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Adaptive changes in spatiotemporal gait characteristics in women during pregnancy

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ABSTRACT

Spatiotemporal gait cycle characteristics were assessed at early (P1), and late (P2) pregnancy, as well as at 2 months (PP1) and 6 months (PP2) postpartum. A substantial decrease in walking speed was observed throughout the pregnancy, with the slowest speed (1 ± 0.2 m/s) being during the third trimester. Walking at slower velocity resulted in complex adaptive adjustments to their spatiotemporal gait pattern, including a shorter step length and an increased duration of both their stance and double-support phases. Duration of the swing phase remained the least susceptible to changes. Habitual walking velocity (1.13 ± 0.2 m/s) and the optimal gait pattern were fully recovered 6 months after childbirth. Documented here adaptive changes in the preferred gait pattern seem to result mainly from the altered body anthropometry leading to temporary balance impairments. All the observed changes within stride cycle aimed to improve gait safety by focusing on its dynamic stability. The pregnant women preferred to walk at a slower velocity which allowed them to spend more time in double-support compared with their habitual pattern. Such changes provided pregnant women with a safer and more tentative ambulation that reduced the single-support period and, hence, the possibility of instability. As pregnancy progressed a significant increase in stance width and a decrease in step length was observed. Both factors allow also for gait stability improvement.

1. Introduction

Spatiotemporal gait pattern (STGP) and its flexibility may serve as a sensitive and clinically relevant measure in the evaluation of normal gait, falls risk and response to therapeutic interventions. Throughout a person's life, the STGP is constantly optimized and fine tuned due to multiple factors including: body mass and load, or fear of a falling. Impact of these factors results in a characteristic STGP, that allows a person to walk safely and efficiently within an optimal range of velocities, whilst expending a minimal amount of energy [1]. When a person walks at the preferred velocity, his/her lower limbs perform cyclic, alternating and repeatable movements, which, in the absence of any disturbances, are characterized by the practically invariable spatiotemporal pattern of the stride cycle [1]. The overall reliability of the human gait does not depend, however, on the repeatability of an invariant STGP, but rather on its flexibility i.e., the susceptibility of gait control to adapt the pattern to actual movement constraints. An example of this is the adaptation of the pattern to increased body weight [1,2]. Pregnancy in young healthy women is another example of an exceptional physiological status that requires temporary though significant changes in optimal STGP [3–6]. Gait adaptation during pregnancy is crucial for the safety of pregnant women.

It is significant that, when walking, pregnant women experience falls at a similar rate to women aged over 70 years [7,8]. The majority of falls occur during advanced pregnancy when the biomechanical and physiological factors alter gait control the most [7,8]. Two-thirds of these falls occur when a pregnant woman is walking on a slippery surface, is rushing, or is carrying an object. The root causes of these falls are usually complex and are likely to remain the subject of scientific debate for many years [9,10]. It was speculated that, unlike pregnant non-fallers, pregnant fallers did not increase their ankle stiffness and hence, generate less ankle torque [9]. Kinesiologists, however, point toward excessive deviations from the optimal habitual STGP as a pivotal factor that may contribute to falls in pregnant women.

Generally, gait control in young healthy people is characterized by considerable flexibility allowing them to move freely under varying conditions. Therefore, it could be expected that a pregnant women, whose body undergoes progressive physiological changes,

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should adapt their STPG smoothly to novel biomechanical conditions. The changes affecting body biomechanics include a substantial weight gain which is often accompanied by upper and lower extremity edema. Additionally, the characteristic late pregnancy spinal lordosis during late pregnancy results in the anterior shift in the location of the center of body mass which also affects the gait pattern [11]. Joint laxity is yet another factor that may contribute to the unsteadiness of gait and an increased fear of falls in pregnant women [3,7].

From results of recent studies emerged a fairly consistent pattern of changes in gait kinematics during pregnancy [4,12]. Most of the studies showed an increase in the time of double-support in pregnant women particularly in the third trimesters [3,4,14]. Some of the studies also found a significant decrease in step length in advanced pregnancy [3]. Lymbery and Gilleard [15] documented that in late pregnancy, there was a wider step width, and that medio-lateral ground reaction forces tended to be increased.

Some discrepancies in the reported results might result from the fact that all of them were assessed: (i) with different control/reference data, (ii) in different phases of pregnancy, and (iii) in diverse and relatively sparse experimental groups [12]. Generally, changes in gait kinematics observed during pregnancy are usually too subtle, and might not be detected by some of the contemporary research techniques [1,4,12]. Moreover, very few studies describe the changes from a longitudinal perspective [4,6,14,16] and none of these studies was carried out in all major phases of pregnancy. Therefore to obtain a reliable insight into gait adaptation mechanisms during pregnancy, the longitudinal study was performed using the precise assessment of spatiotemporal gait diagrams [1,2,17].

2. Materials and methods

The study protocol was approved by the Senate Ethics Committee of the Jerzy Kukuczka Academy of Physical Education in Katowice. Twenty-eight young healthy pregnant women aged 20–38 years (mean age 28.2 ± 3.4 years) were enrolled in the research that focused on changes in gait and postural stability during pregnancy and after delivery [18,19]. Twelve women reported performing regular exercises throughout pregnancy and resumed the exercises after delivery (for details see [18]).

The aim of the study and the experimental procedures were explained to the participants and an informed consent was obtained. They had no history of any musculoskeletal or neurological abnormalities, uncorrectable vision disorders, obesity nor any other medical conditions that could affect walking. Eligibility criteria were confirmed by a physical examination and a survey. Exclusion criteria were any conditions considered by an obstetrician to be a high-risk pregnancy. The survey at each session asked about any medication intake, musculoskeletal complaints, and lifestyle [18]. At the onset of each session, the subjects' anthropometric data (including weight, and their waist and hip circumferences) was measured according to guidelines of the International Society for the Advancement of Kinanthropometry (ISAK 2011 protocol).

Women enrolled in the study reported for testing to the Biomechanics Laboratory at the Academy of Physical Education in Katowice. Four experimental sessions were scheduled for each subject: two during pregnancy (P1 at the end of the first trimester, and P2 at the 3rd trimester), and two sessions after delivery (PP1 and PP2, at 2 and 6 months after delivery, respectively). The results of the second post-delivery session (PP2) were used as reference data. During gait testing, the women were asked to walk along the 10 m long walkway (back and forth 10 times) at their preferred velocity, and their limb-contact signals were recorded by custom made, self-adhesive copper foil electrodes attached to the soles of their shoes [1]. The limb-contact signals were digitized with a sampling frequency of 1 kHz (Axotape v.2.0, Axon Instrument Inc., USA). Thus, limb contact with the surface of the walkway produced an electrical signal that was determined by both the position and timing of the limb stance phase. This method allowed the on-line computation of gait parameters including: walking velocity, stance and swing times, gait cycle (stride cycle), double-support phase durations, cadence, stride length and limb swing velocity [1].

All statistical analyses were performed using Statistica v.6.0 software (Statsoft, Tulsa, OK, USA). Repeated measures analysis of variance (ANOVA) was used to examine statistically significant differences in the gait parameters with normal distribution (Shapiro–Wilk test, $\alpha = 0.05$) between each of the four experimental sessions. The ANOVAs were followed by post hoc Fisher's Least Significant Difference test (LSD). Linear correlation analyses (Pearson r) between the stride spatiotemporal indices and gait velocity were performed at $p \leq 0.05$.

3. Results

Highly significant changes in body weight, waist and hip circumferences were found between the sessions. The group anthropometric characteristics during each session are summarized in Table 1.

In all subjects, the stride spatiotemporal measures did not show limb effect (left vs. right leg) and consecutive analyses were performed on collapsed data. In the following statistical analysis, the effect of pregnancy on walking velocity and gait spatiotemporal characteristics was tested. Results of the PP2 session, i.e., 6 months after childbirth were used as reference values in all statistical analyses.

The ANOVA results, followed by the post hoc LSD test, showed that the preferred gait velocities were changed significantly during each session ($F_{3,81} = 7.9$, $p \leq 0.0002$). The mean velocity reached its maximum value (1.13 ± 0.3 m/s) 6 months after delivery. During the other sessions (P1, P2 and PP1), the subjects walked much more slowly ($p \leq 0.01$). The minimum preferred velocity, measuring 0.99 ± 0.19 m/s ($p \leq 0.00001$), was noticed in the third trimester. Changes in the mean velocity are shown in Fig. 1.

Following the changes in walking velocity specific to pregnancy, the gait kinematics were also modified accordingly. Analysis of variance on stride length ($F_{3,81} = 4.18$, $p \leq 0.01$) showed significant difference at each session. When comparing the stride length between sessions (post hoc LSD test), we found that its mean magnitude (in relation to the reference value 1.25 ± 0.13 m at PP2) was shorter by about: 6 cm at P1 ($p \leq 0.03$), 9 cm at P2 ($p \leq 0.001$), and again, 6 cm at PP1 ($p \leq 0.03$). For details see the lower panel of Fig. 1.

Table 1
Anthropometric characteristics of 28 women at their four test sessions: early (P1) and advanced (P2) pregnancy, and at 2 (PP1) and 6 (PP2) months postpartum.

Session	Body mass [kg]	BMI	Waist circumference [cm]	Hip circumference [cm]	Width of the BOS [cm]
P1	61.1 ± 9.2	22 ± 2.5	76.6 ± 5.9	99.6 ± 5.3	27.7 ± 3.3
P2	73.8 ± 10.6	26.6 ± 3.0	102.3 ± 6.5	106.5 ± 6.6	29.9 ± 3.1
PP1	64.1 ± 9.9	23.1 ± 2.8	79.2 ± 6.5	101.6 ± 6.3	27.9 ± 3.1
PP2	62.3 ± 10.4	22.3 ± 2.7	77.1 ± 7.3	100.3 ± 5.8	28.3 ± 3.0

BOS, base of support.