2008

# A longitudinal study of the effect of pregnancy on rising to stand from a chair

Wendy L. Gilleard
*Southern Cross University*

Jack Crosbie
*University of Sydney*

Richard Smith
*University of Sydney*

## Publication details

Post-print of Gilleard, WL, Crosbie, J & Smith, R 2008, 'A longitudinal study of the effect of pregnancy on rising to stand from a chair', *Journal of Biomechanics*, vol. 41, no. 4, pp. 779-787.
Journal of Biomechanics home page available at www.elsevier.com/locate/jbiomech
Publisher's version of article available at http://dx.doi.org/10.1016/j.jbiomech.2007.11.015

# A Longitudinal study of the effect of pregnancy on rising to stand from a chair.

Authors: Wendy Gilleard PhD

Southern Cross University

Jack Crosbie PhD

University of Sydney

Richard Smith PhD

University of Sydney

Corresponding author:

Dr Wendy Gilleard
Department of Exercise Science and Sport Management
Southern Cross University
PO Box 157
Lismore, NSW, Australia, 2480
Phone (61-2) 6620 3501
Fax: (61-2) 66203880
Email: Wendy.Gilleard@scu.edu.au

**Keywords**: pregnancy, rising to stand, longitudinal, kinematics, kinetics

**Word count**: 3,292

## Abstract

Rising to stand from a chair becomes more difficult to perform as pregnancy progresses, which may lead to altered biomechanics affecting the musculoskeletal demands on the body segments. The kinematic and kinetic adaptations in the lower limbs and trunk as pregnancy progresses are unknown. Nine maternal subjects were investigated using an 8 camera motion analysis system and two force plates, four times throughout pregnancy and once postbirth during rising to stand. Twelve nulliparous female subjects were used to establish natural variation with retesting over the time period. The maternal subjects used temporal-spatial, kinematic and kinetic strategies to widen the base of support, minimize propulsion, increase motion of the thoracic segment and minimize anterior trunk-thigh apposition. A fear of postural instability may have made the subjects more cautious, and as they were able to adequately flex the trunk forward, propulsion was minimized in favor of maintaining upright terminal balance.

## Introduction

Rising to stand from a chair is an important everyday activity. The action requires forward and upward movement of the body mass from a base of support provided by the chair and the feet to the feet only, while maintaining balance. It is a mechanically demanding task which can be affected by restrictions in trunk motion (Shepherd and Gentile, 1994). As pregnancy progresses, maximum forward flexion of the trunk is reduced (Gilleard et al., 2002a) and body mass is increased by adipose tissue and the gravid uterus (Jensen et al., 1996a). Therefore, rising to stand from a chair may be expected to become more difficult to perform as pregnancy progresses and consequently result in altered kinematics and kinetics as strategies to complete the task. The possibility of altered movement patterns is important as this may also affect the musculoskeletal demands on the trunk segments and hence result in injury.

Studies of rising to stand from a chair during pregnancy have shown that in late pregnancy time to rise increases (Hirao and Kajiyama, 1994, Lou et al., 2001) while peak hip joint flexion (Lou et al., 2001) and hip joint flexion velocity at seat-off (Hirao and Kajiyama, 1994) decreases. Ankle joint dorsiflexion moment (Lou et al., 2001), knee joint forces(Ellis et al., 1985) and flexion moments (Lou et al., 2001), and hip joint flexion moments are reported to increase, possibly because of increased mass rather than altered angular acceleration moments (Jensen et al., 1996a). A decreased weight normalized hip joint flexion moment with reduced joint excursion has been reported in late pregnancy, indicating the biomechanical changes were not all due to gravitational components (Lou et al., 2001). Although understanding of the effects of pregnancy on rising has increased using cross sectional or comparison to post-birth designs, further information is required about adaptations as pregnancy progresses and readaptation in the early post-birth period. Therefore, the aim of this study was to investigate the kinematics and kinetics of the lower limb and upper body segments during rising to stand from a chair as pregnancy progressed and in the early post birth period using a longitudinal retest design. Comparisons were also made with the typical range and natural variability from test to retest established using nulliparous subjects.

## Methods

A sample of convenience consisting of nine maternal subjects (32.6 ± 4.3 years, 163.7 ± 6.6 cm, 38 weeks gestation mass 76.8 ± 10.9 kg (n=8), post birth mass 66.8 ± 10.3 kg) and twelve nulliparous subjects (28.9 ± 4.1 years, 165.4 ± 4.9 cm, mass at third test 62.2 ± 7.4 kg) volunteered and were included in the study which was approved by Sydney University Ethics Committee. Maternal subjects included five primigravidas and four multigravidas. The maternal group was tested at 18 weeks or less, 24 weeks, 32 weeks and 38 weeks gestation and again at eight weeks post-birth (Maternal Sessions 1 to 5). The control group was tested initially then re-tested 16 weeks and 32 weeks later (Control Sessions 1 to 3).

Data were collected using a pair of Kistler force platforms, an eight camera (8 mm 60Hz) Expert Vision™ Motion Analysis System (Eva HiRes 5.00) and a purpose built height adjustable stool fitted with a purpose built seat switch consisting of a micro-switch with a closing/opening threshold of approximately 1N. Seat height was set to 110% of fibular head to floor distance while standing (Crosbie et al., 1997). Ground Reaction Forces (GRF) were collected at 960Hz, filtered with a 4th order zero phase shift Butterworth filter (cut off frequency 9Hz) and expressed as a percentage of body weight (%BW). Cut off frequency was determined using residual analysis (Winter, 1990).

Non co-linear retro-reflective markers (2cm diameter) were used to define body segments similar to (Gilleard et al., 2006)(Figure 1). Markers on the medial femoral condyle and tip of the medial malleolus were removed during motion as not to restrict the movement. Definitions of joint centers were derived from the literature (Bell et al., 1989, Chaffin and Andersson, 1991, Eng and Winter, 1995, Kadaba et al., 1989).

A quiet sitting reference trial with arms by the side was recorded with the subject seated such that one foot was resting on each force plate. As pregnancy progressed a companion paper (Gilleard et al., 2002b) showed that there was no significant linear or quadratic trend for change for the quiet sitting posture of the pelvis, thoracic and head segments nor the thoracolumbar spine. The participants rose to stand watching a standing eye level target at their preferred speed for three trials. The participants chose initial foot position, which was maintained throughout the motion. Rising to stand commenced with arms by the side, however arms were free to move during rising.

Start of movement was defined as the time at which the horizontal velocity of the marker on the right greater tubercle was greater than or equal to 10 $mm.s^{-1}$ (Khemlani et al., 1999) and the marker had not begun to move in a vertical direction. Seat-off was determined using the seat switch with confirmation by maximum right posterior GRF (Kralj et al., 1990). Where a clearly defined peak for the right side posterior GRF was not seen, the left foot data in combination with the seat switch data were used to determine seat-off. Movement end was when knee extension was maximal (Kralj et al., 1990), and the vertical displacement of the right greater tubercle marker was also maximal (Crosbie et al., 1997). Each trial was time normalised with seat-off 0% and movement end 100%. Prior to seat-off was indicated by negative percentages of movement time. The pre-extension phase was from start of movement to seat-off and the extension phase was from seat-off to end of movement (Khemlani et al., 1999).

Motion data were processed using Kintrak™ version 5.7 using a cut off frequency of 6Hz (4th order zero phase shift Butterworth filter). Cut off frequency was determined using residual analysis (Winter, 1990). Each lower limb segment coordinate system was realigned to obtain anatomically referenced joint angles. All calculations of angular rotations were made with respect to the reference position described earlier. Relative rotation patterns of the foot and leg segments were taken as motion of the ankle joint and ankle joint inversion-eversion and abduction-adduction were rotations about the anterior and vertical axes respectively. The mediolateral width of the base of support was defined by the placement of the feet and was represented by the mean horizontal distance between the right and left malleolus markers corrected for the markers' radius.

Lower limb joint net applied moments were calculated using an inverse dynamics solution (Kintrak™ version 5.7). All reported moments are relative to the segment coordinate system and are as applied to the distal segment. Moments were expressed relative to body weight and height (Newton.metres. Body Weight$^{-1}$.Height$^{-1}$)(Hof, 1996).

Anthropometric ratios for segmental parameters (centre of mass, moment of inertia, radii of gyration, etc), using values derived from previous studies (Clauser et al., 1969, Plagenhoef et al., 1983, Winter, 1990, Yeadon and Morlock, 1989) were applied to control subjects. Variables were adjusted for stage of pregnancy(Jensen et al., 1996b).. Post birth, subcutaneous adipose tissue laid down in pregnancy is retained by the mother (Ridzon et al., 1998), therefore the methods used for calculation of maternal subject inertial variables (Jensen et al., 1996b) were applied to the post birth data.

## Statistical Analysis

Pregnancy is characterized by continuous changes over time, which may be expected to show systematic trends as the pregnancy progresses. A repeated measures ANOVA was used to investigate the existence of linear and quadratic trends, which would show any systematic change within the maternal group over the four test sessions (average of the three trials at each session) used during pregnancy for each variable. Systematic change, identified by trend analysis, was used rather than differences between the means as differences were more likely to be affected by natural variability associated with retesting. Both linear and non linear trend analysis models were included because the increase in body mass during pregnancy is non linear(Jensen et al., 1996b) and therefore, a quadratic trend was possible. Changes attributed to pregnancy also may have been actually related to variations in human subjects, which occur naturally over time or were due to the psychosocial effects of repeated testing. Therefore, for any significant trend, the magnitude of the change by the maternal subjects was also compared with standard error of the measurement (SEM) associated with retesting established from the control group between Session 1 and Session 3. For changes less than the natural variability of the control group a note was made against the significant trend in the data tables. Where an effect of pregnancy was seen the results were also investigated graphically (an example of which is illustrated in Figure 2 and 3) and post-hoc Student t-tests assuming unequal variance (Domholdt, 1993) were used to verify graphical results of differences between the maternal group and the control group. Two tailed Student t-test assuming unequal variance (Domholdt, 1993) was used to compare the maternal post birth

(Session 5) variable results with the control Session 3. Although bilateral kinematic and kinetic data lower limb data were collected, for succinctness only right side data are presented.

Missing data for two maternal subjects occurred due to late entry for one subject with her first test at 24 weeks gestation and early delivery at 38 weeks gestation for another subject. Linear extrapolation on the remaining three pregnancy test session data points was used to predict missing data. These data represented 5.6% of the total maternal data set for each variable.

## Results

In early pregnancy the temporospatial, kinematic and kinetic variables were similar to the control subjects (Tables 1-3). However, as pregnancy progressed some variables were altered.

### *Temporospatial variables*

The pre-extension phase duration showed a significant decreasing trend as pregnancy progressed ($F_{linear} = 7.26$, $p = 0.03$), however, these maternal group values were not significantly different to the control group at any session (Figure 2). The extension phase increased from 59.6±3.8% of movement duration at Session 1 to 61.9 3±.8% of movement duration at Session 4 ($F_{linear} = 4.79$, $p = 0.06$). The total movement duration for rising was unchanged as pregnancy progressed.

The base of support width showed a significant increasing trend as pregnancy progressed ($F_{linear} = 8.92$, $p = 0.02$) and was significantly greater at Maternal Session 4 in comparison to the control group (Figure 3).

### *Ground Reaction Forces*

Table 1 shows the peak (extension phase) vertical GRF showed a significant decreasing trend ($F_{linear} = 6.37$, $p = 0.04$) and occurred later ($F_{linear} = 7.89$, $p = 0.02$) as pregnancy progressed. The timing of the minimum pre-extension vertical GRF indicated the peak occurred later and closer to seat-off ($F_{linear} = 15.42$, $p = 0.004$) as pregnancy progressed. The peak medial GRF to stand showed a significant increasing trend ($F_{linear} = 6.40$, $p = 0.04$) as pregnancy progressed, although not significantly different from the control group at any test session (Figure 4). Post birth the peak (extension phase) vertical GRF ($p < 0.01$) and the minimum pre-extension vertical GRF ($p < 0.01$)were significantly less than the Control group at Session 3 (Table 2).

*Sagittal plane kinematics*

There were no significant trends seen in peak angle, timing of peak or range of motion at the right ankle, knee and hip joints as pregnancy progressed (Table 3). A significant increasing trend ($F_{linear} = 8.91$, $p = 0.02$) was seen for peak ankle dorsiflexion velocity and a decreasing trend for peak hip extension velocity ($F_{linear} = 6.19$, $p = 0.04$; $F_{quadratic} = 7.60$, $p = 0.02$) as pregnancy progressed. Postbirth the peak knee joint flexion was significantly greater ($p = 0.02$) and the hip joint peak flexion velocity was significantly less ($p < 0.01$) than the Control group at Session 3 (Table 4).

Peak flexion of the thoracic segment showed a significant increasing trend ($F_{linear} = 10.87$, $p = 0.01$) as pregnancy progressed. The pelvic and head segments and thoracolumbar and cervicothoracic spine motion showed no significant trends as pregnancy progressed although the means indicated a tendency for increased thoracolumbar spine and head segment peak motion (Table 5). The mean right shoulder range of motion increased from 16.5° ± 9.2 at Maternal Session 1 to 24.5° ± 16.3 at Maternal Session 4, however the trend was not significant ($F_{linear} = 3.75$, $p =$

0.08). Postbirth, the pelvic segment peak flexion ($p = 0.04$) was significantly less than the Control Group at Session 3 (Table 6).

As pregnancy progressed, peak flexion of the thoracolumbar spine was delayed, occurring closer to seat-off ($F_{linear} = 5.27$, $p = 0.05$) and was significantly different to the control group at Maternal Sessions 3 and 4 (Figure 5). Cervicothoracic peak extension occurred progressively later in the extension phase ($F_{linear} = 5.44$, $p = 0.047$) and was significantly different to the control group at Maternal Session 4 (Figure 6). Peak flexion velocity also showed a progressive decrease ($F = 22.03$, $p = 0.001$) as pregnancy progressed. Postbirth the thoracolumbar spine range of motion ($p < 0.01$) was significantly less than the Control Group at Session 3 (Table 6).

*Sagittal, coronal and transverse plane net external moments for right lower limb (Table 4)*

With advancing pregnancy, the sagittal plane net moments at seat-off remained similar. There were significant trends for knee joint transverse plane net moment ($F_{linear} = 13.79$, $p = 0.01$) and coronal plane external moment ($F_{linear} = 9.45$, $p = 0.02$) and for the ankle joint transverse plane net moment at seat-off ($F_{linear} = 8.99$, $p = 0.02$) as pregnancy progressed. Postbirth the knee ($p = 0.04$) and hip ($p = 0.04$) joint net extension moment at seat-off were significantly less than the Control Group at Session 3 (Table 8).

## Discussion

In early pregnancy the kinematics and kinetics were similar to the control subjects. As pregnancy progressed from early to late, changes occurred in the biomechanics, which exceeded those accounted for by natural variability. These changes suggest adaptations to minimize the effects of movement obstruction and to increase stability during the rising motion.

The trend for increased width between the feet as pregnancy progressed would increase side to side stability during the rising motion. The increasing medial GRF and altered coronal and transverse plane net moments, greater than can be accounted for by increased body mass, also suggests that altered kinetic strategies were used to centrally stabilize the body within the medio-lateral base of support during the motion as has been proposed by (Gilleard et al., 2006). The increased foot width and possible consequent increased width between the knees would also have reduced the effect of enlarged trunk girth and consequent apposition between the abdomen and the thighs during trunk forward flexion as seen in a companion report in this group of subjects for maximal trunk flexion in sitting and standing (Gilleard et al., 2002a). Sufficient space would need to be available in any workspace and an adequate chair size and structure used in order to allow increased width between the feet and between the thighs to facilitate rising from a chair.

A combination of strategies by the maternal group was used to control the forward motion. A reduction in pre-extension time and a decreased hip joint extension velocity, in combination with a decreased and delayed vertical GRF, may have been used to control the momentum which would otherwise be amplified by the increased mass of the trunk. The need to control upright balance at the end of rising to stand is paramount (Pai and Lee, 1994) and subjects will voluntarily limit the propulsive impulse to maintain upright stance under varying conditions. Maternal subjects are aware of instability during functional tasks (Nicholls and Grieve, 1992) and fear of falling forward may have also made the subjects more cautious. Therefore propulsion was minimized and as a result increased the extension phase duration, a fact noted in other studies(Hirao and Kajiyama, 1994, Lou et al., 2001). Increased rising time therefore may not be evidence of difficulty in rising (Hirao and Kajiyama, 1994, Lou et al., 2001), rather it is the outcome of a more considered motion.

The increased trunk segment mass as pregnancy progresses may also have been an advantage for rising to stand. Forward trunk flexion generates horizontal linear momentum, which is essential for rising to stand(Pai and Rogers, 1991). As the trunk mass increases, sufficient horizontal linear momentum may have been generated with a lower velocity thus allowing a delayed trunk flexion.

Rising to stand requires the upper body to flex forward to position the center of mass over the feet at seat-off (Crosbie et al., 1997). As pelvic segment flexion motion would be limited (Gilleard et al., 2002a) due to the gravid uterus, increased thoracic and head segment flexion motion and upper limb forward motion possibly contributed to the forward motion. Dynamic stability, however was maintained as this increased magnitude of motion was performed at an unchanged (Thoracolumbar spine) or slower (Cervicothoracic spine) velocity.

The maternal subjects were able to flex the upper body forward and raise the total body mass as pregnancy progressed, however, the effect of pregnancy on patterns of motion differed in the thoracic, head and upper limb segments. Different effects of pregnancy including both peak velocity and displacements, and timing and suggest different strategies being employed for different body segments. The relatively large standard deviations as a proportion of the mean also indicate variability between pregnant women in these strategies. Altered movement patterns may affect the mechanical demands on the segment as patterns of loading may also alter as a consequence. It is interesting that similar percentages of women in pregnancy report thoracic pain as low back pain (Sturesson et al., 1997). Although no participants reported lumbar or pelvic pain during the study, for some women altered thoracic movement during tasks involving trunk motion such as the present study, and other previously reported activities (Gilleard et al., 2002a) may contribute to thoracic pain in pregnancy. The etiology of back pain during pregnancy or post-birth remains unclear (Lindal et al., 2000, Ostgaard et al., 1993, To and Wong, 2003), however, an altered range of motion reflects altered musculoskeletal demand which may lead to injury or pain. Further research is required to investigate the inter-relationship between trunk segment motion and back pain at these times.

Post-birth kinematic and kinetic variables were generally similar to the control group Session 3 as shown in Tables 2, 4, 6 and 8. Where differences did occur, the post-birth variable was similar to late pregnancy (Tables 1, 3, 5, and 7). Therefore the differences were attributed to inherent differences between the groups rather than a continuing effect of pregnancy.

For some variables (indicated by # in the tables), a significant trend as pregnancy progressed indicated a consistent pattern of change, and were concluded to have been affected by pregnancy. The differences between the means in early pregnancy at Session 1 and late pregnancy at Session 4, however, were smaller than the natural variability associated with retesting and did not differ significantly from the control group. Care should be taken in the implications of these changes. The magnitude of change required to have clinical implications however is unknown and the effects may be cumulative given the frequency of rising from a chair.

## **Conclusions**:

As pregnancy progresses there are biomechanical changes some which were greater than that accounted for by natural variability with retesting. Overall, the results show that the maternal subjects minimized the propulsion and increased motion of the thoracic segment. A fear of postural instability may have made the subjects more cautious and as they were able to adequately flex the trunk forward, propulsion was minimized in favor of maintaining upright terminal balance. Altered patterns of motion for the thoracic, head and upper limb segments may have implications for back pain during pregnancy and further research is required.

## Acknowledgments:

The authors wish to acknowledge the assistance Ray Patton for technical assistance and Dr Roger Adams for advice concerning statistical analysis.

## References

Bell, A., Brand, R., Pedersen, D., 1989. Prediction of hip joint centre location from external landmarks. Human Movement Science 8, 3-16.

Chaffin, D. B., Andersson, G. B., 1991. Occupational Biomechanics. John Wiley & Sons Inc, New York.

Clauser, C. E., McConville, J. T., Young, J. W.: Weight, volume and center of mass of segments of the human body. Ohio, Wright Patterson Air Force Base, 1969.

Crosbie, J., Herbert, R. D., Bridson, J. T., 1997. Intersegment dynamics of standing up from sitting. Clinical Biomechanics 12, 227-235.

Domholdt, E., 1993. Physical Therapy Research, Principles and Applications. W. B. Saunders, Philadelphia.

Ellis, M. I., Seedhom, B. B., Wright, V., 1985. A comparison of knee joint and muscle forces in women 36 weeks pregnant and four weeks after delivery. Engineering in Medicine 14, 95-99.

Eng, J., Winter, D., 1995. Kinetic analysis of the lower limbs during walking: What information can be gained from a three-dimensional model? Journal of Biomechanics 28, 753-758.

Gilleard, W., Crosbie, J., Smith, R., 2002a. Effect of pregnancy on trunk range of motion when sitting and standing. Acta Obstetricia et Gynecologica Scandinavica 81, 1011-1020.

Gilleard, W., Crosbie, J., Smith, R., 2002b. Static trunk posture in sitting and standing during pregnancy and early post-birth. Archives of Physical Medicine and Rehabilitation 83, 1739-1744.

Gilleard, W., Crosbie, J., Smith, R., 2006. Rising to stand from a chair: Symmetry and Coronal and transverse plane kinematics and kinetics. Gait and Posture doi:10.1016/j.gaitpost.2006.11.002,

Hirao, N., Kajiyama, M., 1994. Seating for pregnant workers based on subjective symptoms and motion analysis. In: Lueder, R., Noro, K. (Eds.), Hard facts about soft machines: the ergonomics of seating, Taylor and Francis, London, pp. 317-331.

Hof, A. L., 1996. Scaling gait data to body size. Gait and Posture 4, 222-223.

Jensen, R. K., Doucet, S., Treitz, T., 1996a. Changes in segment mass and mass distribution during pregnancy. Journal of Biomechanics 29, 251-256.

Jensen, R. K., Treitz, T., Doucet, S., 1996b. Prediction of human segment inertias during pregnancy. Journal of Applied Biomechanics 12, 15-30.

Kadaba, M. P., Ramakrishnan, H. K., Wootten, M. E., Gainey, J., Gorton, G., Cochran, G. V., 1989. Repeatability of kinematic, kinetic, and electromyographic data in normal adult gait. Journal of Orthopaedic Research 7, 849-860.

Khemlani, M. M., Carr, J. H., Crosbie, W. J., 1999. Muscle synergies and joint linkages in sit-to-stand under two initial foot positions. Clinical Biomechanics 14, 236-246.

Kralj, A., Jaeger, R. J., Munih, M., 1990. Analysis of standing up and sitting down in humans: Definitions and normative data presentation. Journal of Biomechanics 23, 1123-1138.

Lindal, E., Hauksson, A., Arnardottir, S., Hallgrimsson, J., 2000. Low back pain, smoking and employment during pregnancy and after delivery - a 3-month follow-up study. Journal of Obstetrics and Gynaecology 20, 263-266.

Lou, S., Chou, Y., Chou, P., Lin, C., Chen, U., Su, F., 2001. Sit-to-stand at different periods of pregnancy. Clinical Biomechanics 16, 194-198.

Nicholls, J. A., Grieve, D. W., 1992. Performance of physical tasks in pregnancy. Ergonomics 35, 301-311.

Ostgaard, H. C., Andersson, G. B., Schultz, A. B., Miller, J. A., 1993. Influence of some biomechanical factors on low-back pain in pregnancy. Spine 18, 61-65.

Pai, Y., Rogers, M., 1991. Segmental contributions to total body momentum in sit-to-stand. Medicine and Science in Sports and Exercise 23, 225-230.

Pai, Y., Lee, W., 1994. Effect of a terminal constraint on control of balance during sit-to-stand. Journal of Motor Behaviour 26, 247-256.

Plagenhoef, S., Evans, F. G., Abdelnour, T., 1983. Anatomical data for analysing human motion. Research Quarterly for Exercise and Science 54, 169-178.

Ridzon, S. E., Clapp, J. F., Little, K. D., Tomaselli, J., Applebywineberg, S., 1998. Comparison of five-site skinfold thicknesses in late pregnancy vs early postpartum. American Journal of Human Biology 10, 299-305.

Shepherd, R. B., Gentile, A. M., 1994. Sit-to-stand: Functional relationship between upper body and lower limb segments. Human Movement Science 13, 817-840.

Sturesson, B., Uden, G., Uden, A., 1997. Pain pattern in pregnancy and "catching" of the leg in pregnant women with posterior pelvic pain. Spine 22, 1880-1884.

To, W., Wong, M., 2003. Factors associated with back pain symptoms in pregnancy and the persistence of pain 2 years after pregnancy. Acta Obstetricia et Gynecologica Scandinavica 82, 1086-1091.

Winter, D. A., 1990. Biomechanics and Motor Control of Human Movement. John Wiley & Sons, New York.

Yeadon, M. R., Morlock, M., 1989. The appropriate use of regression equations for the estimation of segmental inertia parameters. Journal of Biomechanics 22, 683-689.

Captions to Illustrations

Figure 1. Anterior and posterior views of marker placement.

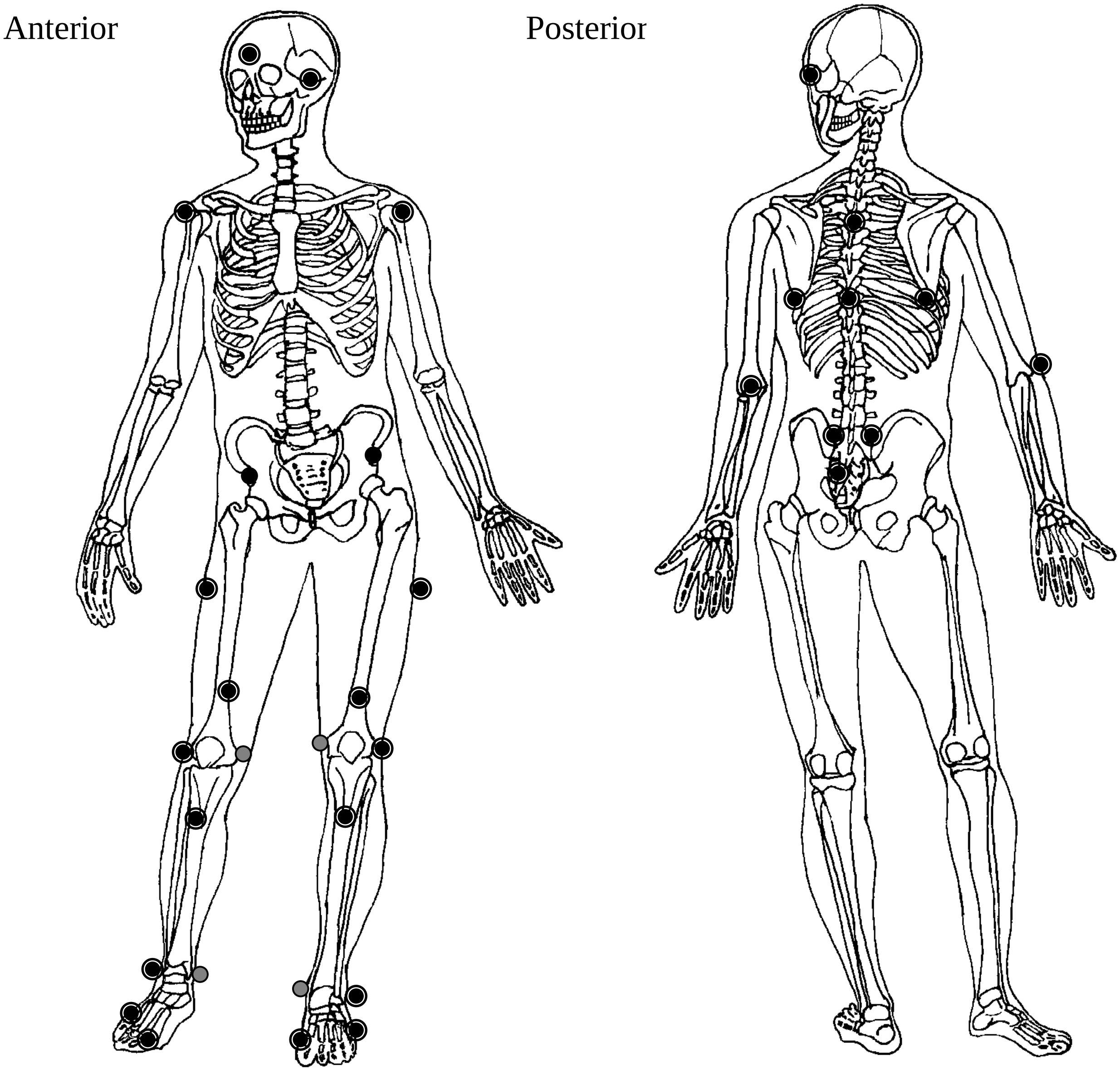
Figure 2. Pre-extension phase duration as a proportion of total movement time for Maternal Session 1 to 4 and postbirth (Session 5) mean (2 SE) and the control group over three sessions expressed as mean+2 SE and mean-2 SE.

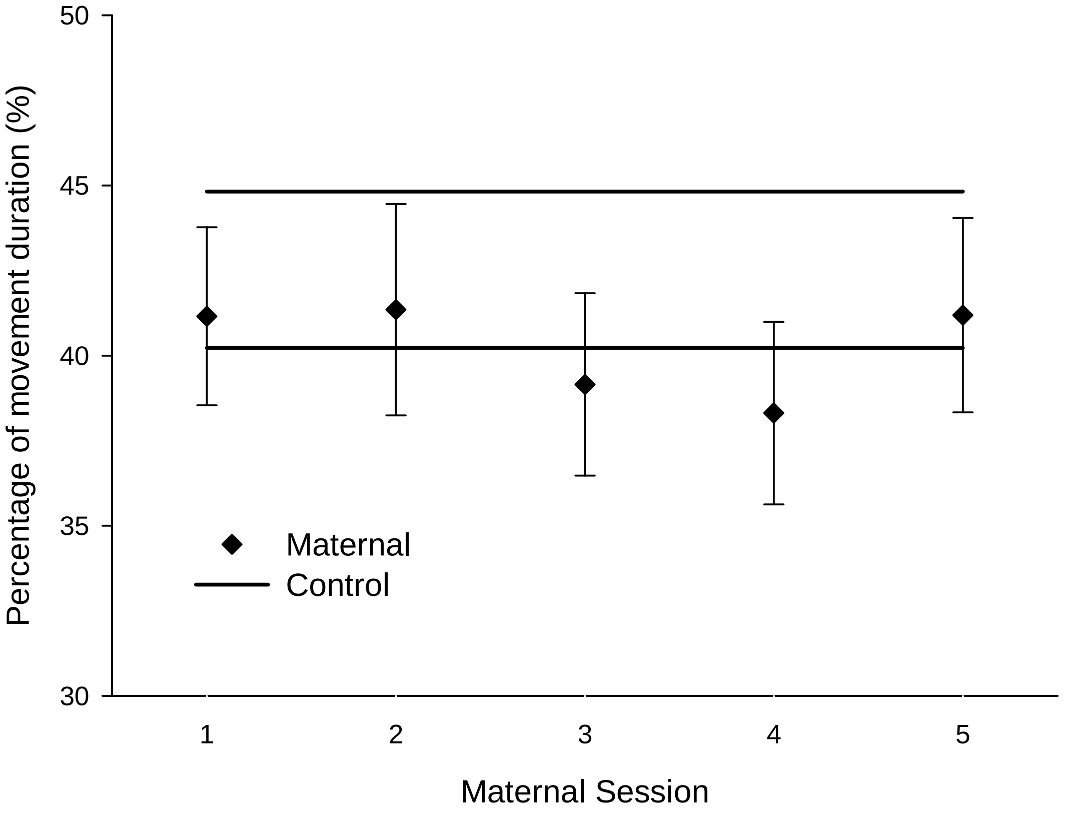
Figure 3. Base of support medio-lateral width for Maternal Session 1 to 4 and postbirth (Session 5) mean (2 SE) and the control group mean over three sessions expressed as mean+2 SE and mean-2 SE. * indicates significant difference for the maternal group at that session.

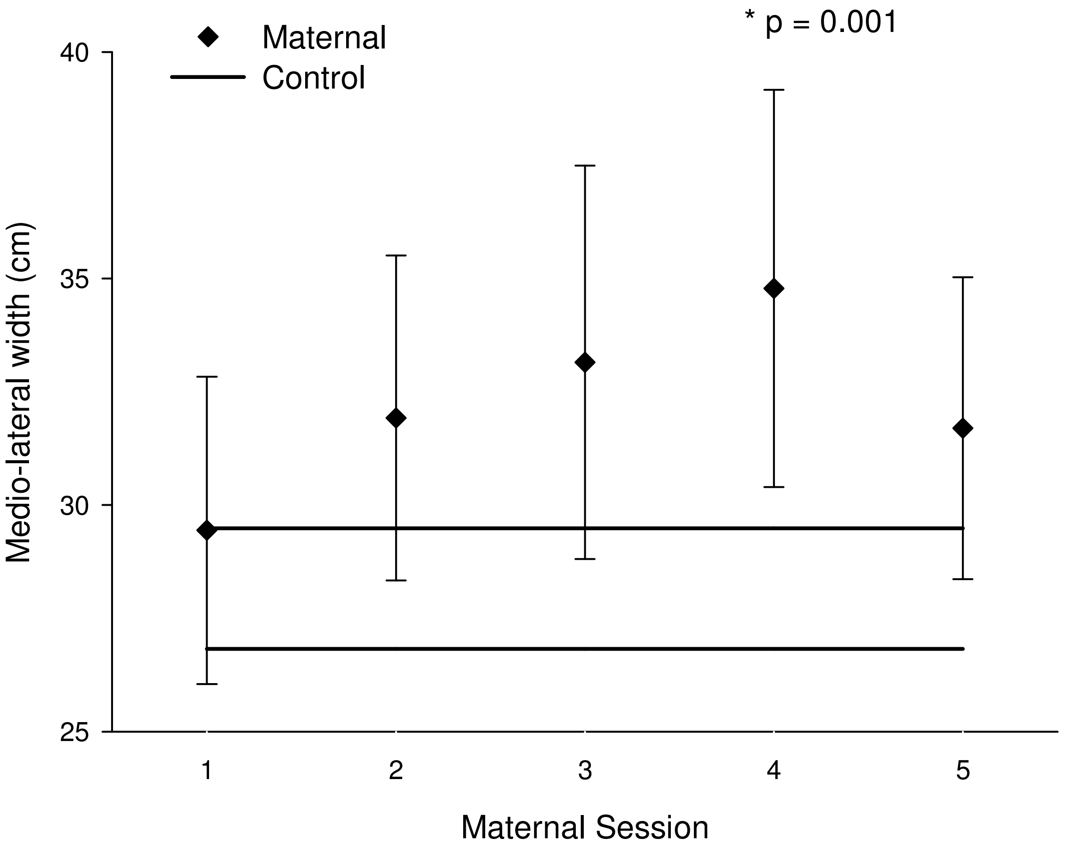
Figure 4. Peak medial GRF (%BW) for Maternal Session 1 to 4 and postbirth (Session 5) mean (2 SE) and the control group mean over three sessions expressed as mean+2 SE and mean-2 SE.

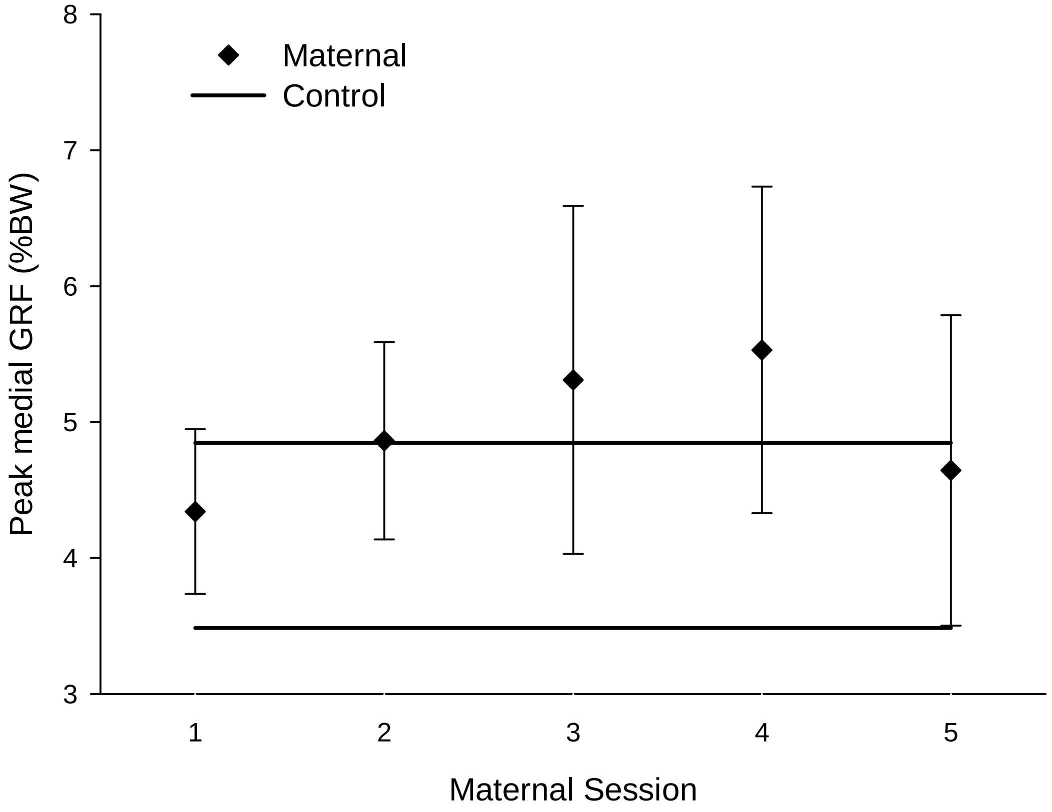
Figure 5. Timing as a proportion of total movement time of thoracolumbar spine peak flexion for Maternal group mean (2SE) at Session 1 to 4 and Postbirth (Session 5) and Control group over three sessions expressed as mean+2 SE and mean-2 SE.* indicates significant difference for the maternal group at that session.

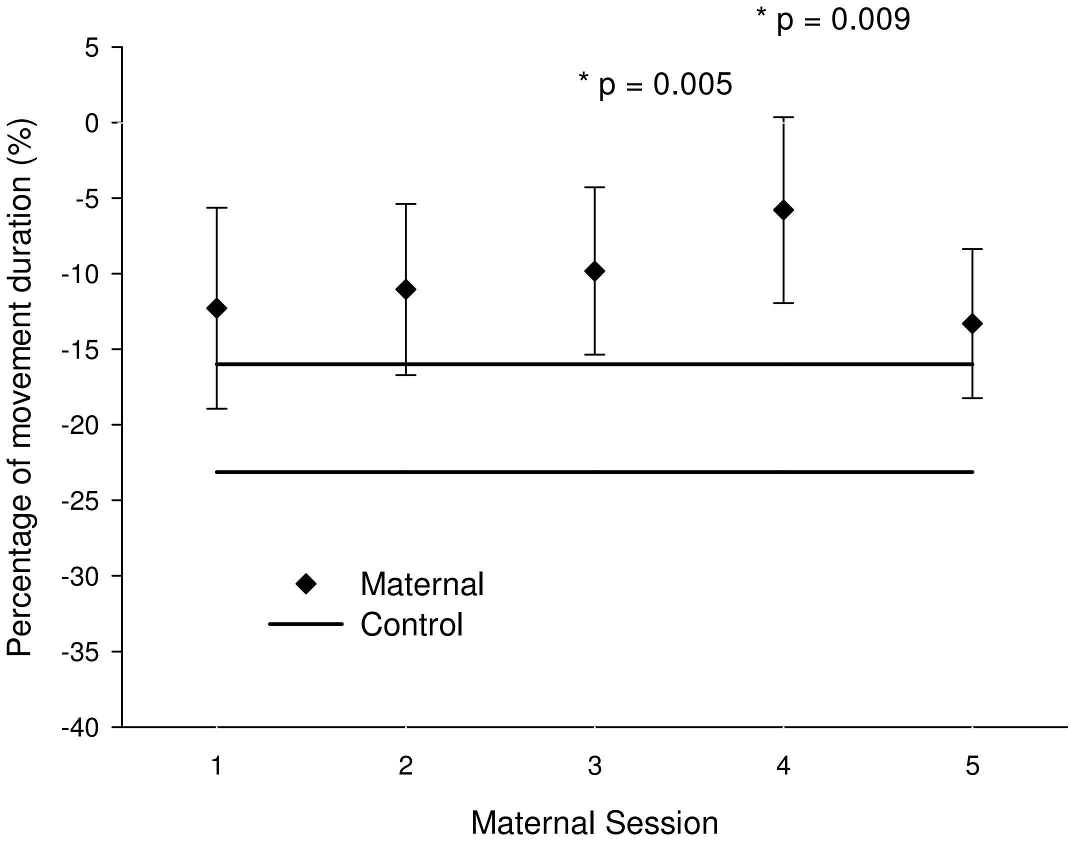
Figure 6. Timing as a proportion of total movement time of cervicothoracic spine peak flexion for Maternal group mean (2SE) at Session 1 to 4 and Postbirth (Session 5) and Control group over three sessions expressed as mean+2 SE and mean-2 SE.* indicates significant difference for the maternal group at that session.

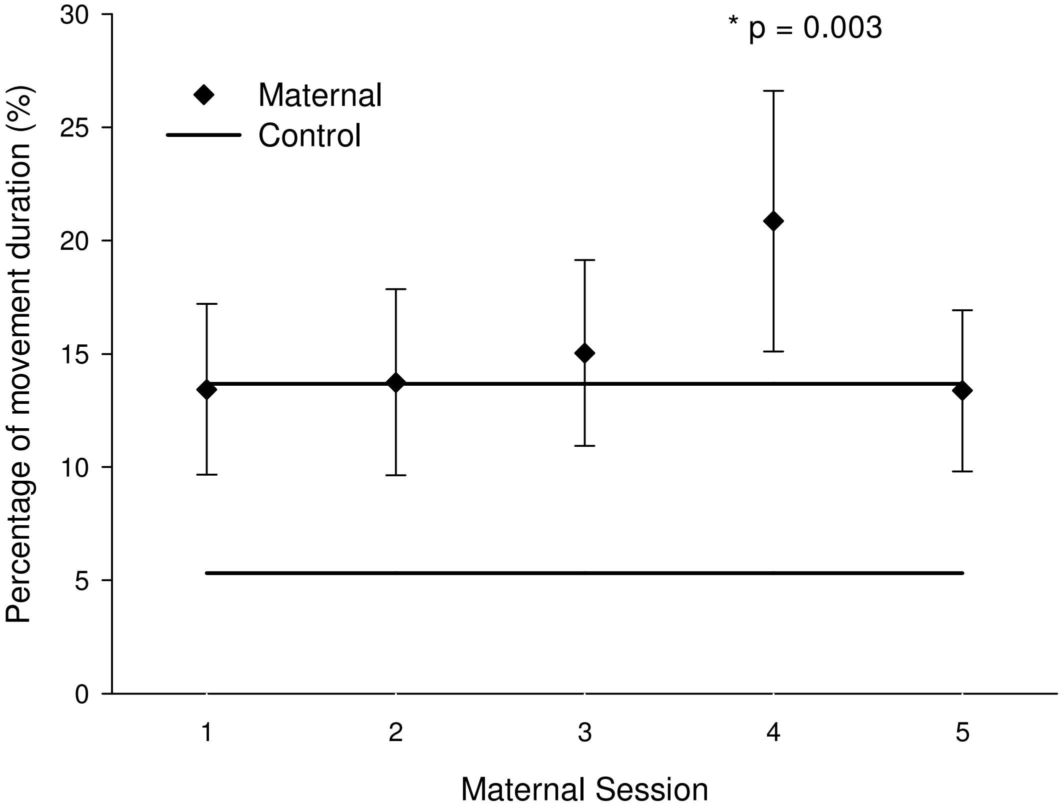

Anterior
Posterior


50
45
40
35
30
Percentage of movement duration (%)
1
2
3
4
5
Maternal Session
◆ Maternal
Control


Maternal
Control
* p = 0.001
Medio-lateral width (cm)
40
35
30
25
1
2
3
4
5
Maternal Session


8
7
6
5
4
3
Peak medial GRF (%BW)
Maternal
Control
1
2
3
4
5
Maternal Session


* p = 0.009
* p = 0.005
5
0
-5
-10
-15
-20
-25
-30
-35
-40
Percentage of movement duration (%)
Maternal
Control
1
2
3
4
5
Maternal Session


* p = 0.003
◆ Maternal
Control
Percentage of movement duration (%)
30
25
20
15
10
5
0
1
2
3
4
5
Maternal Session