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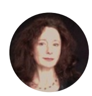
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Gait coordination in pregnancy: transverse pelvic and thoracic rotations and their relative phase

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Abstract

Objective. To examine the effects of pregnancy on the coordination of transverse pelvic and thoracic rotations during gait.

Design. Gait of healthy pregnant women and nulligravidae was studied during treadmill walking at predetermined velocities ranging from 0.17 to 1.72 m/s.

Background. Pelvis–thorax coordination during walking is altered in women with postpartum pregnancy-related pelvic girdle pain. This coordination has not been investigated in a healthy pregnant population.

Methods. Comfortable walking velocity was established. Amplitudes of pelvic and thoracic rotations were calculated. Their coordination was characterized by relative Fourier phase and its standard deviation.

Results. Comfortable walking velocity was significantly reduced. The amplitudes of pelvic and thoracic rotations were somewhat reduced, with significantly smaller intra-individual standard deviations. Also pelvis–thorax relative Fourier phase was somewhat smaller, its intra-individual standard deviation was negatively correlated with week of pregnancy, and significantly lower at velocities $\geqslant 1.06$ m/s.

Conclusions. The general pattern of gait kinematics in pregnant women is very similar to that of nulligravidae. Still, it appears that pregnant women experience difficulties in realizing the more anti-phase pelvis–thorax coordination that is required at higher walking velocities.

Relevance

The present study shows that gait in healthy pregnancy is remarkably normal, but some differences in pelvis–thorax coordination were detected. In healthy pregnancy, anti-phase pelvis–thorax coordination appears difficult, but less so than in pregnancy-related pelvic girdle pain. Better understanding of gait in healthy pregnancy may provide insight into the gait problems of women with pregnancy-related pelvic girdle pain.
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Keywords: Pregnancy; Treadmill walking; Kinematics; Transverse rotations; Trunk coordination

1. Introduction

There is little doubt that gait is affected by pregnancy. Still, differences between pregnant and non-pregnant gait are hard to identify.

For instance, a forward displacement of the center of mass during pregnancy is often assumed (e.g., Hainline, 1994; Taves et al., 1982), but no replacement (Dumas et al., 1995), or backward displacement (Golomer et al., 1991) were also reported. Lumbar lordosis was increased in two studies (Bullock et al., 1987; Franklin and Conner-Kerr, 1998), unchanged in two others (Hummel, 1987; Östgaard et al., 1993), and decreased in a study by Snijders et al. (1976). Thus, the literature suggests that there are large inter-individual differences in postural

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adaptations to pregnancy, with, perhaps, each woman solving the problems in her own way.

Pregnant women are often described as having a "waddling gait" (Foti et al., 2000), that is, an increased base of support, a larger foot progression angle, increased pelvic movements around the sagittal axis, and increased pelvic transverse rotations. However, reported data are again inconsistent (Alvarez et al., 1988; Bird et al., 1999; Foti et al., 2000), and "waddling gait", as defined above, fails to characterize "the" typical gait pattern of pregnant women. Again, it is quite possible that systematic effects fail to become significant in group studies because of large inter-individual differences.

Foti et al. (2000) did find a decreased plantar flexion moment during gait (implying less forceful propulsion), an increased hip abduction moment, and a greater pelvic tilt in pregnant women, with, however, large inter-individual variation—ranging from −10° to +13°. Comfortable walking velocity was reported to be significantly lower in pregnancy by Nagy and King (1983), with high inter-individual variability, while others reported a non-significant decrease (Foti et al., 2000). No significant effects of pregnancy on step length or stride length were found (Foti et al., 2000; Taves et al., 1982).

In sum, significant changes have been reported for gait during pregnancy, but group studies published so far do not reveal a consistent pattern. Note that the existence of large inter-individual differences is only one explanation for this lack of consistency. Perhaps there is a lack of systematic focus on differentiating variables. Also, it is possible that systematic effects are too subtle to always lead to significance. Actually, we suspect that this is the case for pelvic movements.

The elusiveness of gait during normal pregnancy may hamper understanding of gait in pregnancy-related pelvic girdle pain (PPP), a condition which leads to complaints that deserve medical attention in 25% of pregnant women, and 5% of women postpartum (Wu et al., in press; see also, e.g., Mens et al., 1996; Östgaard, 1997). Women with severe forms of PPP find it difficult to walk quickly, and are unable to cover large distances (Mens et al., 1996; Norén et al., 2002). Recently, Wu et al. (2002) found that the coordination of pelvic and thoracic rotations during gait is affected in PPP. At higher walking velocities, patients had a lower relative phase of transverse trunk rotations, that is to say, thoracic and pelvic rotations in the same direction were more synchronous ("in-phase") than in healthy controls.

The objective of the present study was to determine the effects of pregnancy on the coordination of transverse pelvic and thoracic rotations during gait. We also measured comfortable walking velocity and maximum attainable velocity. We calculated the amplitudes of transverse rotations and their relative phase, as well as the intra-individual standard deviations of both. Note that we see healthy pregnancy, without complaints, as a baseline condition, better knowledge of which will allow for a more valid contrast with PPP during pregnancy.

2. Methods

2.1. Subjects

Volunteers were recruited by word of mouth and flyers at the Departments of Obstetrics and Gynaecology and Orthopaedic Surgery (both of the Vrije Universiteit Medical Centre), the Faculty of Human Movement Sciences (Vrije Universiteit), and the clinics of exercise therapists Mensendieck in Amsterdam. Women with interest in the study received an information package. If they decided to participate, they signed the informed consent statement, and were then seen by an orthopaedic surgeon who ensured that they fulfilled all criteria, and registered age, weight (at the time of the investigation), height, week of pregnancy, and parity.

Inclusion criteria were nulligravidae or pregnant women (between weeks 20 and 34 inclusive), between 20 and 45 years of age inclusive. Exclusion criteria were problems with walking; surgery of the lumbar spine, pelvis, hip or knee; fracture, tumor or active inflammation in the lumbar spine or pelvis; Bechterew's syndrome, Scheuermann's syndrome, active polyarthritis, rheumatoid arthritis or severe osteoporosis; hormone induced pregnancy or in vitro fertilisation (Kristiansson et al., 1998); and/or pulmonary, cardiac, visual, auditive or cognitive disorders. The protocol was approved by the Medical Ethical Committee of the VU Medical Centre.

2.2. Instrumentation and procedure

To account for possible effects of fear of movement, we asked subjects, before the experiment proper, to complete the Tampa Scale for Kinesiophobia (TSK) (Vlaeyen et al., 1995). The experimental task (Fig. 1)

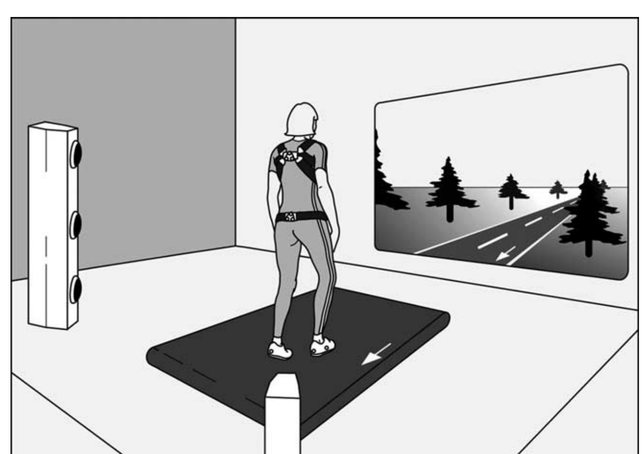

Fig. 1. Experimental set-up.

consisted of walking on a treadmill (Biostar Giant™, Biometrics, Almere, The Netherlands) at different velocities. Pelvic and thoracic rotations were recorded by a 2×3-camera optoelectronic system (OptoTrak®, Northern Digital Inc., Waterloo, Ontario, Canada). Two light metal frames, each with three infrared-emitting diodes, were attached to the pelvis (between the posterior superior iliac spines) and the thorax (at the level of T6) with neoprene bands. In front of the subject, an optical flow field, synchronized to the belt velocity, was projected on a large screen to mimic walking on a road. To detect heel strike and toe-off, infrared-light emitting markers were placed on the heels and over the fifth metatarsophalangeal joints. The cameras were located 5 m behind the subject.

To become accustomed to the experimental set-up, subjects walked on the treadmill for about 5 min. Then, treadmill velocity was increased by increments of 0.11 m/s, from 0.17 up to 1.72 m/s (a total of 15 "velocity levels"). Subjects were asked to indicate which velocity was most comfortable. At each velocity, the pregnant women were asked if the treadmill was moving too fast. If so, the experiment was stopped, and the preceding level designated as their maximum walking velocity. Subjects walked for about 3 min at each velocity level. When they were accustomed to a new velocity, data were collected for 30 s at a sampling frequency of 100 Hz.

2.3. Determination of angular data and relative phase

Motions of the three non-collinear markers in a cluster were taken to represent motions of the thorax or the pelvis. For each cluster, increasing x, z, and y values were labelled as movement forwards, upwards, and to the left, in line with the global reference system. The time series of the transverse pelvic and thoracic rotations were derived by calculating the arctangent (four quadrant) specified by the xy-coordinates. Heel strike was taken to coincide with the point of minimum vertical velocity of the toe marker, and toe-off with its maximum (Pijnappels et al., 2001). A stride cycle was defined as the time distance between two consecutive heel strikes of the same leg. Pelvic and thoracic rotational amplitudes were calculated as the absolute angular difference from maximum to minimum rotation within one stride cycle. Trunk rotation was obtained by subtracting the pelvic time series from that of the thorax. Angular measures were averaged over all strides for each velocity level, and the intra-individual standard deviations (stride-to-stride within one velocity level) were calculated.

Relative Fourier Phase (RFP) was calculated with a method that is insensitive to the emergence of higher harmonics in the pelvic oscillation as walking velocity increases (Lamoth et al., 2002a). From the power spectra of the pelvic and thoracic time series, a windowed Fourier phase was calculated by using a discrete fast Fourier transform algorithm. The window length was four times the period of the first harmonic; it was shifted sample by sample over the entire length of each time series. Pelvic and thoracic Fourier phases were estimated for each window at the fundamental frequency of the thorax. The signal was then reconstructed in the time domain, yielding a continuous estimate of the Fourier phase. The continuous pelvis–thorax RFP was calculated by subtracting the so determined phase of the pelvic rotation from that of the thoracic rotation.

Within each time series of thorax–pelvis relative phase (one time series per velocity condition per subject), mean RFP and its intra-individual standard deviation were calculated by using circular statistics (Fisher, 1993). A phase difference of 0° indicates in-phase coordination. At a 180° phase difference, anti-phase coordination, pelvis and thorax move simultaneously in opposite directions.

2.4. Statistical analysis

Age, weight, height, body mass index (BMI), and comfortable walking speed were compared between groups with unpaired t-tests. In view of the dependence of comfortable walking speed on age and height (Bohannon, 1997), simple regression of these two factors was performed on comfortable walking speed in the whole sample.

Repeated measures ANOVAS were applied to rotational amplitudes of thorax, pelvis, and trunk, their standard deviations, mean pelvis–thorax RFP, and its standard deviation, with "velocity" (15 levels) as within-factor, and "group" as between-factor. We extrapolated missing values for pregnant women who could not walk at the highest velocities, and inspected the resulting interaction plots to further analyse (significant) effects. Since we expected effects of pregnancy to be dependent upon week of pregnancy, we also calculated Pearson correlations between "week" and all dependent variables, using, where relevant, the average over velocities.

As additional analyses, we determined the values of dependent variables at comfortable walking velocity, and then compared the groups with unpaired t-tests. And we recalculated the repeated measures ANOVAS for the higher velocities only (above the average comfortable walking velocity of the pregnant women), again focusing on the effects of "group".

SPSS software (version 10.0) was used throughout; $P < 0.05$ was considered to be significant. In view of the possible importance of subtle effects, we decided to describe all results, also if non-significant.

3. Results

3.1. Subjects and their walking velocities

Thirteen nulligravidae and 12 healthy pregnant women (Table 1) participated in the study. The pregnant women were about six years older on average (33.1 versus 26.8 years, $t = -4.0$, $P = 0.0006$), around 10 kg heavier (76.9 versus 66.8 kg, $t = -2.4$, $P < 0.05$), and had a larger BMI (26.1 versus 22.2, $t = -4.0$, $P = 0.0006$), but were similar in height. One of the pregnant women (TSK 39 points), and one of the nulligravidae (44 points) could be labelled as "afraid of movement". On average, the pregnant group was slightly less fearful than the nulligravidae (30.8 versus 32.8), but the difference was not significant ($t = 1.0$, $P = 0.33$).

All control subjects and 10 of the pregnant women were able to walk at all velocities. One of the pregnant women could not walk faster than 1.39 m/s, and another not faster than 1.61 m/s. In the total sample, comfortable walking velocity had no significant relationship with age ($R^2 = 0.021$, $P = 0.49$) or height ($R^2 = 0.036$, $P = 0.36$). In further analyses, therefore, the raw data of comfortable walking velocity was used, rather than any form of normalized data. Comfortable walking velocity ranged from 0.72 to 1.28 m/s in the pregnant women, and from 0.83 to 1.50 m/s in the controls. The difference was significant (1.03 versus 1.19 m/s, $t = 2.72$, $P =< 0.05$).

3.2. Rotational amplitudes and their intra-individual standard deviations

Overall, the amplitudes of the pelvic rotations (Fig. 2) decreased with increasing walking velocity until 0.94–1.06 m/s to then increase. Pelvic rotations were about 1° smaller in the pregnant subjects. On a repeated measures ANOVA (Table 2, with *F*- and *P*-values), the effect of

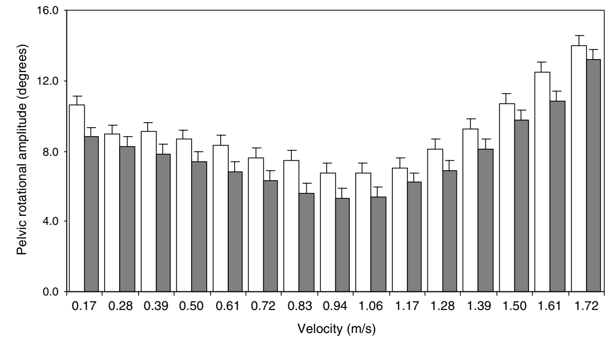

Fig. 2. Mean rotational amplitudes of the pelvis during gait (T-bars representing standard errors) at different walking velocities of the control subjects (white) and the healthy pregnant women (grey).

velocity was significant, while that of group and their interaction were not. The intra-individual standard deviations of pelvic rotations were significantly smaller (mean 1.2°, SD 0.4°) in the pregnant women than in the controls (1.6°, SD 0.5°). There was a significant effect of velocity (with an overall pattern similar to that of the pelvic rotations themselves), but no significant interaction.

Thoracic rotations (Fig. 3) remained stable until about 0.83 m/s to then decrease somewhat at higher velocities. Again, rotations were around 1° smaller in the pregnant women. On a repeated measures ANOVA, the effect of velocity was significant, while that of group and their interaction were not. The intra-individual standard deviations of thoracic rotations were significantly smaller (1.2°, SD 0.3°) in the pregnant women than in the controls (1.7°, SD 0.6°). Again, there was a significant effect of velocity (with an overall pattern as that of the thoracic rotations), but no significant interaction.

Trunk rotations increased monotonically with increasing walking velocity. Again, rotations in the pregnant women were about 1° smaller than in the

Table 1
Intake variables of the healthy pregnant women

Subject #	Age (year)	Weight (kg)	Height (m)	BMI[a] (kg/m^2)	Pregnancy #	Week of pregnancy	Tampa score
1	30	80	1.72	27.0	3	25	30
2	37	85	1.80	26.2	2	28	29
3	38	78	1.70	27.0	1	33	24
4	31	70	1.71	23.9	1	31	27
5	36	85	1.68	30.1	3	34	29
6	36	68	1.78	21.5	3	21	30
7	31	89	1.70	30.8	1	25	28
8	32	68	1.62	25.9	1	28	32
9	27	69	1.73	23.1	1	25	32
10	36	82	1.78	25.9	1	21	39
11	31	75	1.73	25.1	1	22	35
12	32	74	1.68	26.2	1	31	35
Mean	33.1	76.9	1.72	26.1	1.6	27	30.8

[a] Body Mass Index (weight divided by height squared).

Table 2
The effects of velocity and group (repeated measures ANOVAS)

Analysis	Velocity		Group		Interaction	
	$F_{1,14}$	P	$F_{1,21}$	P	$F_{1,14}$	P
Pelvic rotations						
Mean amplitudes	24.11	<0.0001*	3.71	0.07	0.18	>0.99
Intra-individual SDs	4.42	<0.0001*	10.14	0.005*	0.96	0.50
Thoracic rotations						
Mean amplitudes	20.03	<0.0001*	1.56	0.23	0.33	0.99
Intra-individual SDs	4.04	<0.0001*	6.95	0.02*	0.84	0.63
Trunk rotations[a]						
Mean amplitudes	192.55	<0.0001*	1.29	0.27	0.72	0.75
Intra-individual SDs	22.79	<0.0001*	10.31	0.004*	1.07	0.39
Relative Fourier phase						
Mean values	127.36	<0.0001*	0.94	0.34	0.29	>0.99
Intra-individual SDs	10.40	<0.0001*	2.22	0.15	0.46	0.95

* Significant ($P < 0.05$).
[a] Thoracic rotations minus pelvic rotations.

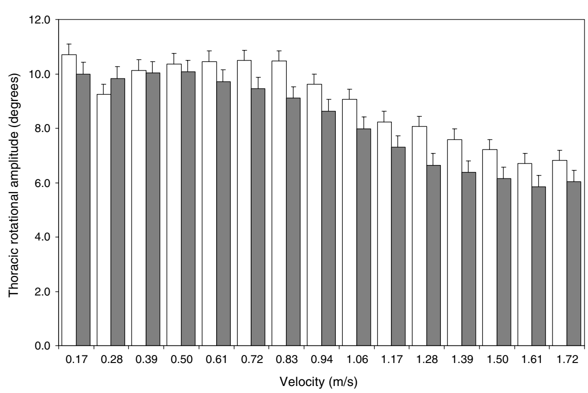

Fig. 3. Mean rotational amplitudes of the thorax during gait (T-bars representing standard errors) at different walking velocities of the control subjects (white) and the healthy pregnant women (grey).

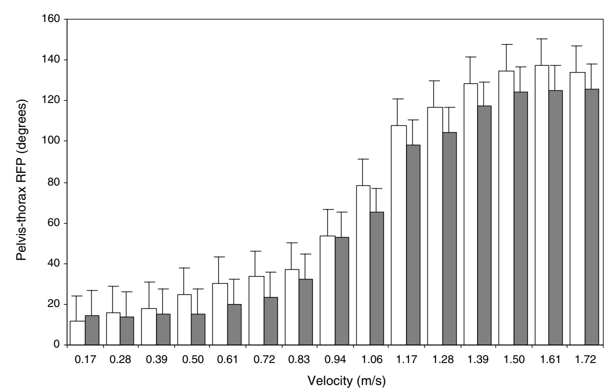

Fig. 4. Mean relative Fourier phase (T-bars representing standard errors) between transverse pelvic and thoracic rotations at different walking velocities of the control subjects (white) and the healthy pregnant women (grey).

controls. The effect of velocity was significant, while that of group and their interaction were not. The intra-individual standard deviations of trunk rotations were significantly smaller (0.7°, SD 0.3°) in the pregnant women than in the controls (1.0°, SD 0.4°). There was again a significant effect of velocity (with a similar pattern as that of the trunk rotations), but no significant interaction.

3.3. Mean RFP and its intra-individual standard deviation

In both groups, mean pelvis–thorax RFP (Fig. 4) increased along a logistic curve, with the steepest increase between 0.83 and 1.17 m/s. RFP was about 7° smaller in the pregnant women than in the controls. The effect of velocity was significant, while that of group and their interaction were not. Velocity dependence of the intra-individual standard deviation of RFP (Fig. 5) was somewhat irregular, but it was possible to see a pattern: an increase up to 0.94–1.17 m/s, and then a plateau or a slight decrease. The intra-individual standard deviations

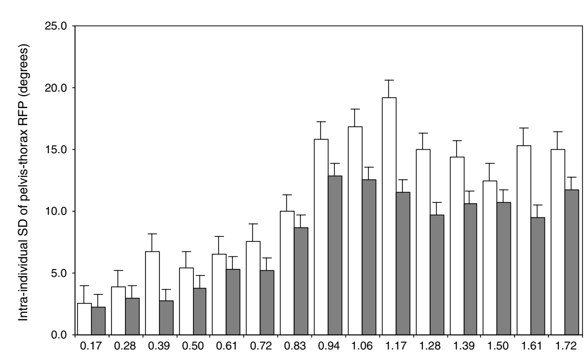

Fig. 5. Intra-individual standard deviation of relative Fourier phase (T-bars representing standard errors) between transverse pelvic and thoracic rotations at different walking velocities of the control subjects (white) and the healthy pregnant women (grey).

of RFP were often highest around comfortable walking velocity. Post hoc analysis showed that the velocity level with the highest standard deviation was, on average, not more than one step away from comfortable walking velocity. At all velocities, the intra-individual standard deviation of RFP was about 3° smaller in the pregnant women. Overall, the effect of velocity was significant, whereas that of group and their interaction were not.

3.4. Correlations with week of pregnancy

Correlations between week of pregnancy and pelvic as well as thoracic rotations and their intra-individual standard deviations, values between 0.0 and 0.3, remained far from significant (P-values > 0.3). Correlations with trunk rotation, its intra-individual standard deviation, and pelvis–thorax RFP, between −0.4 and −0.5, did not reach significance (P-values between 0.1 and 0.2). The correlation between week of pregnancy and the intra-individual standard deviation of RFP, $r_P = -0.68$, was significant ($P = 0.01$).

3.5. Additional analyses

In general, the additional analyses gave the same pattern of results as the above analyses, with only a few exceptions. At comfortable walking velocity, pregnant women demonstrated significantly less pelvic (6° versus 8°; $t = 2.72$, $P < 0.05$) and trunk (8° versus 11°, $t = 2.71$, $P < 0.05$) rotation than the controls, and their mean RFP was significantly smaller (64° versus 108°, $t = 2.58$, $P < 0.05$). Moreover, at the higher velocities, the intra-individual standard deviation of RFP was significantly smaller in the pregnant women (11° versus 15°, $F_{1,21} = 4.58$, $P < 0.05$).

4. Discussion

4.1. Limitations of the present study

We studied the effects of pregnancy on gait kinematics, with an emphasis on variables known to be affected in pregnancy-related pelvic girdle pain (PPP) (Wu et al., 2002). We enrolled 12 pregnant women between 20 and 34 weeks of pregnancy. Thus, we did not cover the whole span of pregnancy. Moreover, our sample size may have been too small to detect subtle effects. To control walking velocity, we used treadmill walking, which is mechanically identical to overground walking (Van Ingen Schenau, 1984), but may differ slightly in terms of kinematics (Vogt et al., 2002). It is possible that pregnant women walk more cautiously on a treadmill. Any signs of cautious walking in the present study can, thus, not be generalized to overground walking. The pregnant women in our study were about six years older than the controls, but age-dependence of gait parameters in adults has only been observed in the elderly (Judge et al., 1996).

4.2. Gait in pregnancy is remarkably normal

Velocity effects on rotational amplitudes, pelvis–thorax RFP, and the intra-individual standard deviations were very similar in both groups (Figs. 2–5), which leads us to conclude that gait in pregnancy is "remarkably normal", and that pregnancy and walking are highly compatible. From an evolutionary point of view (cf. McNeill Alexander, 2002), this had to be expected.

Still, comfortable walking velocity was significantly lower in the pregnant women. Rotational amplitudes were smaller, significantly so for the pelvis and the trunk at comfortable walking velocity. Intra-individual standard deviations of all angular rotations were significantly smaller. Pelvis–thorax RFP was smaller, significantly at comfortable walking velocity. Finally, the intra-individual standard deviation of RFP was smaller, significantly so at the higher velocities (⩾1.06 m/s), and there was a significant negative correlation between week of pregnancy and this intra-individual standard deviation. Of course, pregnant women must adapt to the changes of pregnancy (Foti et al., 2000), such as weight gain (Alvarez et al., 1988). In contrast with the inconsistent changes in posture, our study suggests subtle but consistent changes in gait kinematics.

In postpartum PPP (Wu et al., 2002), and PPP during pregnancy (Wu et al., submitted), angular rotations during gait were relatively large, opposite to the situation in healthy pregnancy. Larger rotational amplitudes in PPP may be taken as a local sign, specific to problems in the pelvic girdle. On the other hand, all changes in gait kinematics we found in healthy pregnancy appear to be non-specific, consistent with a general picture of "careful" walking.

4.3. The importance of pelvis–thorax relative phase

The preference of pregnant women to walk at a lower velocity cannot be explained as a way to save energy since walking with a lower (higher) than comfortable velocity takes more energy (McNeill Alexander, 2002). However, lower walking velocities afford more time to react to perturbations (Maki, 1997), which may be preferable in pregnancy because of the extra load or because of disturbed proprioception. Another interpretation may be that pregnant women prefer to walk slower in order to avoid the coordination pattern typical of faster walking.

In our study, the nulligravidae walked comfortably at the beginning of the high plateau of the RFP curve (Fig. 4), and the pregnant women halfway up the steep incline, with a large RFP difference (44°) between the groups. When the pregnant women walked faster, RFP was high, but its variability small. This suggests that walking with a large RFP was difficult for them, as in subjects carrying a load on the back (LaFiandra et al., 2003), in chronic low back pain (Lamoth et al., 2002b), and in postpartum PPP (Wu et al., 2002). A preference for small RFP appears to result from very different constraints, of which pregnancy may be one.

Post hoc, we compared the intra-individual standard deviations of pelvis, thorax, and trunk rotations. They were, averaged over subjects and velocities, 1.25°, 1.29°, and 0.66°, respectively. If pelvic and thoracic rotations were controlled independently from each other, the variance of trunk rotation should equal that of pelvic rotation plus thoracic rotation. It was, in fact, much smaller. Hence, pelvic and thoracic rotations appear to be controlled together. Still, trunk rotation is not an "essential variable" (Gel'fand and Tsetlin, 1961) in the coordination of fast walking since trunk rotation lacks the dimension of time. RFP is clearly time-related, and may be an essential variable at higher walking velocities, ensuring that pelvic rotations at higher walking velocities are counterbalanced by opposite thorax rotations (Lamoth et al., 2002a). As to gait in pregnancy, it is important to note that the moments of inertia of both the pelvis and the thorax will have increased, which will cause small errors in relative timing to become of great consequence, a possible reason that pregnant women tend to avoid the gait patterns where a large RFP would be required.

4.4. Variability

Since Bernstein introduced "search variability" (cf. Bongaardt et al., 2000), interest for movement variability has slowly but steadily grown. Movement variability is generally considered functional (Heiderscheit, 2000), allowing for flexibility, adaptation, and learning. Variability will, however, cost energy and increase the risk for certain kinds of injury (Van Dieën et al., 2001). Thus, the functionality of variability is probably context-dependent (Tseng et al., 2003).

We were surprised to find that the maximum intra-individual variability of pelvis–thorax RFP occurred close to comfortable walking velocity. Masani et al. (2002) found variability in ground reaction forces to be minimal at comfortable speed. Perhaps, at comfortable walking velocity the essential variable is the vertical movement of the center of mass, whereas transverse pelvis–thorax RFP becomes essential at higher velocities. Refraining from the question how functional RFP variability is, there remains the problem of how it is increased around comfortable walking velocity, and decreased at the higher velocities in pregnant women, particularly so in late pregnancy.

An attractive hypothesis would be that RFP variability is regulated through the stiffness (Seidler-Dobrin et al., 1998) of the muscles that rotate the trunk, perhaps comparable to a "rotational spring" (LaFiandra et al., 2002). Post hoc, we found that RFP and its intra-individual standard deviation were somewhat correlated in our data (ranging from +0.48 for relative phase to +0.70 for trunk rotation), which may be seen as support for the above hypothesis. Hence, the relationship between stiffness and RFP variability needs to be tested directly.

Another possibility is that variability depends upon the control system. It was observed that attention reduces relative phase variability (Amazeen et al., 1997). Maybe this is related to cortical, as opposed to extrapyramidal control, as a sign of conscious and careful walking. Future studies may focus on the control and variability of normal walking (Hausdorff et al., 1997), and of walking in uncomplicated pregnancy.

5. Conclusions

The general pattern of gait kinematics in healthy pregnant women was found to be largely the same as that of nulligravidae. Still, many subtle differences were present. Comfortable walking velocity of the pregnant women was significantly lower than that of the nulligravidae. The amplitudes of pelvic, thoracic, and trunk rotations were smaller than in the controls (significant for pelvis and trunk at comfortable walking velocity), with significantly smaller intra-individual standard deviations. Relative Fourier phase between pelvic and thoracic rotations was smaller in the pregnant women (not significant), with smaller standard deviations (significant at velocities $\geqslant 1.06$ m/s), particularly late in pregnancy. It is hypothesized that pregnant women tend to avoid the large relative phase between pelvic and thoracic rotations that is typical for high walking velocities, possibly because the moments of inertia of their pelvis and thorax have increased which renders the control of relative phase more critical.

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