Gait & Posture 130 (2026) 110608

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

Free-living sit-to-stand angular velocity derived from thigh-worn accelerometry slows during pregnancy, but is not associated with binary self-reported discomfort prevalence

Liam P. Pellerine [a,b,*], Hannah Nørtoft Frankel [c,d], Luise Mølenberg Begtrup [c,d], Myles W. O'Brien [a,e,f], Magnus Svartengren [b,g], Pasan Hettiarachchi [b]

[a] Department of Medicine, Dalhousie University, Halifax, Canada
[b] Occupational and Environmental Medicine, Department of Medical Sciences, Uppsala University, Uppsala, Sweden
[c] Department of Occupational and Environmental Medicine, Copenhagen University Hospital - Bispebjerg and Frederiksberg, Copenhagen, Denmark
[d] Department of Public Health, University of Copenhagen, Copenhagen, Denmark
[e] Centre de Formation Médicale du Nouveau-Brunswick, Université de Sherbrooke, Moncton, Canada
[f] Department of Medicine, Université de Sherbrooke, Sherbrooke, Québec, Canada
[g] Occupational and Environmental Medicine, Uppsala University Hospital, Uppsala University, Uppsala, Sweden

ARTICLE INFO

Keywords:
Physical activity
sedentary time
physical function
biomechanical changes
sit-to-stand performance

ABSTRACT

Background: The sit-to-stand transition is a key movement influenced by coordination, balance, and lower-limb strength. While laboratory-based studies show slower sit-to-stand angular velocity during pregnancy, free-living sit-to-stand angular velocity and its relationship to pregnancy-related discomforts remain unclear.
Purpose: This study examined differences between the second and third trimesters of pregnancy in free-living sit-to-stand angular velocity, movement behaviours, and discomfort frequency, and assessed whether changes in sit-to-stand angular velocity predicted discomfort changes.
Methods: Pregnant participants (n = 176) from the PRECISE Occupational Cohort in Denmark wore thigh-worn accelerometers for ~one week during the second and third trimesters to measure sit-to-stand transitions, step counts, and movement behaviours. Weekly questionnaires reported the presence of lower back pain, pelvic pain, Braxton-Hicks contractions, fatigue, and lower-limb edema.
Results: Linear mixed models compared second and third trimesters, and regression models tested whether sit-to-stand angular velocity change predicted discomfort change, adjusting for age and pre-pregnancy body mass index. Median (d=-0.53) and 90th percentile sit-to-stand angular velocity (d=-0.47) were significantly lower in the third trimester, accompanied by fewer daily sit-to-stand angular transitions (d=-0.14) and reductions in step count (d=-0.29), standing time (d=-0.21), and moderate-to-vigorous physical activity (d=-0.43; all, $p < 0.001$). Pregnancy-related discomforts increased in frequency ($p < 0.001$), with pelvic pain (odds ratio (OR)= 5.02), Braxton-Hicks contractions (OR=17.9), and lower-limb edema (OR=9.23) showing the largest rises. Changes in median and 90th percentile sit-to-stand angular velocity were not associated with changes in the composite weekly discomforts (both, $p > 0.235$).
Conclusion: Free-living sit-to-stand angular velocity declines and discomfort prevalence rises between the second and third trimesters.

1. Introduction

The sit-to-stand (STS) transition (i.e., the transition from a sedentary to upright posture) is an essential movement for daily life which requires coordination, balance, and musculoskeletal power [1]. The STS transition is routinely evaluated to assess for fall risk, functional capacity, and

Abbreviations: BMI, body mass index; LPA, light-intensity physical activity; MPA, moderate-intensity physical activity; MVPA, moderate-vigorous-intensity physical activity; OR, odds ratio; P90, 90th percentile; STS, sit-to-stand; VPA, vigorous-intensity physical activity.

* Correspondence to: Dalhousie University, 6260 South St, Halifax, NS B3H 4R2, Canada.
E-mail address: liam.pellerine@dal.ca (L.P. Pellerine).

https://doi.org/10.1016/j.gaitpost.2026.110608
Received 10 April 2026; Received in revised form 30 July 2026; Accepted 1 August 2026
Available online 4 August 2026
0966-6362/© 2026 The Authors. Published by Elsevier B.V. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).

lower limb function [2]. The five-repetition STS test is commonly used to quantify STS performance by calculating the time required to complete five STS transitions [3]. While this test has been extensively used in clinical settings to assess functional health [3,4], research has also explored the angular velocity of the STS transition using free-living thigh accelerometry [5–7]. Clinical tests are designed to assess maximal STS performance in standardized settings [3,4], but these results may not reflect real-life performance. Recent work has demonstrated that free-living STS angular velocity processed from thigh-worn accelerometry can accurately assess STS performance [8]. Thus, it is relevant to investigate how free-living STS angular velocity is related to progressive biomechanical and physiological changes.

Maintaining mobility during pregnancy is essential for supporting musculoskeletal health, reducing the risk of functional decline and discomforts [9,10]. To complete the STS transition, flexion of the trunk and extension of the lower back, hips, and knees are required [11]. There are biomechanical changes to the STS transition during pregnancy due to increased abdominal mass, particularly during the third trimester [11–13]. There is a progressive increase in thoracic kyphotic and lumbar lordotic curvatures of the spine throughout gestation [11]. During the third trimester, there is an increase in the knee joint moment, a decrease in the hip joint moment, and an observed increase in anterior pelvic tilt [12]. These biomechanical changes lead to progressive weakening of the abdominal and pelvic floor muscles [13]. Existing laboratory-based research has demonstrated the STS transition takes longer to complete during pregnancy [12,13] and may lead to more frequent pain, fluid retention, and fatigue [14].

There are several pregnancy-related discomforts which can negatively impact one's daily function [14]. High-quality evidence indicates the prevalence of common discomforts during pregnancy to be ~40% for lower back pain [15], ~40% for pelvic pain [16], and 66% for lower-limb edema [17]. These discomforts are reported throughout pregnancy but occur at higher rates during the third trimester [14]. In conjunction with inflammatory discomforts, many pregnant people experience Braxton-Hicks contractions (sporadic uterine contractions), especially during the third trimester [18]. Fatigue is also a discomfort reported throughout pregnancy that can impact one's ability to engage in daily activities [14]. Some research has investigated the relationship between STS performance and pregnancy-related discomforts in clinical settings [4]. For example, one study demonstrated that pregnant people experiencing pelvic pain took 20% longer to complete the five-repetition STS test compared to pain-free pregnant people [19]. Laboratory tests such as the five-repetition STS test are useful measure of task independence and discomforts such as pelvic pain [4,19]. However, laboratory-based tests are designed to test maximal performance in controlled settings [2]. The relationship between STS performance and pregnancy-related discomforts in the free-living setting remains unknown.

The purpose of this study was, 1) to determine if there were changes in free-living STS frequency, STS angular velocity, and frequency of common discomforts (i.e., lower back pain, pelvic pain, Braxton-Hicks contractions, lower-limb edema, and fatigue) between the second and third trimesters of pregnancy, 2) to compare free-living movement behaviours (e.g., step counts, sedentary time, standing time, physical activity between the second and third trimesters of pregnancy, and 3) to investigate whether changes in free-living STS angular velocity from the second to third trimester are associated with the prevalnce of pregnancy-related discomforts. Based on existing evidence [12,19], it was hypothesized that free-living STS transitions would become slower during the third trimester. It was hypothesized that the frequency of lower back pain, pelvic pain, Braxton-Hicks contractions, lower-limb edema, and fatigue would increase in the third trimester. We also expected to see active movement behaviours (i.e., standing time, physical activity) be replaced with sedentary activity during the third trimester [9,10]. We hypothesized that a larger between-trimester reduction in free-living STS angular velocity would be associated with a larger change in the frequency of pregnancy-related discomforts.

2. Methodologies

2.1. Participants

Based on $f^2 = 0.086$ computed from a study investigating laboratory-based 5-times STS performance [19], a significance level of 0.05, desired power of 0.8, and three predictor variables (STS angular velocity, age, BMI), the required sample size for model development was 131 people. This was an approximate justification for regression modelling since no existing study has presented effect sizes based on free-living STS angular velocity values. From January 2023 to June 2024, 197 pregnant people were recruited at six obstetric departments in Denmark as a subgroup of the PRECISE Occupational Cohort study [20]. Participants were recruited during their first-trimester ultrasound scan performed between gestational weeks 11–13. To be eligible for study inclusion, participants had to be 18 years of age or older and able to read English/Danish. Pregnant people who were unemployed/on permanent sick leave (n = 8), had a multiple pregnancy (n = 9), or did not have valid accelerometry data (n = 4) were excluded. For more PRECISE Occupational cohort demographic and recruitment details, refer to the previously published cohort profile [20]. Research ethics approval (P−2022–201) and clinical trial approval (NCT05670145) were granted by the Knowledge Centre on Data Protection Compliance within the Capital Region of Denmark on July 7th, 2022. All research conformed to the Declaration of Helsinki.

2.2. Thigh-worn accelerometry

To assess free-living movement behaviours, participants wore research-grade tri-axial accelerometers (Axivity AX3™, Axivity Ltd., Newcastle, UK) at the beginning of the second trimester (mean ± standard deviation: 15 ± 3 weeks) and the beginning of the third trimester (28 weeks). The accelerometers were adhered to the anterior right thigh for approximately one week (5.6 ± 1.3 days). A research team member either visited participants or provided verbal instructions over the phone to ensure consistent accelerometer placement on the anterior thigh [20]. The accelerometers were programmed with the Axivity Software Open Movement (Version 1.0.0.43). Participants were asked to self-report their work, sleep, and non-wear times in a standardized diary. Thigh-worn acceleration data was processed with ActiPASS (Version 1.66.8) [21]. ActiPASS uses quality checks to identify invalid days (e.g., not enough wear time, inappropriate location on thigh) and these were removed from analyses (n = 41 days). Movement behaviour variables included number of steps, wear time, wake time, sleep time, sedentary time, standing time, and STS transitions. ActiPASS estimated time spent in light-intensity physical activity (LPA), moderate-intensity physical activity (MPA), vigorous-intensity physical activity (VPA), and moderate-vigorous physical activity (MVPA) using validated step-rate thresholds [21]. Free-living STS angular velocity and number of free-living STS transitions were calculated using processed ActiPASS outputs using a 1 Hz low-pass Butterworth filtering method. For this study, free-living STS angular velocity was the peak angular velocity value achieved during each STS transition. To identify valid STS transitions in a free-living environment, the ActiPASS software was used to automatically detect transitions from a sitting to an upright posture that resulted in a thigh angle change of $\geq 30^{\circ}$ (n = 130,350 valid STS transitions). The median and 90th percentile STS angular velocity were selected to provide weekly values. To assess the change in free-living STS angular velocity between pregnancy timepoints, the mean difference (third – second trimester) in weekly STS angular velocity was calculated for each participant.

2.3. Self-reported outcomes

Questionnaires were created using existing literature, clinical experience, and feedback from pregnant people [20]. All questionnaires were completed in the Capital Region of Denmark's Research Electronic Data Capture (RedCap) system. Participant descriptors (e.g., age, pre-pregnancy height, pre-pregnancy body mass, employment status) were collected via a standardized baseline questionnaire. Pre-pregnancy body mass index (BMI) was calculated using pre-pregnancy values for height (m) and body mass (kg). Weekly RedCap questionnaires were sent every six days to alter the response day for each week. The questionnaires asked participants if they experienced common pregnancy-related discomforts (i.e., lower back pain, pelvic pain, Braxton-Hicks contractions, fatigue, lower-limb edema) during the previous week (see Additional File 1). The questions provided binary response variables ("Yes" or "No") for each pregnancy-related discomfort. These items were not validated severity-based instruments such as the Pelvic Girdle Questionnaire or visual analogue pain scales; they were designed as brief weekly screening items within the larger PRECISE Occupational Cohort to reduce participant burden. Within the baseline questionnaire, a diagram was provided to illustrate the anatomical regions referred to as pelvic pain and lower back pain, respectively. A composite pregnancy-related discomfort score was created by summating the number of discomforts experienced each week, providing a 0–5 ordinal scale outcome. Weekly questionnaire responses from the time of study recruitment until week 27 of the pregnancy were defined as the second trimester. Weekly questionnaire responses from week 28 of pregnancy until birth were defined as the third trimester. The number of weeks a participant experienced a pregnancy-related discomfort was reported as a percentage of the total number of weekly questionnaire responses for each trimester.

2.4. Statistical analyses

Free-living movement behaviours (e.g., step counts, sedentary time, standing time), the number of STS transitions, and STS angular velocity were compared between the second and third trimesters using linear mixed modelling. Every valid day of accelerometry was inputted as a unique observation (n = 1967 observations). Linear mixed modelling adjusted for any between-participant variations in daily observations and wear time. To account for the repeated timepoint measures within participants, a random intercept for participants was included. Random-intercept-adjusted Cohen's d effect size were reported with p-values. Cohen's d effect sizes were interpreted using thresholds for small (d=0.20), medium (d=0.50), or large (d=0.80) effects [22]. Generalized logistic mixed-effects models were used to compare the number of weeks each pregnancy-related discomfort was reported between trimesters. Generalized logistic mixed-effects modelling accounted for between-participant variation in the number of weekly responses, with participant ID included as a random effect. For each discomfort, the model produced an odds ratio indicating whether the odds of experiencing that discomfort were higher or lower in third trimester compared to the second trimester. To examine the association between STS angular velocity and pregnancy-related discomforts, linear regression modelling was used. Two separate models were constructed using the change (Δ) between the two accelerometry timepoints as the primary independent variable—one for median STS angular velocity and one for 90th percentile angular STS velocity. Age and pre-pregnancy BMI were included in the regressions based on existing evidence [3]. The dependent variable was the change (Δ) in average weekly composite discomforts, calculated by subtracting the mean number of weekly reported discomforts in the 3rd trimester from those in the 2nd trimester. The unstandardized β-values and 95% confidence intervals (95% CI) were reported for model predictors. The proportion of model variance (R^2) was adjusted for the number of predictors. The estimated effect size of the predictors on the model variance was reported as Cohen's f^2. For each model, Cook's distance inspected for potential outliers using a conventional cutoff of $4/n$ (where n = sample size) [23]. Models were reviewed with and without Cook's distance adjustment to assess the impact of outliers. No significant model estimates changes were observed. All statistical analyses were completed in RStudio (Version 2024.04.2, Posit Software, PBC, Boston, MA). Data were reported as means±standard deviation and statistical significance was $p < 0.05$.

3. Results

3.1. Participant characteristics

Table 1 provides a summary of participant characteristics. All participants were assigned female sex at-birth and identified as women.

3.2. Thigh-worn accelerometry measures

The free-living movement behaviours collected at the beginning of the second and third trimesters are shown in Table 2. Between-trimester comparisons demonstrated a consistent reduction in all active movement behaviours and sleep time (all, $p < 0.001$), with an average mean difference of 38 additional minutes of sedentary time ($p < 0.001$) during the third trimester. There were no significant between-trimester differences in wear time or waking time (both, $p > 0.09$).

Table 2 summarizes the between-trimester comparisons for accelerometry-derived STS frequency and performance outcomes. There was a reduction in the change in thigh angle during the third trimester compared to the second trimester ($p = 0.009$). However, there were no between-trimester differences for the time required to complete the STS transition ($p = 0.13$). There were fewer STS transitions during the third trimester compared to the second trimester ($p = 0.002$).

Fig. 1A depicts the between-trimester reduction in median STS

Table 1
Baseline participant characteristics for 176 pregnant people.

Variable	n = 176
Age (years), Mean ± SD [Minimum, Maximum]	31.2 ± 4.1 [22, 47]
Height (cm), Mean ± SD [Minimum, Maximum]	169 ± 6 [150, 189]
Weight (kg), Mean ± SD [Minimum, Maximum]	70.4 ± 14.0 [47, 128]
Body mass index (kg/m^2), n (%)	
Underweight (<18.5)	5 (3%)
Normal (18.5–24.9)	104 (59%)
Overweight (25.0–29.9)	44 (25%)
Obese (>30)	23 (13%)
Smoking status, n (%)	
Daily	< 3 (<2%)
Formerly	37 (21%)
Never	134 (76%)
Other nicotine product use	0 (0%)
Did not answer	3 (2%)
Average alcohol consumption (units/week), n (%)	
None	> 173 (>98%)
1–4	0 (0%)
5 or more	0 (0%)
Did not answer	< 3 (<2%)
Highest Educational level, n (%)	
Primary school	< 3 (<2%)
High school	5 (3%)
Vocational education	16 (9%)
Short post-secondary education (<2.5 years)	18 (10%)
Medium post-secondary education (3–4 years)	82 (47%)
Long post-secondary education (>4.5 years)	54 (31%)
Baseline pregnancy week, Mean ± SD [Minimum, Maximum]	15 ± 3 [10, 24]
Lives with partner, n (%)	173 (98%)
Children at home, n (%)	78 (44%)
Previously pregnant, n (%)	80 (45%)
History of miscarriage, n (%)	41 (23%)
Fertility treatment for current pregnancy, n (%)	20 (11%)
Diagnosed with chronic disease, n (%)	30 (17%)

Note: SD, standard deviation.

Table 2
Free-living postural outcomes comparisons for the difference between second and third trimesters using Linear Mixed Modelling in 176 pregnant individuals.

Variable	Timepoint		Mean Difference (3^{rd} – 2^{nd})	*p*-value	Adjusted-*d*
	2^{nd} Trimester	3^{rd} Trimester			
Valid Wear Time (min/d)	1428 ± 15 [1380, 1440]	1429 ± 19 [1312, 1440]	1 ± 23	0.27	0.05
Waking Time (min/d)	946 ± 64 [753, 1190]	954 ± 83[626, 1308]	9 ± 87	0.09	0.08
Sleep Time (min/d)	412 ± 63 [193, 579]	394 ± 77 [91, 653]	−18 ± 70	**< 0.001**	−0.18
Sedentary Time (min/d)	582 ± 85 [316, 801]	620 ± 98 [328, 1005]	38 ± 103	**< 0.001**	0.31
Standing Time (min/d)	192 ± 49 [81, 401]	179 ± 49 [56, 341]	−12 ± 42	**< 0.001**	−0.21
Step Count (steps/d)	9901 ± 2888 [4755, 19189]	9029 ± 2784 [3102, 19676]	−872 ± 2443	**< 0.001**	−0.29
LPA (min/d)	285 ± 66 [130, 518]	267 ± 66 [90, 498]	−18 ± 53	**< 0.001**	−0.23
MPA (min/d)	63 ± 20 [29, 126]	56 ± 20 [14, 141]	−7 ± 18	**< 0.001**	−0.35
VPA (min/d)	15 ± 13 [1, 68]	12 ± 11 [1, 55]	−4 ± 9	**< 0.001**	−0.27
MVPA (min/d)	78 ± 26 [30, 162]	68 ± 25 [18, 162]	−11 ± 21	**< 0.001**	−0.43
Median Δ Thigh Angle (°)	53.8 ± 5.8 [36.9, 69.1]	52.7 ± 5.5 [38.8, 67.2]	−1.1 ± 4.7	**0.009**	−0.23
P90 Δ Thigh Angle (°)	72.2 ± 7.4 [44.8, 91.2]	69.8 ± 7.0 [49.6, 91.0]	−2.4 ± 5.9	**< 0.001**	−0.38
Median Transition Time (s)	0.82 ± 0.13 [0.50, 1.15]	0.83 ± 0.12 [0.50, 1.15]	0.004 ± 0.112	0.13	0.07
P90 Transition Time (s)	1.50 ± 0.22 [0.92, 2.30]	1.51 ± 0.22 [0.98, 2.09]	0.006 ± 0.224	0.32	0.05
STS Transitions (reps/d)	43 ± 13 [16, 104]	41 ± 12 [18, 73]	−1 ± 9	**0.002**	−0.14

Note: Mean Difference, the mean of participant-level differences between timepoints; LPA, light-intensity physical activity; MPA; moderate-intensity physical activity; VPA, vigorous-intensity physical activity; MVPA, moderate-vigorous-intensity physical activity; P90, 90th percentile; STS, sit-to-stand. Adjusted-*d*, Cohen's effect size adjusted for random intercepts. Trimester data reported as mean ± standard deviations [minimum, maximum].

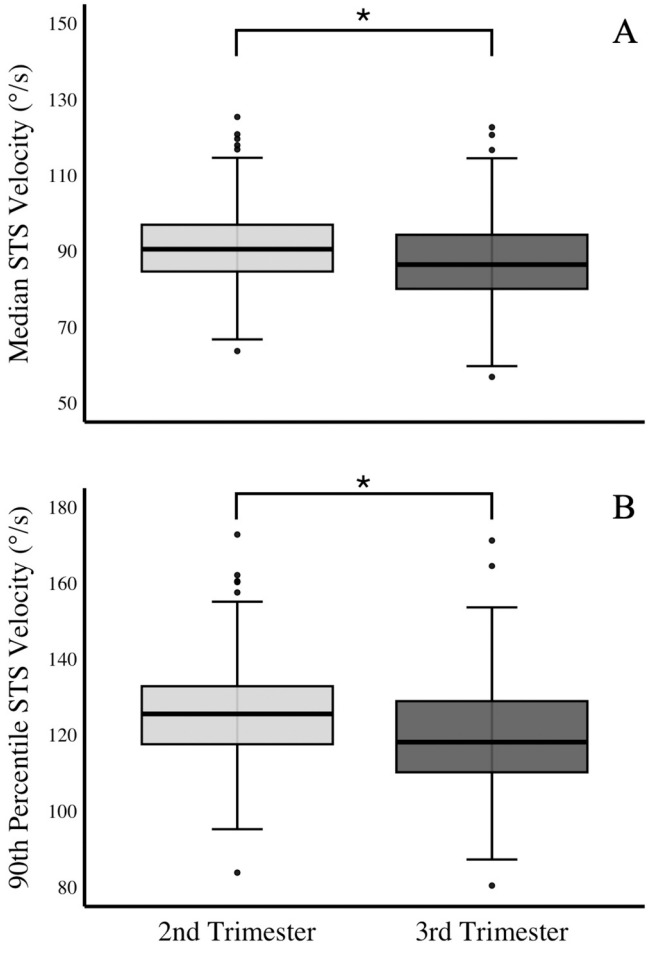

Fig. 1. [A] The median sit-to-stand (STS) velocity values compared between trimesters using Linear Mixed Effects modelling for 176 participants, [B] The 90th percentile sit-to-stand velocity values compared between trimesters using Linear Mixed Effects modelling for 176 participants. *, indicates between-trimester difference, $p < 0.001$. Note: The box represents the interquartile range. The horizontal line within the box denotes the median. The whiskers represent the largest and smallest values within 1.5 x interquartile range. Individual points plotted beyond the whiskers represent outliers.

angular velocity ($p < 0.001$, d=−0.53). Fig. 1B shows the between-trimester reduction in 90th percentile STS angular velocity ($p < 0.001$, d=−0.47).

3.3. Weekly pregnancy-related discomforts

Table 3 shows the changes in the frequency of pregnancy-related discomforts between trimesters. The frequency of all pregnancy-related discomforts increased from the second to third trimester (all, $p < 0.001$). The mean number of weekly questionnaire responses was 10 ± 3 for the second trimester and 14 ± 3 for the third trimester ($p < 0.001$).

Fig. 2 illustrates an increase in the average number of weekly pregnancy-related discomforts reported during the third trimester compared to the second trimester ($p < 0.001$, d=1.07). The proportion of weeks where participants reported experiencing at least one pregnancy-related discomfort increased from 86 ± 22% in the second trimester to 94 ± 17% in the third trimester ($p < 0.001$, d=0.41).

3.4. Multiple linear regression modelling

Table 4 presents the results of multiple linear regression analyses. The between-trimester change in median STS angular velocity was not associated with the between-trimester change in composite pregnancy-

Table 3
Change in the proportion of weeks with pregnancy-related discomforts between the second and third trimester using Generalized Logistic Mixed Modelling for 176 pregnant people.

Variable	Timepoint		Mean Difference (3^{rd} – 2^{nd})	*p*-value	Odds Ratio
	2^{nd} Trimester	3^{rd} Trimester			
Lower Back Pain (% of weeks)	48 ± 37	56 ± 37	7 ± 29	**< 0.001**	1.69
Pelvic Pain (% of weeks)	34 ± 36	53 ± 39	19 ± 40	**< 0.001**	5.02
Braxton-Hicks Contractions (% of weeks)	21 ± 30	60 ± 33	40 ± 32	**< 0.001**	17.9
Fatigue (% of weeks)	64 ± 33	69 ± 32	5 ± 27	**< 0.001**	1.41
Lower-Limb Edema (% of weeks)	13 ± 24	34 ± 34	22 ± 30	**< 0.001**	9.23

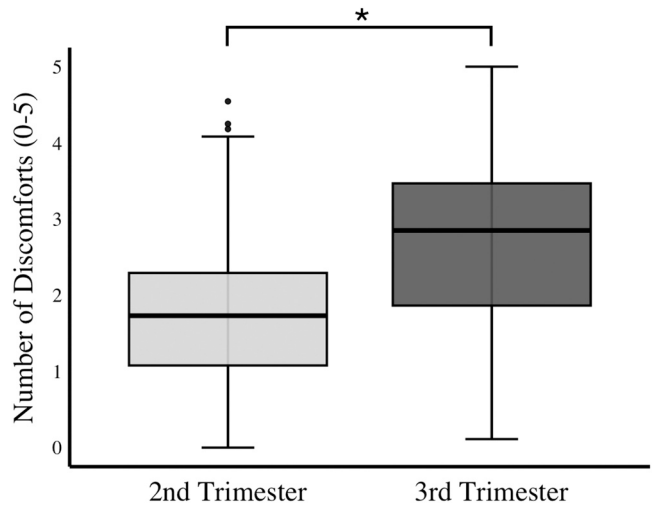

Fig. 2. The average number of pregnancy-related discomforts (0–5 scale) experienced was compared between trimesters using Linear Mixed Effects modelling for 176 participants. *, indicates between-trimester difference, $p < 0.001$. Note: The box represents the interquartile range. The horizontal line within the box denotes the median. The whiskers represent the largest and smallest values within 1.5 x interquartile range. Individual points plotted beyond the whiskers represent outliers.

Table 4
Linear regression modelling of the predictive value of change in sit-to-stand velocity values on the change in the composite number of pregnancy-related discomforts between the second and third trimesters in 176 pregnant people after adjusting for age and body mass index (BMI).

Predictor	Unstandardized β	95% CI	*p*-value	Adjusted R^2	Cohen's f^2
Intercept	0.896	[−0.092, 1.883]	0.075	0.025	0.044
Δ Median STS Velocity	0.001	[−0.012, 0.013]	0.880		
Age	−0.021	[−0.047, 0.006]	0.132		
BMI	0.027	[0.005, 0.050]	**0.019**		
Intercept	0.915	[−0.069, 1.899]	0.068	0.033	0.052
Δ P90 STS Velocity	0.005	[−0.003, 0.013]	0.235		
Age	−0.021	[−0.047, 0.006]	0.125		
BMI	0.028	[0.005, 0.051]	**0.016**		

Note: Δ Median sit-to-stand (STS) velocity, the change in median sit-to-stand velocity (°/s); Δ 90th percentile (P90) STS velocity, the change in 90th percentile sit-to-stand velocity (°/s); Age, in years; BMI, body mass index (kg/m^2). Adjusted R^2, proportion of variance adjusted for predictors; Cohen's f^2, estimated effect size of the predictors on model variance.

related discomforts after controlling for age and BMI (β=0.001, $p = 0.880$). The between-trimester change in 90th percentile STS angular velocity was not associated with the between-trimester change in pregnancy-related discomforts after controlling for age and BMI (β=0.005, $p = 0.235$). In both models, pre-pregnancy BMI was a significant positive covariate for the between-trimester change in pregnancy-related discomforts (both, $p < 0.019$).

4. Discussion

This study purpose was to test the hypotheses that, 1) STS transitions would become slower and less frequent, 2) active movement behaviours would be replaced with sedentary time, 3) pregnancy-related discomforts would increase during the third trimester of pregnancy compared to the second and, 4) greater reductions in STS angular velocity would be associated with greater increases in number of pregnancy-related discomforts. Based on our findings, these hypotheses were partially supported. The median and 90th percentile STS angular velocities decreased in the third trimester, accompanied by reductions in movement behaviours such as step counts, standing time, and time spent in MVPA. Sedentary time and pregnancy-related discomforts increased significantly across all domains. However, based on binary discomfort prevalence data, changes in STS angular velocity were not predictive of changes in the composite discomfort score, even after adjusting for age and pre-pregnancy BMI.

The observed reductions in median and 90th percentile STS angular velocity align with laboratory-based studies showing slower STS performance during pregnancy [12,19]. These reductions may reflect biomechanical adaptations to accommodate increased abdominal mass, altered spinal curvature, and changes in joint loading during the third trimester [11–13]. Replacing active movement behaviours like step counts, standing time, and MVPA with sedentary time were consistent with existing evidence [9,10]. These behavioural and biomechanical adaptations may both influence STS performance. However, the magnitude of the between-trimester change in STS angular velocity was moderate (d=−0.53), suggesting functional capacity was largely preserved. Despite reductions in activity levels, our sample of pregnant people remained active throughout pregnancy. These findings support that physical activity during pregnancy can help maintain functional capacity despite an increase in self-reported discomforts.

As anticipated, all pregnancy-related discomforts increased in frequency from the second to third trimester, consistent with previous estimates [14–17]. The magnitude of these changes varied, with pelvic pain and Braxton-Hicks contractions showing the most pronounced increases, followed by lower-limb edema. These increases may be driven by a combination of biomechanical strain [24], hormonal changes affecting ligament laxity [25], increased fluid retention [26], and increased uterine activity in later pregnancy [27]. Lower back and pelvic pain can likely be explained by alterations to spinal alignment, increased anterior pelvic tilt, and weakened abdominopelvic musculature [11–13]. The near-universal prevalence of at least one discomfort in the third trimester highlights the significant symptom burden experienced.

Despite the clear increases in discomfort prevalence, STS angular velocity was not associated with the change in binary prevalence of pregnancy-related discomforts. This lack of association may be due to the binary measurement of pregnancy-related discomforts. It is worth noting that we did investigate individual discomforts and attempted to group pain-related discomforts with no changes in the predictive capacity of STS angular velocity. Furthermore, the composite number of pregnancy-related discomforts captured the prevalence but not the severity or timing. It is logical to assume that an individual experiencing more severe pain would experience a larger reduction in STS performance. The absence of a relationship could be due to a mismatch between when discomforts were experienced and when STS performance was assessed. STS performance and pregnancy-related discomforts could be influenced by different physiological mechanisms. For example, movement behaviours and physical function could be driven by biomechanical adaptations (11–13), while discomforts might be more closely tied to internal physiological responses like hormonal changes [25], increased fluid retention [26], and increased uterine activity [27]. These distinct mechanisms may have limited our ability to find a correlation between STS angular velocity and discomforts.

This study has several strengths, including the use of thigh-worn accelerometry. This method enabled objective, high-resolution assessment of free-living STS performance and daily movement behaviours. The longitudinal design allowed for within-participant comparisons across trimesters. Pregnancy-related discomforts were assessed using

binary self-report questionnaires on a weekly basis, which limited the ability to detect day-to-day changes and symptom severity. However, weekly self-reported measures provided more time resolution than usual, as most questionnaires are completed only a few times throughout pregnancy. The sample consisted primarily of healthy, highly educated individuals who were working throughout their pregnancy, which may limit generalizability. While accelerometry provides an ecologically valid measure of free-living performance, it cannot capture factors such as intentional activity avoidance or pain-related biomechanical and physiological adaptations.

5. Conclusion

Free-living STS angular velocity decreased between the second and third trimesters of pregnancy, while pregnancy-related discomforts became more frequent. However, reductions in STS angular velocity were not correlated with between-trimester changes in the binary pregnancy-related discomfort prevalence. Although no relationship was observed, this may be due to the lack of severity quantification and inability to detect day-to-day changes in discomforts. Future studies should attempt to pair continuous thigh-worn accelerometry with validated, site-specific, severity-based daily discomfort questionnaires or complete an ecological momentary assessment to better temporally align symptom reporting with accelerometer-derived movement data.

CRediT authorship contribution statement

Hannah Nørtoft Frankel: Writing – review & editing, Supervision, Software, Resources, Investigation, Funding acquisition, Data curation, Conceptualization. **Luise Mølenberg Begtrup:** Writing – review & editing, Supervision, Resources, Project administration, Funding acquisition, Data curation, Conceptualization. **Liam P. Pellerine:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Formal analysis, Data curation, Conceptualization. **Magnus Svartengren:** Writing – review & editing, Supervision, Resources, Project administration, Funding acquisition, Conceptualization. **Pasan Hettiarachchi:** Writing – review & editing, Validation, Software, Project administration, Methodology, Investigation, Formal analysis, Data curation. **Myles W. O'Brien:** Writing – review & editing, Visualization, Resources, Methodology, Formal analysis, Conceptualization.

Ethics Approval and Consent to Participate

Research ethics approval (P−2022–201) was granted by the Knowledge Centre on Data Protection Compliance within the Capital Region of Denmark on July 7th, 2022. The cohort was also registered and approved as a clinical trial (NCT05670145) before data collection. All conducted research conformed to the Declaration of Helsinki.

Funding

The data used in this study are from the PRECISE cohort, which has received funding from the Danish Working Environment Research Fund (Grant #24-2021-04) and A.P. Møller Foundation (Grant #L-2023-00086). LPP was supported by the Lalia B. Chase scholarship.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Hannah Nortoft Frankel reports financial support was provided by Danish Working Environment Research Fund. Hannah Nortoft Frankel reports financial support was provided by The AP Møller Support Foundation. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

LPP was supported by the Lalia B. Chase scholarship.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.gaitpost.2026.110608.

Data Availability

The dataset supporting the conclusions of this article can be provided upon request.

References

[1] R.C. van Lummel, S. Walgaard, M. Pijnappels, P.J.M. Elders, J. Garcia-Aymerich, J. H. van Dieën, et al., Physical performance and physical activity in older adults: associated but separate domains of physical function in old age, PLoS. One 10 (2015) e0144048, https://doi.org/10.1371/journal.pone.0144048.

[2] F. Zhang, L. Ferrucci, E. Culham, E.J. Metter, J. Guralnik, N. Deshpande, Performance on five times sit-to-stand task as a predictor of subsequent falls and disability in older persons, J. Aging Health 25 (2013) 478–492, https://doi.org/10.1177/0898264313475813.

[3] R.W. Bohannon, D.J. Bubela, S.R. Magasi, Y.-C. Wang, R.C. Gershon, Sit-to-stand test: performance and determinants across the age-span, Isokinet. Exerc. Sci. 18 (2010) 235–240, https://doi.org/10.3233/IES-2010-0389.

[4] A.M. Klukowska, V.E. Staartjes, W.P. Vandertop, M.L. Schröder, Five-repetition sit-to-stand test performance in healthy individuals: reference values and predictors from 2 prospective cohorts, Neurospine 18 (2021) 760–769, https://doi.org/10.14245/ns.2142750.375.

[5] C.G. Pickford, A.H. Findlow, A. Kerr, M. Banger, A.M. Clarke-Cornwell, K. L. Hollands, et al., Quantifying sit-to-stand and stand-to-sit transitions in free-living environments using the activPAL thigh-worn activity monitor, Gait Posture 73 (2019) 140–146, https://doi.org/10.1016/j.gaitpost.2019.07.126.

[6] A. Löppönen, C. Delecluse, K. Suorsa, L. Karavirta, T. Leskinen, L. Meulemans, et al., Association of sit-to-stand capacity and free-living performance using thigh-worn accelerometers among 60- to 90-yr-old adults, Med. Sci. Sports Exerc. 55 (2023) 1525–1532, https://doi.org/10.1249/MSS.0000000000003178.

[7] A. Löppönen, L. Karavirta, E. Portegijs, K. Koivunen, T. Rantanen, T. Finni, et al., Day-to-day variability and year-to-year reproducibility of accelerometer-measured free-living sit-to-stand transitions volume and intensity among community-dwelling older adults, Sensors 21 (2021) 6068, https://doi.org/10.3390/s21186068.

[8] S.E. Rayner, J. Waghorn, E.E. Macdonald, M.E. Shivgulam, L.P. Pellerine, M. W. O'Brien, Accelerometer determined free-living sit-to-stand velocity: a scoping review of methodological developments, participant-level factors, and link to health, J. Meas. Phys. Behav. 8 (2025), https://doi.org/10.1123/JMPB.2024-0046.

[9] K. Ambika, V. Vijayalakshmi, Redefining maternal wellness: the role of antenatal exercises in musculoskeletal issues among primigravida mothers, Cureus 15 (2023) 2023, https://doi.org/10.7759/CUREUS.50494.

[10] K. Bø, B. Stuge, G. Hilde, Specific musculoskeletal adaptations in pregnancy: Pelvic floor, pelvic girdle, and low back pain: implications for physical activity and exercise, Exerc. Sport. Act. Pregnancy. Evid. - Based Guidel. (2019) 135–155, https://doi.org/10.1007/978-3-319-91032-1_6.

[11] R. Conder, R. Zamani, M. Akrami, The biomechanics of pregnancy: a systematic review, J. Funct. Morphol. Kinesiol. 4 (2019) 72, https://doi.org/10.3390/JFMK4040072.

[12] S.Z. Lou, Y.L. Chou, P.H. Chou, C.J. Lin, U.C. Chen, F.C. Su, Sit-to-stand at different periods of pregnancy, Clin. Biomech. 16 (2001) 194–198, https://doi.org/10.1016/S0268-0033(00)00114-5.

[13] E.C.S. Furtado, Y.S. De Azevedo, D. dos R. Galhardo, I.P.C. Miranda, M.E. C. Oliveira, P.F.M. das Neves, et al., Influence of gestational age on pelvic floor muscle activity, plantar contact, and functional mobility in high-risk pregnant women: a cross-sectional study, Sens. 24 (2024) 4615, https://doi.org/10.3390/S24144615.

[14] J. Meyerhoff, C. Belew, Y. Joo, J.V. Gatewood, M.A.M. Israel, K.W. McGrath, Common discomforts of pregnancy. Collins-Bride & Saxe's Clinical Guidelines for Advanced Practice Nursing, Joan & Bartlett Learning, Burlington, MA, 2024, pp. 371–388.

[15] N. Salari, A. Mohammadi, M. Hemmati, R. Hasheminezhad, S. Kani, S. Shohaimi, et al., The global prevalence of low back pain in pregnancy: a comprehensive systematic review and meta-analysis, BMC Pregnancy Childbirth 23 (2023) 830, https://doi.org/10.1186/S12884-023-06151-X.

[16] N. Mathew, V.K. Nambiar, G. Jyothi, Prevalence of pelvic girdle pain in pregnancy: a narrative review, Indian. J. Physiother. Occup. Ther. 5 (2023) 120–124, https://doi.org/10.4103/IJPTR.IJPTR_3_23.

[17] A. Rafique, N. Rafique, K. Afzal, H.A. Khan, N. Ashfaq, A. Rubab, Prevalence of lower limb edema in natal and post-natal period, J. Med. Sci. 31 (2023) 281–285, https://doi.org/10.52764/JMS.23.31.4.5.

[18] D.A. Raines, D.B. Cooper, Braxton Hicks contractions, StatPearls (2023). https://doi.org/10.53347/rid-170548.
[19] S. Yenişehir, İ. Çıtak Karakaya, A.A. Sivaslıoğlu, D. Özen Oruk, M.G. Karakaya, Reliability and validity of five times sit to stand test in pregnancy-related pelvic girdle pain, Musculoskelet. Sci. Pract. 48 (2020), https://doi.org/10.1016/j.msksp.2020.102157.
[20] H.N. Frankel, K.K. Hærvig, E.M. Flachs, M. Korshøj, C. Bertelsen, M. Backhausen, et al., Occupational physical activity among pregnant employees in the Danish workforce: the PRECISE occupational cohort profile, Clin. Epidemiol. 17 (2025) 211–224, https://doi.org/10.2147/CLEP.S496585.
[21] P. Hettiarachchi, K. Aili, A. Holtermann, E. Stamatakis, M. Svartengren, P. Palm, Validity of a non-proprietary algorithm for identifying lying down using raw data from thigh-worn triaxial accelerometers, Sensors (3) (2021) 904, https://doi.org/10.3390/s21030904.
[22] J. Cohen, Statistical power analysis for the behavioral sciences, Stat. Power Anal. Behav. Sci. (2013), https://doi.org/10.4324/9780203771587.
[23] R.D. Cook, Detection of influential observation in linear regression, Technometrics 19 (1977) 15–18, https://doi.org/10.1080/00401706.1977.10489493.
[24] K.M. Myers, D. Elad, Biomechanics of the human uterus, Wiley Interdiscip. Rev. Syst. Biol. Med. 9 (2017), https://doi.org/10.1002/WSBM.1388.
[25] T. Widelock, J. Denney, B. Brost, Pregnancy and parturition: the physical and physiological changes and their pathologies, Post. - Matern. body Chang. (2023) 25–47, https://doi.org/10.1007/978-3-030-43840-1_3.
[26] E.G. Robertson, Water metabolism, Clin. Obstet. Gynaecol. 2 (1975) 431–440, https://doi.org/10.1016/S0306-3356(21)00304-6.
[27] K. Donaldson, A. Huntington, R.De Vita, Mechanics of uterosacral ligaments: current knowledge, existing gaps, and future directions, Ann. Biomed. Eng. 49 (2021) 1788–1804, https://doi.org/10.1007/S10439-021-02755-6/METRICS.