Journal of Human Kinetics volume 26 2010, 5-11
Section I - Kinesiology

The Influence of Pregnancy on the Location of the Center of Gravity in Standing Position

by

Agnieszka Opala-Berdzik[1], Bogdan Bacik[2], Joanna Cieślińska-Świder[1], Michał Plewa[1], Monika Gajewska[1]

The purpose of the study was to compare the average location of the center of gravity vertical projection in sagittal plane in women at the beginning of and in advanced pregnancy as well as after delivery. The experiment was performed with the use of a force platform during four test sessions. A group of 44 women (8-16 weeks of pregnancy) participated in the initial test session. In the following sessions the number of the subjects reduced mainly due to medical and childcare problems: 33 women were tested in late pregnancy (2-3 weeks before delivery), and 39 women were tested two and six months after delivery.

The results showed the statisticaly significant (p<0,05) posterior displacement of the projection of the center of gravity of the lenth of approximately 4 mm in late pregnancy comparing to the beginning of pregnancy. The displacement may be the result of the body's adaptation to the increased mass in the anterior trunk area in late pregnancy. No discrepancy was found when comparing the average center of gravity location in the early pregnancy and after delivery.

We concluded that the change of the center of gravity location in late pregnancy is temporary and two months after delivery the vertical projection of the center of gravity is located as it was at the beginning of pregnancy.

Key words: *pregnancy, center of gravity, standing*

Introduction

The weight gain during pregnancy is between 9 and 14 kg. Considering segment body mass this weight gain is unique because it is mainly located in the trunk. The mean rate of increase for the lower trunk mass is 0.29 kg per week (Jensen et al. 1996). As a result of the weight gain in the anterior trunk area the abdominal muscles become overstretched. Due to the structural adaptations the function of the abdominal muscles is affected and they become insufficient (Fast et al. 1990, Gilleard and Brown 1996). The increase of the body weight and the insufficiency of abdominal muscles together with the increased ligaments laxity and joints mobility observed as early as in the second trimester of pregnancy (Dumas and Reid 1997, Marnach et al. 2003) may all lead to adaptational posture changes. The increased lumbar lordosis (Franklin and Conner-Kerr 1998, Otman et al. 1989), increased cervical lordosis, protraction of the shoulder girdle, hyperextension of the knees (Gleeson and Pauls 1988, Konkler 1990) and increased extension of the ankle joints (Fries and Hellebrandt 1943) are the most frequently mentioned posture changes in pregnancy.

Because the greatest increase of the mass is in the anterior trunk area it appears that the posture adaptations must also occur in pregnant women to maintain postural stability while standing. Consid-

[1] - *Academy of Physical Education, Faculty of Physiotherapy, Katowice, Poland*
[2] - *Academy of Physical Education, Faculty of Physical Education, Katowice, Poland*

Authors submitted their contribution of the article to the editorial board.
Accepted for pinting in Journal of Human Kinetics vol. 26/2010 on September 2010.

Kinesiology

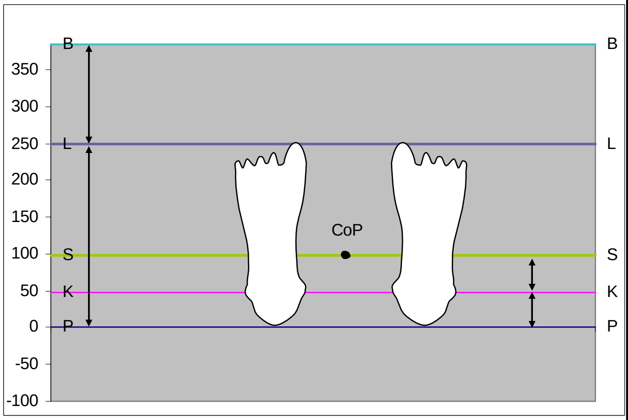

Figure 1

The average location of the CoG vertical projection within the base of support (force platform)

B – anterior border of the platform, L – line marked on the platform in frontal plane – anterior borders of the feet (tips of the toes), P – posterior borders of the feet (heels), K – vertical projection of lateral malleolus, S – CoP = the average location of the CoG vertical projection in sagittal plane

ering these body adaptations the location of the center of gravity (CoG) may change as pregnancy progresses.

According to Fries and Hellebrandt (1943) and Konkler (1990) there is an increase in the height of the CoG at the end of term comparing to the first trimester of pregnancy. It is mentioned by Konkler (1990) and Nobel (1995) that the body's CoG moves forward in sagittal plane due to the increase in weight of the pregnant uterus and the weight shifts toward the heels to bring the CoG to a more posterior position**.** This opinion appears to be unclear and insufficient and may lead to misunderstanding of the problem. The results of the study of the foot pressure in the static measurement in pregnant women showed significantly lower maximal forefoot pressures and higher hindfoot pressures comparing to the results of the nonpregnant women (Nyska et al. 1997). Fries and Hellebrandt (1943) in their study performed on a single individual in standing position recorded the posterior displacement of the gravitational center in the sagittal plane during the third trimester of pregnancy. This study was the only one found in the literature regarding the location of the CoG in pregnancy during stance. Foti et al. (2000) in their work analyzed gait parameters thrughout pregnancy and observed the changes of center of mass location during ambulation.

Concerning the insufficient data from published works the purpose of our study is to compare the CoG location in the sagittal plane in the group of women tested at the beginning of as well as in advanced pregnancy and than two and six months after delivery. Our presumption is that the location of the CoG may change in late pregnancy. The changed posture in pregnancy which often maintains as learned posture postpartum (Konkler 1990) may still have some influence on the CoG location two months after delivery. We assume the results recorded six months after birth should be similar to those observed at the beginning of pregnancy. We also assume that the number of pregnancies (primigravida and multigravida) or a type of delivery (natural and C-section) do not influence the average location of vertical projection of the CoG in women.

Material and Methods

Fifty five healthy pregnant women, all singleton gestation were assigned to the study. Informed consent was given by all subjects and the study was accepted by the Senate Ethics Committee of the Katowice Academy of Physical Education. The women were tested 4 times: at the beginning of pregnancy (8-16 weeks), at the end of pregnancy (2-3 weeks before delivery), two months and six months after delivery. Eight subjects withdrew after first test session due to disintrest and their data and results were not analyzed. Three other participants were excluded from the study due to overweight and obesity (BMI 28.6, 30.0 and 31.6 kg/m²) recorded during

Table 1

Description of the group of women over the four test sessions: at the beginning of pregnancy (1), at the end of pregnancy (2), two months after delivery (3), six months after delivery (4)

	TEST SESSION			
PARAMETER^	1 (N=44)	2 (N=33)	3 (N=39)	4 (N=39)
Age [years]	27.87±3.56	28.19±3.61	28.20±3.45	27.85±3.58
Body mass [kg]	60.42±9.19	72.64*±10.04	62.65*±9.60	60.82±9.13
Height [cm]	165.69±5.80	165.55±5.79	165.60±5.84	165.67±5.46
BMI [kg/m²]	21.94 ± 2.57	26.42* ± 2.69	22.75* ± 2.64	22.11 ± 2.72

*^ - data given as mean and ± SD.*p<0.001 signifficance of differences between sessions 2,3,4 and session 1*

Table 2

The average location of CoG projection [mm] in primigravida and multigravida women at the beginning of pregnancy (1) and six months after delivery (4). ANOVA. Statistica 6.0.

SESSION	PRIMIGRAVIDA			MULTIGRAVIDA			F	P
	N	MEAN	SD	N	MEAN	SD		
1	35	47.4	13.08	9	55.6	12.85	2.88	NS
4	31	46.5	15.88	8	55.5	16.71	1.91	NS

NS – non statistically significant at p > 0.05

Table 3

The average location of the CoG projection [mm] at the beginning of pregnancy (1) and at the end of pregnancy (2), Student t-test.

SESSION	MEAN	SD	N	DIFFERENCE	P
1	58.0	12.67	33		
2	53.9	13.07	33	4.1	S

S – statistically significant at p < 0.05

first session, because according to Błaszczyk et al. (2009) postural characteristics of overweight and obese women is different from the women with normal weight. Therefore the number of the subjects was reduced to 44. Finaly in the 1st test session there were 35 primigravida aged 19-35 (mean±SD: 27.16±3.14) years and 9 multigravida aged 26-38 (mean±SD: 30.67±3.94) years participating in the study. Some of the 44 women were not able to participate in the 2nd, 3rd or 4th test session due to medical problems during late pregnancy, transportation or caregiving problems with the newborn child. At the time of the 2nd session 33 subjects were tested and 39 at 3rd and 4th sessions. In the sessions after delivery there were 27 women after natural birth and 12 women after the C-section. The description of the stady patricipants is shown in table 1.

According to the literature the projection of the CoG in normal healthy individuals is located approximately 4-5 cm in front of the imaginary line connecting lateral malleoles of both ankle joints (Hellebrandt et al. 1940). Based on the recorded force of the feet pressure and their momentum while standing still on the force platform the computer calculates the location of the center of feet pressure (CoP). The CoP in the static measurement is located in the point of the average location of the CoG vertical projection within the base of support.

To record the location of the CoP in each test session the women were instructed to stand with both feet on the force platform (Kistler 9281C), placing the tips of their toes directly behind a line marked in frontal plane on the platform, and they could select their preferred stance width. The women were instructed to stand quietly with arms at their sides looking at the wall at eye level. Each test session was conducted for 30 s. The force platform data were filtered and transmitted through AC/DC converter to the computer.The calculation of the location of the CoP in the static standing position was performed with the use of the modified version of the computer program "Platforma 2". In order to calculate a value of the distance between the CoP and the axis of rotation in the ankle joints (lateral malleolus) the subjects' feet lengths [mm] and the distances between the centers of the heels and the projections of the lateral malleoles [mm] were measured in sagittal plane (figure 1).

At the beginning of statistical analysis the Wilk-Shapiro test was used to analyse the data distribution and it was in accordance with the normal distribution. The significance of differences between primigravida and multigravida grups were calculated using analysis of variance (ANOVA). The differences between the initial session measurements (beginning of pregnancy) and further sessions measurements (late pregnancy, two and six months postbirth) were analysed with the use of the Student t-test for the correlated data. Because this test can be only used to compare the equal number of the populations, the statistical analysis concerned only those women who participated in both test sessions: 1 and 2, 1 and 3, 1 and 4. The statistical analysis also included the calculation of the significance of differences between subjects after natural birth and the C-section using analysis of variance (ANOVA).The accepted p level was < 0.05. All statistical analyses were performed using the Statistica 6.0 software (StatSoft Inc., USA) and Microsoft Excel 2002.

Kinesiology

Table 4

The average location of CoG projection [mm] at the beginning of pregnancy (1) and two months after delivery (3), Student t-test.

SESSION	MEAN	SD	N	DIFFERENCE	P
1	59.6	13.93	39		
3	59.8	14.13	39	-0.2	NS

NS – non statistically significant at p > 0.05

Table 5

The average location of CoG projection [mm] at the beginning of pregnancy (1) and six months after delivery (4), Student t-test.

SESSION	MEAN	SD	N	DIFFERENCE	P
1	59.1	13.53	39		
4	58.5	16.42	39	0.6	NS

NS – non statistically significant at p > 0.05

Table 6

The average location of CoG projection [mm]after natural birth and the C-section two (session 3) and six (session 4) months after delivery. ANOVA.Statistica 6.0.

SESSION	NATURAL DELIVERY			C - SECTION			F	P
	N	MEAN	SD	N	MEAN	SD		
3	27	60.2	13.47	12	58.9	16.12	0.06	NS
4	27	57.6	15.99	12	60.7	18.10	0.27	NS

NS – non statistically significant at p > 0.05

Results

The comparison of the primigravida and multigravida subjects results at the beginning of pregnancy and six months after delivery using ANOVA did not show any discrepancies (p>0.05) in average location of the CoG projection within the base of support in sagittal plane so the whole group's results were considered in further analyses (table 2).

The data analysis showed the significant posterior displacement of the projection of the CoG within the base of support in late pregnancy (p<0.05) comparing to the beginning of pregnancy (table 3). The difference of the CoG location between early and late pregnancy although statistically significant, amounts only to the length of approximately 4 mm. Comparing the location of the CoG vertical projection in sagittal plane before and after birth, no discrepancies were found in the results two and six months after delivery in comparison to the beginning of pregnancy. (table 4 and 5). Only the values of the distance between the CoP and the ankle axis of rotation in the advanced pregnancy were shorter comparing to three other test sessions. The results indicate that two months after delivery the CoG is located again as it was at the beginning of pregnancy. There was no differences found in the location of the CoG projection within the base of support between the results of the women after natural delivery and the C-section two and six months postbirth (table 6).

Discussion

This study appears to be the first to analyse the changes of the average location of the CoG projection within the base of support in the static standing position in a group of women tested at the beginning of pregnancy, in late pregnancy and after delivery with the use of the force platform. The significant posterior displacement of the CoG in advanced pregnancy (p<0.05) comparing to early pregnancy found in our study, indicates it is a common phenomenon. Fries and Hellebrandt (1943) presented a study of a single individual over nine sessions (3 months of pregnancy to 6 weeks postpartum). In order to record the location of the CoG they used a kymogram (an instrument that recorded movement by stylus and rotating drum). A planimetric average of the CoG shifting for the single stance period was calculated and projected into the footprints. Experimentally determined gravity lines were erected into each photograph taken every 15 s. Their work as well as the results of our study indicate the posterior displacement of the CoG projection on the base of support in women in the third trimester of pregnancy. Although Nyska et al. (1997) did not analyse the location of the CoG, they focused on the measurement of the foot pressure in the static stance in full-term pregnant women and found significantly lower maximal forefoot pressures and higher hindfoot pressures comparing to the nonpregnant control group's results. It may be concluded that their findings are also in accordance with our results regarding the posterior displacement of the CoG in the third trimester of pregnancy.

The observed adaptational change of the CoG location as pregnancy progresses may be related to postural stability and energy expenditure in standing position. A typical compensatory mechanism to improve postural stability and reduce the risk of falling is an anterior displacement of the CoG observed in elderly individuals (Woodhull-McNeal 1992) and patients with balance impairements (Błaszczyk et al. 2007). This change of the CoG location may be necessary for an individual to use the "step-initiating strategy" in order to regain stability. Therefore we assume the opposite phenomenon observed in our experiment is not related to compensatory improvement of postural stability. The mechanism of the posterior displacement of the CoG at the end of pregnancy may be rather the result of the mass increase especially in the anterior trunk area. This mechanism may be necessarily to decrease the body's gravity force momentum in the relation to the ankle joints axis of rotation. The energy expenditure required for the maintenance of the standing position may be decreased due to the equalisation of the gravity force momentum by the momentum of the feet plantar flexors (calf muscles) force. The significant increase of the BMI from 21.9 kg/m² in early pregnancy to 26.4 kg/m² in advanced pregnancy may lead to the adaptational posterior displacement of the CoG. On the other hand although the difference between BMI = 21.9 kg/m² at the beginning of pregnancy and BMI = 22.7 kg/m² two months after delivery was also statistically significant, the CoG location was not changed. Therefore it seams there may be a border value of the proportions of the body mass distribution that leeds to adaptational changes of the CoG location (table 1).

A psychological factor concerning the protection of the fetus against a risk of injury in case of foreward falling may also be related to the significant posterior displacement of the CoG in late pregnancy.

The results of the present study indicate the change of the whole body's location in the relation to the base of support only in late pregnancy. Two months after delivery the CoG is back at the initial location (beginning of pregnancy). It is in accordance with the results of the study of Fries and Hellebrandt (1943) who reported in a single woman 6 weeks postpartum the return of the CoG location to the early pregnancy state. It means that the changed posture which usually does not correct spontaneously and maintains as learned posture postpartum (Konkler 1990) has no influence on the whole body's location in the relation to the base of support after delivery. Therefore it is not surprising that there were no significant changes in the CoG location six months after childbirth.

The weakness of the presented study may be a single measurement of the CoP during 30s standing position trials on the force platform upon each test session. Some authors recomend the everaging of the repeated measurements in order to achive the most reliable results (Collins and De Luca 1993). In the study of balance during pregnancy Jang et al. (2008) calculated the average of ten 30s trials performed by the womem on the force platform for each session. Butler at al. (2006) computed the average of three 30s trials in their work with the use of the force platform concerning postural equilibrium during pregnancy. On the other hand Collins and De Luca (1993) sugest it may sometimes be difficult to perform additional repetitions of the trials in clinical or scientific investigation in posturography due to the undesired risk of fatigue of the patient. They state it may be nesseserly to accept some trade-off between reliability and experimental practicality. In the study of Nagai et al. (2009) concerning the characteristics of the standing posture control during pregnancy it is not mentioned whether the measurements of the trials performed on the force platform were repeated. The authors of the above works investigated the CoP displacements in the aspect of postural sway and not the average CoP location during standing position. Only Fries and Hellebrandt (1943) measured the average location of the CoG projection within the base of support during pregnancy and postpartum in a single woman. The authors did not describe the measuring device in their study. We belive the reliability of our study with a single measurement during 30s trials is higher comparing to the study performed over 65 years ago due to the bigger number of participants.

Conclusions

There is a posterior displacement of the average location of the CoG vertical projection within a base of support in a sagittal plane in late pregnancy. The adaptational change of the CoG location in the advanced pregnancy is temporary. Two months after delivery the location of CoG is as it was in the early pregnancy and it is the same in women after natural childbirth and the C-section.

References

Błaszczyk JW, Orawiec R, Duda-Kłodowska D et al. Assessment of postural instability in patients with Parkinson's disease. Exp Brain Res. 2007, 183 (1): 107-14.

Błaszczyk JW, Cieślińska-Świder J, Plewa M et al. Effect of excessive body weight on postural control. J Biomech. 2009,42:1295-300.

Butler EE, Colon I, Druzin ML, Rose J Postural Equilibrium during pregnancy: Decreased stability with an increased reliance on visual cues. Am J Obstet Gynecol. 2006, 195: 1104-8.

Collins J, De Luca C Open loop and closed loop control of posture: a random-walk analysis of center of pressure trajectories. Exp Brain Res. 1993, 95: 308-318.

Dumas GA, Reid JG Laxity of knee cruciate ligaments during pregnancy. J Orthop Sports Phys Ther. 1997, 26 (1): 2-6.

Fast A, Weiss L, Ducommun EJ et al. Low-back pain in pregnancy. Abdominal muscles, sit-up performance, and back pain. Spine. 1990, 15 (1): 28-30.

Foti T, Davids JR, Bagley A A biomechanical analysis of gait during pregnancy. J Bone & Joint Surg. 2000, 82 (5): 625-33.

Franklin ME, Conner-Kerr T An analysis of posture and back pain in the first and third trimesters of pregnancy. J Orthop Sports Phys Ther. 1998, 28 (3): 133-8.

Fries EC, Hellebrandt FA The influence of pregnancy on the location of the center of gravity, postural stability, and body alignment. Am J Obstet Gynecol. 1943, 46: 374-80.

Gilleard WL, Brown JM Structure and function of the abdominal muscles in primigravid subjects during pregnancy and the immediate postbirth period. Phys. Ther. 1996, 76 (7): 750-62.

Gleeson PB, Pauls JA Obstetrical Physical Therapy. Review of literature. Phys Ther. 1988, 68 (11): 1699-702.

Hellebrandt F, Brogdon E, Tepper R Posture and it's cost. Am J Physiol. 1940, 129: 773-81.

Jang J, Hsiao KT, Hsiao-Wecksler ET Balance (perceived and actual) and preffered stance width during pregnancy. Clin Biomech. 2008, 23: 468-76.

Jensen RK, Doucet S, Treitz T Changes in segment mass and mass distribution during pregnancy. J Biomech. 1996, 29 (2): 251-6.

Konkler CJ Principles of exercise for the obstetric patient: Kisner C, Colby LA (ed). Therapeutic Exercise Foundations and Techniques. Davis Company, 1990 Philadelphia.

Marnach ML, Ramin KD, Ramsey PS et al. Characterization of the relationship between joint laxity and maternal hormones in pregnancy. Obstet Gynecol. 2003, 101 (2): 331-5.

Nagai M, Isida M, Saitoh J et al. Characteristics of the control of standing posture during pregnancy. Neuroscience Letters. 2009, 462: 130-4.

Nobel E Essential Exercises for the Childbearing Year. New Life Images, 1995 Harwich.

Nyska M, Sofer D, Porat A et al.. Plantar foot pressures in pregnant women. Isr J Med Sci. 1997, 33 (2): 139-46.

Otman AS, Beksac MS, Bagoze O The importance of 'lumbar lordosis measurement device' application during pregnancy, and post-partum isometric exercise. Eur J Obstet Gynecol Reprod Biol. 1989, 31 (2): 155-62.

Woodhull-McNeal AP Changes in posture and balance with age. Aging (Milano). 1992, 4 (3): 219-25.

Kinesiology

Acknowledgements

This project was supported by a Polish Ministry of Science and Higher Education grant 2 P05D 052 27

Corresponding author

Agnieszka Opala-Berdzik,
Academy of Physical Education,
Faculty of Physiotherapy, Katowice, Poland
ul. Mikołowska 72B, 40-065 Katowice
Phone: +48 32 2075100
Fax: +48 32 2075200
E-mail: aga.berdzik@wp.pl