\textsubscript{2} have been found when a subject in late pregnancy is changed from supine to a sitting position (Spiropoulos et al. 2004), though fetal parameters were not assessed in that study.

Strengths of our study include the standardization of experimental conditions within a realistic clinical environment and the blinding of the data and analysis. Outcome data on all women (not shown) confirmed that all pregnancies were delivered at term without maternal or fetal complications and all neonates were normal. The benefit of using a cross over method meant each mother and fetus acted as its own control increasing the power of the study. We controlled for external factors known to affect FBS such as gestation, time of day, exercise, caffeine intake and time from last meal. Other strengths of this study were the small amount of data loss and that the same investigators performed the studies on every woman.

Limitations included the difficulties in studying maternal haemodynamic parameters non invasively, and some signal loss from the Monica AN 24 device. However, we and others have found long term recordings generally are feasible with good quality signals (Graatsma et al. 2009), including in the obese subject (Cohen& Hayes-Gill, 2014). The definition of fetal sleep states in the study was based on fetal activity as seen on ultrasound scanning with subsequent analysis of fetal heart rate patterns. Whilst such an approach enabled us to distinguish clearly the heart rate patterns attributed to states 1F, 2F and 4F short periods of indeterminate patterns were not included in the analysis.

We could also not control for maternal discomfort or need for bathroom breaks. If a woman requested, she was allowed to stop between (but not during) positions and get up before returning and carrying on with the next position. It was not possible to estimate the effect that this might have on the experimental paradigm and FBS.

This study demonstrates that maternal position affects the state in which the fetus is in and FBS changes occur with maternal position change. During this study where the women were awake, the fetus was most active when the woman lay on the left side. State 4F occurred infrequently when the woman was supine or semi recumbent. State 1F-fetal quiescence was more commonly seen in the supine position. Changes in FHRV were also seen which were consistent with the changes in FBS. Should the supine position indeed be a physiological stressor, healthy fetuses make adaptive responses into states which use less oxygen.

Conclusions:

In this controlled experiment in normal healthy late third trimester pregnancy, maternal position was significantly associated with FBS and FHRV. Maternal supine position reduced the time the fetus spent in active 4F with a switch to quiet sleep states. These findings are consistent with the concept that state changes occur as an adaptive response and shift the fetus to a lower oxygen consuming state. The supine position maybe disadvantageous for fetal wellbeing and in compromised pregnancies may be a sufficient stressor to contribute to fetal demise.
Translational Perspective

Late stillbirth is independently related to the position women adopt during sleep. We hypothesised that fetal behavioural state as an indicator of fetal welfare would be affected by maternal position. We studied 29 healthy normal singleton pregnancies between 35 and 38 weeks gestation and examined the effects of 4 maternal positions of fetal behavioural state which was determined by blinded assessment of fetal heart rate patterns and ultrasound assessment of fetal activity. The results show that in normal healthy third trimester pregnancy, maternal position influences the behavioural state of the fetus. Changes were also seen in measures of fetal heart rate variability, a marker of autonomic responsiveness. Compared with being in state 2F in the left lateral position, there was almost a 5 fold risk of the fetus being in 1F when the mother was supine. It was also more than twice as likely that the fetus would change state (towards 1F) when the mother was supine. A switch to state 1F or fetal quiescence when the mother is supine suggests the fetus is adopting a low oxygen consuming state. The results offer insights into physiological mechanisms that the fetus may utilise to adapt to the effects of maternal position. We speculate that the findings may be due to reduced uterine perfusion and that vulnerable fetuses, which may already be hypoxic are unable to adapt to the stressor of maternal supine position. Further research into the effects of maternal position overnight and in vulnerable fetuses is indicated.

Word count: 247

Additional Information

Competing Interests

The authors declare no competing financial interests.

Author contributions

Fetal Behavioural State scoring was performed by PS and WB. Position sensing, initial analysis of fetal heart rate variability and conversion of fetal heart rate data to conventional cardiotocography was carried out by JM. JT performed all the statistical analyses. AG, LB and CL contributed to analytical design. PS, JT and EM wrote the manuscript with input from all authors. All authors have approved the final version of the manuscript. All persons listed as authors qualify for authorship, and all those who qualify for authorship are listed.

The Maternal Sleep in Pregnancy Research Group also includes:


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Romanini C Rizzo G Fetal behaviour in normal and compromised foetuses. An overview.


Table 1: Number (%) of blocks of time in relation to maternal position and fetal state

<table>
<thead>
<tr>
<th>Maternal position</th>
<th>State 1F</th>
<th>State 2F</th>
<th>State 4F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left</td>
<td>13 (11.3)</td>
<td>91 (79.1)</td>
<td>11 (9.6)</td>
</tr>
<tr>
<td>Right</td>
<td>28 (22.0)</td>
<td>91 (71.7)</td>
<td>8 (6.3)</td>
</tr>
<tr>
<td>Semi-recumbent</td>
<td>23 (16.3)</td>
<td>113 (81.9)</td>
<td>2 (1.4)</td>
</tr>
<tr>
<td>Supine</td>
<td>45 (34.4)</td>
<td>83 (63.3)</td>
<td>3 (2.3)</td>
</tr>
</tbody>
</table>
Table 2 Univariable Odds ratios associated with being in fetal state 1F and 4F compared to state 2F according to maternal position (left lateral position referent).

<table>
<thead>
<tr>
<th>Position</th>
<th>Fetal state 1 vs 2</th>
<th>Fetal state 4 vs 2</th>
<th>State change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>p=0.0001</td>
<td>p=0.033</td>
<td>p=0.0005</td>
</tr>
<tr>
<td>left</td>
<td>ref</td>
<td>ref</td>
<td>ref</td>
</tr>
<tr>
<td>right</td>
<td>2.36 (1.11, 5.04)</td>
<td>0.57 (0.19, 1.71)</td>
<td>0.96 (0.49, 1.85)</td>
</tr>
<tr>
<td>semi recumbent</td>
<td>1.60 (0.74, 3.46)</td>
<td><strong>0.11 (0.02, 0.55)</strong></td>
<td>2.17 (1.19, 3.95)</td>
</tr>
<tr>
<td>supine</td>
<td><strong>4.99 (2.41, 10.43)</strong></td>
<td>0.27 (0.07, 1.10)</td>
<td><strong>2.67 (1.46, 4.85)</strong></td>
</tr>
</tbody>
</table>

Figures in bold show significant differences from referent position.
Table 3: Differences in measures of FHR according to fetal state

<table>
<thead>
<tr>
<th>Fetal State</th>
<th>FHR</th>
<th>SDNN</th>
<th>RMSSD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>P&lt;0.0001</td>
<td>p&lt;0.0001</td>
<td>P&lt;0.0001</td>
</tr>
<tr>
<td>1F</td>
<td>-6 (-4, -7)</td>
<td>-8.1 (-9.7, -6.4)</td>
<td>-1.8 (-1.2, -2.3)</td>
</tr>
<tr>
<td>2F</td>
<td>Mean=139 (s.e.=0.35)</td>
<td>Mean=23.0 (s.e.=0.40)</td>
<td>Mean=9.9 (s.e.=0.14)</td>
</tr>
<tr>
<td>4F</td>
<td>13 (10, 16)</td>
<td>-2.9 (-5.1, 1.2)</td>
<td>-2.8 (-1.7, -3.9)</td>
</tr>
</tbody>
</table>

Figures in bold show significant differences from referent position
Table 4: Differences in measures of HRV by position for states 1F and 2F

<table>
<thead>
<tr>
<th>State 1F</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>N=109</td>
<td>FHR</td>
<td>SDNN</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P=0.013</td>
<td>P=0.0005</td>
<td>P=0.14</td>
</tr>
<tr>
<td>Left</td>
<td>Mean=128.2</td>
<td>Mean=19.9</td>
</tr>
<tr>
<td></td>
<td>(s.e.=2.0)</td>
<td>(s.e.=2.0)</td>
</tr>
<tr>
<td>Right</td>
<td>2.8 (-2.0, 7.6)</td>
<td>-1.8 (-6.6, 3.1)</td>
</tr>
<tr>
<td>Semi-recumbent</td>
<td>7.4 (2.4, 12.4)</td>
<td>-5.7 (-10.8, -0.7)</td>
</tr>
<tr>
<td>Supine</td>
<td>5.6 (1.1, 10.1)</td>
<td>-7.9 (-12.5, -3.4)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>State 2F</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>N=375</td>
<td>FHR</td>
<td>SDNN</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P=0.014</td>
<td>P=0.07</td>
<td>p=0.25</td>
</tr>
<tr>
<td>Left</td>
<td>Mean=139</td>
<td>mean=24.3</td>
</tr>
<tr>
<td></td>
<td>(s.e.=0.67)</td>
<td>(s.e.=0.78)</td>
</tr>
<tr>
<td>Right</td>
<td>-2.3 (-4.2, -0.5)</td>
<td>-0.3 (-2.5, 1.9)</td>
</tr>
<tr>
<td>Semi-recumbent</td>
<td>0.0 (-1.7, 1.8)</td>
<td>-2.3 (-4.4, -0.3)</td>
</tr>
<tr>
<td>Supine</td>
<td>0.5 (-1.4, 2.4)</td>
<td>-2.0 (-4.2, 0.2)</td>
</tr>
</tbody>
</table>

Figures in bold show significant differences from referent position.