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Association of wearable-device-measured physical activity among pregnant women with pregnancy trimesters and lifestyle

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Abstract

Pregnant women are advised to engage in at least 150 min per week of moderate-to-vigorous physical activity (MVPA). The study aimed to elucidate any correlations between physical activity levels and lifestyle factors, such as parity and employment type. We employed wearable devices to measure the total amount, frequency, and duration of daily physical activity among pregnant women. The results revealed three-factor interactions for sedentary behavior and MVPA percentages with trimester, parity, and employment type. The sedentary behavior percentage was highest among primiparas engaged in sedentary jobs throughout their pregnancy and was higher for primiparas than multiparas across all employment types during the third trimester. Among primiparas, the MVPA percentage declined from the second to the third trimester, irrespective of employment type, whereas in multiparas, the percentage decreased for unemployed women or those engaged in standing work. Our findings indicate that sedentary behavior and MVPA of pregnant women are substantially influenced by trimester, parity, and employment type.

Introduction

A certain level of physical activity is recommended for pregnant women due to benefits including reduced pregnancy-related risks such as hypertension, diabetes and premature birth, improved cardiopulmonary function, prevention of urinary incontinence and lower back pain, alleviation of depressive symptoms, and suppression of excessive weight gain during pregnancy [1][2][3].

Physical activity can be quantified using the metabolic equivalent of tasks (METs). Sedentary behavior is defined as 1.5 METs or lower, light physical activity (LPA) as 1.6–2.9 METs, moderate physical activity (MPA) as 3.0–5.9 METs and vigorous physical activity (VPA) is classified as 6.0 METs or greater. Activity of 3.0 METs or greater is classified as moderate-to-vigorous physical activity (MVPA) [4]. Based on survey results regarding correlations between the intensity and quantity of physical activity with non-infectious diseases such as diabetes, cancer, and cardiovascular disease, The U.S.[5] and World Health Organization (WHO) 2020[2] guidelines recommend that adults engage in 150–300 min of MPA, or 75–150 min of VPA per week, or a combination of both to maintain health and prevent disease. It is also recommended that pregnant women incorporate physical activity into their routines, with the WHO recommending at least 150 min of MPA per week [2]. However, as few pregnant women achieve this level of physical activity[6], the lack of physical activity amongst pregnant women is becoming a considerable global concern [7][8][9].

Recent research involving adult participants has indicated that prolonged sedentary behavior is associated with adverse health outcomes irrespective of MVPA [10][11][12]. However, incorporating brief intervals of LPA amidst sedentary behavior has been shown to reduce waist circumference, obesity, triglyceride levels, and 2-h blood glucose levels[13], as well as mitigate the risk of hypertension[14]. Conventional studies examining physical activity among adults and pregnant women have predominantly relied on self-administered questionnaire surveys to assess physical activity, which lacked

objectivity and quantitative measurements, thereby complicating the detailed investigation of factors other than physical activity intensity, such as frequency and duration.

Recent advancements have revealed that short periods of high-intensity physical activity in daily life, as measured by wearable devices, can reduce mortality risks associated with cancer and cardiovascular diseases [15]. It has been reported that, in adults, the quality of physical activity, in terms of frequency and duration, is crucial alongside sedentary behavior and total physical activity time. However, conventional wearable devices have encountered challenges in accurately measuring LPA, including sedentary behavior. In the present study, we enhanced the precision of LPA evaluation by employing a corrected algorithm previously developed by our team [16], enabling more accurate quantification of daily physical activity levels, including sedentary behavior.

The study examined changes in the physical activity of pregnant women during the second and third trimesters, focusing on variations in parity and employment status. Wearable devices were utilized to measure the total amount, frequency, and duration of daily physical activity among pregnant women, aimed at clarifying correlations between changes in physical activity levels and lifestyle factors.

Methods

Ethics statements

The study protocol was approved by the Observational Study Institutional Review Board of Osaka University Hospital (approval no.: 21346). Informed consent was obtained from all subjects in writing and verbally. The study followed the ethical recommendations for human studies, as suggested by the Declaration of Helsinki. All methods were performed in accordance with the relevant guidelines and regulations.

The duration of sedentary behavior duration was considered continuous if episodes of LPA occurred for less than 1 min [13][14][17]. MVPA was considered continuous as long as episodes of non-MVPA activities lasted for less than 2 min [15][18][19].

Physical activity on each day included sedentary behavior, LPA, and MVPA of varying durations. An exponential distribution approximation was used to calculate the mean duration of each type of physical activity per day. The exponential distribution conforms to the period until the subsequent phenomena occur while physical activity duration is characterized by shortest duration being the most common and each duration subsequently appearing less frequently. Therefore, we decided that it was appropriate to use exponential distribution approximation. The expected value for exponential distribution (1/λ) was defined as the mean duration of a specific type of activity. We confirmed that the expected value (1/λ) was not impacted by total wearing time [1][2].

$$P(x) = \begin{cases} \lambda e^{-\lambda x} & (\&x \geq 0) \\ 0 & (\&x < 0) \end{cases} \cdots [1]$$

$$E(X) = \frac{1}{\lambda} \cdots [2]$$

P(x) represents exponential distribution probability density function, x represents duration, λ represents mean number of transitions per time and e represents exponential distribution. E represents the expected value, and X represents the random variable.

Results

Informed Consent was obtained from 332 women during the study period. Of these, 43 women withdrew, and valid physical activity data could not be obtained for 44 women in either the second or the third trimester. Of the 245 women with valid physical activity data, 26 women were excluded due to missing data related to parity and employment status. Consequently, 219 participants were included in the analysis. The mean age was 34.0 years (SD 4.9), and the mean body mass index was 21.1 ± 3.6 kg/m² . Analysis of parity revealed that 140 participants (64.0%) were primiparas and 79 (36.0%) were multiparas. Regarding employment status, 103 participants (47.0%) were engaged in sedentary work, 63 (28.8%) were unemployed, and 53 (24.2%) were engaged in standing work. Among primiparas, 81 (57.9%) were engaged in sedentary work, 31 (22.1%) were unemployed, and 28 (20.0%) engaged in standing work. For multiparas, 22 (27.8%) were engaged in sedentary work, 28 (35.5%) were unemployed, and 29 (36.7%) engaged in standing work (Fig. 1 and Tables 1–3).

Sedentary behavior

Sedentary behavior percentage

Significant three-factor interactions were observed for parity, employment status and pregnancy trimester (p = 0.001). Different combinations of these three factors resulted in differing percentages of sedentary behavior. Specifically, in the second trimester, sedentary behavior was significantly more frequent (p < 0.001) for primiparas engaged in sedentary work (66%; interquartile range [IQR]: 60.9–72.6%) than those engaged in standing work (53.6%; IQR: 41.2–60.3%) and also significantly higher for those who were unemployed (58.7%; IQR: 52.3–67.9%) compared with those engaged in standing work (p = 0.031). Similarly, in multiparas, during the second trimester, sedentary work (58.2%; IQR: 54.8–63.4%) was significantly more prevalent than standing work (44.8%; IQR: 41.1–49.1%) (p = 0.005). Similar trends were observed in the third trimester, with primiparas engaged in sedentary work (65.2%; IQR: 60.7–70.8%) exhibiting significantly higher percentages than those engaged in standing work (59.3%; IQR: 50.8–65.8%) (p = 0.022), and multiparas engaged in sedentary work (56.4%; IQR: 51.3–61.5%) exhibiting significantly higher percentages than those engaged in standing work (47.7%; IQR: 43.4–51.3) (p = 0.031).

Our results also demonstrated parity-related differences in employment status during the third trimester. The percentage of sedentary behavior was significantly higher in primiparas engaged in sedentary work (65.2%; IQR: 60.7–70.8%) than that of multiparas engaged in sedentary work (56.4%; IQR: 51.3–61.5%)

(p= 0.030). For unemployed women, the percentage of sedentary behavior was also significantly higher for primiparas (57.7%; IQR: 54.8–64.6%) than multiparas (50.3%; IQR: 44.9–58.2%) (p= 0.037). For standing work, the percentage of sedentary behavior was also significantly higher for primiparas (59.3%; IQR: 50.8-65.8%) than multiparas (47.7%; IQR: 43.4–51.4%) (p= 0.007).

Results indicated that trimester changes tended to differ depending on employment status and parity. In unemployed multiparas, the percentage decreased significantly from the second (53.2%; IQR: 42.7–60.5%) to the third (50.3%; IQR: 44.9–58.2%) trimester (p = 0.001), demonstrating that sedentary behavior decreased as pregnancy progressed. Meanwhile, this percentage significantly increased from the second trimester (53.6%; IQR: 41.2–60.2%) to the third trimester (59.3%; IQR: 50.8–65.8%) for primiparas engaged in standing work (p < 0.001), demonstrating that the percentage of sedentary behavior increased as pregnancy progressed (Fig. 2).

Sedentary behavior frequency

Three-factor interaction among parity, employment status, and pregnancy trimester was significant (p = 0.039), indicating that the frequency of sedentary behavior varied depending on combinations of these factors. Specifically, for unemployed women in the second trimester, sedentary behavior frequency was significantly lower (p = 0.039) for primiparas (4.4 times/h; IQR: 3.7–5.0 times/h) than for multiparas (4.6 times/h; IQR: 4.0–5.0 times/h).

Sedentary behavior duration

Comparison of sedentary behavior duration depending on pregnancy trimester revealed no significant main effect between the second trimester (6.8 min; IQR: 4.9–9.3 min) and third trimester (6.8 min; IQR: 5.2–9.3 min), indicating that it was not impacted by the progression of pregnancy. When examined in terms of parity, no significant main effect was observed between primiparas (7.8 min; IQR: 5.9–10.2 min) and multiparas (5.4 min; IQR: 4.1–7.0 min), indicating that parity did not impact the duration of sedentary behavior. Conversely, a comparison based on employment status revealed that duration was significantly longer (p < 0.001) for women who were unemployed (6.2 min; IQR: 4.7–8.4 min) and women engaged in sedentary work (8.1 min; IQR: 6.1–10.5 min) than women engaged in standing work (5.7 min; IQR: 4.5–6.8 min), demonstrating that employment status influenced the duration of sedentary behavior. Post-hoc testing revealed significant differences between sedentary work and standing work (p < .001) and between being unemployed and being engaged in standing work (p = 0.024). In terms of interactions, no significant effects were identified.

MVPA

MVPA percentage

Three-factor interaction among parity, employment status and pregnancy trimester was significant (p = 0.031), indicating that the percentage of MVPA varied depending on combinations of these factors. MVPA percentages decreased significantly from the second to the third trimester for primiparas across

all employment statuses. Specifically, for women engaged in sedentary work, the percentage decreased significantly from the second (5.8%; IQR: 4.4–8.1%) to the third (5.1%; IQR: 2.9–7.1%) trimester ($p < 0.001$). For unemployed women, it decreased significantly from 5.1% in the second trimester (IQR: 2.3–8.3%) to 4.0% in the third trimester (IQR: 2.6–6.3%) ($p < 0.001$) and for women engaged in standing work, it decreased significantly from 8.6% in the second (IQR: 5.7–11.0%) to 6.1% in the third (IQR: 4.0–8.5%) trimester ($p < 0.001$).

Multiparas also exhibited decreased MVPA percentages as pregnancy progressed for some employment statuses. For unemployed women, the percentage significantly decreased from the second (5.4%; IQR: 3.5–8.0%) to the third (4.0%; IQR: 2.5–6.0%) trimester ($p < 0.001$). For women engaged in standing work, it also significantly decreased from the second (6.9%; IQR: 5.8–9.3%) to the third (5.5%; IQR: 3.9–7.3%) trimester ($p = 0.020$) (Fig. 3).

To evaluate individual variations in physical activity levels across pregnancy trimesters more comprehensively, we categorized the participants into five groups comprising 20% of participants each ranging from higher percentages of MVPA during the second trimester (q1: highest MVPA percentage group to q5: lowest MVPA percentage group) and compared the rate of change compared to that of the third trimester for each group. The group results were as follows: q1 (second trimester: 12.2%, third trimester: 9.8%, rate of change: -20%), q2 group (second trimester: 8.3%, third trimester: 6.8%, rate of change: -18%), q3 (second trimester: 6.2%, third trimester: 5.0%, rate of change: -19%), q4 (second trimester: 4.6%, third trimester: 4.3%, rate of change: -6%), and q5 group (second trimester: 2.1%, third trimester: 2.9%, rate of change: +36%). Notably, all groups exhibited decreases except q5, with reductions of 18% or more observed in q1, q2 and q3 groups and a particularly pronounced decrease of 20% in the q1 group. These results indicate that women with higher initial activity levels tend to exhibit more substantial declines in activity levels as they transition into the third trimester (Fig. 4 and Table 4).

MVPA frequency

Comparison of MVPA frequency based on pregnancy trimester revealed no significant main effect between second (1.3 times/h; IQR: 1.0–1.7 times/h) and third (1.1 times/h; IQR: 0.9–1.5 times/h) trimesters, indicating that pregnancy progression did not impact MVPA frequency. Regarding parity, no significant main effect was observed between primiparas (1.2 times/h; IQR: 0.8–1.5 times/h) and multiparas (1.3 times/h; IQR: 1.0–1.7 times/h), demonstrating that parity did not influence MVPA frequency. In contrast, comparison by employment type revealed that compared to sedentary work (1.1 times/h; IQR: 0.8–1.5 times/h) and being unemployed (1.2 times/h; IQR: 0.9–1.6 times/h), MVPA frequency was significantly higher ($p = .0001$) for standing work (1.4 times/h; IQR: 1.2–1.9 times/h). Therefore, occupational type impacted MVPA frequency. Post-hoc testing revealed significant differences between sedentary work and standing work ($p = 0.003$) and between standing work and being unemployed ($p = 0.005$). No significant effects were observed for interactions between parity or employment status.

MVPA duration

A comparative analysis of the duration of MVPA across pregnancy trimesters revealed no significant main effect between the second (1.8 min; IQR: 1.0–2.3 min) and third (1.4 min; IQR: 0.8–2.1 min) trimesters, indicating that pregnancy progression did not impact MVPA duration. In terms of parity, no significant main effect was observed between primiparas (1.7 min; IQR: 1.0–2.4 min) and multiparas (1.4 min; IQR: 0.8–1.9 min), demonstrating that parity did not impact MVPA duration. Furthermore, comparison based on employment status did not reveal any significant main effect between sedentary work (1.8 min; IQR: 1.0–2.4 min), being unemployed (1.3 min; IQR: 0.7–1.9 min) and standing work (1.7 min; IQR: 1.2–2.2 min), demonstrating that employment status did not impact MVPA duration. Additionally, no significant interaction effects were identified.

Discussion

To elucidate how variations in pregnancy trimester and lifestyle factors (parity, employment status) influence pregnant women's physical activity (percentages, frequency and duration of sedentary behavior, and MVPA), we conducted objective measurements employing wearable devices on 219 pregnant women.

Our findings revealed that the three factors—pregnancy trimester, parity, and employment status—were intricately involved in sedentary behavior. Percentages of sedentary behavior were particularly high among primiparas and women engaged in sedentary work, with these trends becoming more pronounced in the third trimester. Physical activity levels easily declined in these groups, suggesting increased health risks. MVPA percentages also decreased from the second to the third trimester, with substantial reductions observed particularly among primiparas, irrespective of employment status. For multiparas, MVPA decreased as pregnancy progressed for unemployed women and those engaged in standing work, demonstrating that differences in parity and lifestyle environment influenced changes in physical activity levels.

Our results revealed the highest percentages of sedentary behavior throughout the second and third trimesters for primiparas engaged in sedentary work. It has been reported that anxiety is easily heightened during pregnancy [20][21], and that numerous personal, interpersonal, and environmental challenges make exercise difficult [22]. It has been suggested that physical activity levels tend to decrease during pregnancy compared to pre-pregnancy levels [23]. Interactions amongst these factors may contribute to increased sedentary behavior during pregnancy.

Sedentary work, which involves prolonged periods of sitting, is also associated with longer durations of sedentary behavior in the general adult population, and has been linked to health risks such as obesity, diabetes, hypertension, and increased mortality rates[24][25]. This suggests that pregnant women may also experience heightened health risks associated with extended periods of sedentary behavior. Therefore, pregnant women engaged in sedentary work should make a conscious effort to increase their physical activity levels outside of working hours.

Women engaged in occupations requiring standing exhibited a trend towards lower percentages of sedentary behavior. However, primiparas engaged in standing work had greater percentages of sedentary behavior in the third trimester than in the second. In the third trimester, primiparas exhibited significantly higher percentages of sedentary behavior than multiparas regardless of employment status. This finding may be attributable to multiparas being required to maintain a certain level of physical activity during the third trimester to care for their older child or children. Primiparas, however, experienced decreased physical activity levels in daily life overall as they stopped having to commute to and engage in work in the third trimester, resulting in increased percentages of sedentary behavior. Decreased percentages of sedentary behavior observed in unemployed multiparas during the third trimester may have been because their physical activity increased during the third trimester when their older child developed further and required more hands-on care.

We observed a trend of decreased MVPA percentages from the second to the third trimester in primiparas regardless of employment status. We also noted the same trend of decreased percentages in multiparas who were unemployed and those engaged in jobs requiring standing. There are two main possible reasons for decreased physical activity levels in the third trimester. First, as mentioned above, starting maternity leave meant that women no longer had to engage in physical activity to commute to work. Second, it has been documented that the intensity of physical activity that women can engage in decreases as pregnancy progresses [26][27]. During the third trimester, the increasing size of the fetus imposes a greater physical burden on the mother, making sleep disorders, frequent urination, fatigue and lower back pain more prevalent [28][29]. These physical burdens may contribute to decreased physical activity levels. Furthermore, decreased physical activity levels during the third trimester are associated with increased risk of complications such as pregnancy-induced hypertension, premature birth and gestational diabetes [30][31]. This underscores the critical importance of women continuing to engage in MVPA to the greatest extent possible during the third trimester to safeguard the health of both the mother and fetus.

One possible explanation for MVPA percentages being lower in unemployed women than those engaged in sedentary work is the impact of commuting to work which involves physical activity. The WHO guidelines [2] indicate that walking and cycling are important modes of transport and effective means of increasing daily physical activity levels, suggesting that commuting to work contributed to MVPA. These findings highlight the substantial impact that the type of work engaged in has on MVPA and that physical activity during free time such as involvement in hobbies and exercise may be insufficient. This underscores the importance of deliberately incorporating MVPA into leisure activities.

The frequency of sedentary behavior was lower for primiparas than multiparas for unemployed women during the second trimester. It is possible that seated periods were shorter and more frequent for unemployed multiparas because they spent more time engaged in child-rearing due to not being employed.

Although no significant differences associated with pregnancy trimester or parity were observed for MVPA frequency, we confirmed that MVPA frequency was highest for women engaged in standing work. This may be attributable to physical demands and movement associated with their occupation, potentially contributing to short bursts of MVPA.

The duration of sedentary behavior was considerably longer for women engaged in sedentary work and unemployed women, and tended to be shorter for women engaged in standing work. A previous study targeting adults reported that incorporating 2–3-min intervals of LPA between sedentary periods reduced the duration of sedentary behavior, resulting in decreased waist circumference, obesity, triglyceride levels, and 2-h postprandial glucose and aided in the prevention of hypertension [13]. This suggests that women engaged in sedentary work or who are unemployed should incorporate activity into their daily lifestyles by consciously standing up and engaging in light physical movement. No significant differences were observed for MVPA duration associated with pregnancy trimester, parity or employment status.

Thus, our findings clarified that in pregnant women, sedentary behavior, and MVPA vary substantially as a result of interactions amongst pregnant trimester, parity and employment status. In particular, the highest percentages of sedentary behavior were exhibited by primiparas engaged in sedentary work and MVPA was found to decrease in the third trimester of pregnancy. These lifestyle factors suggest the need to provide individually tailored support and intervention based on pregnancy trimester, parity and employment status rather than recommending a uniform approach for all pregnant women. Preventing a reduction in MPVA during the third trimester is important for mitigating obstetric complications, such as pregnancy-induced hypertension and gestational diabetes. Therefore, future interventional studies should develop strategies that consider these lifestyle factors.

The participants in this study were all pregnant women attending general hospitals in Japan. Although the absence of contraindications for exercise was a requirement for eligibility, the study included a relatively high proportion of high-risk pregnancies, including participants with underlying diseases. However, as similar physical activity times were measured as those reported by the National Health and Nutrition Examination Survey which targeted a wide range of pregnant women[32], we believe that our results can be generalized to apply to pregnant women overall.

In the present study, we used wearable devices to conduct quantitative and longitudinal evaluation of physical activity changes during the second and third trimesters. We found that parity and employment status impacted the quality of physical activity (percentages, duration and frequency) during the second and third trimesters.

We identified three-factor interactions for sedentary behavior and MVPA percentages, indicating that multiple factors were related to physical activity during pregnancy. Specifically, primiparas engaged in sedentary work exhibited the highest levels of sedentary behavior throughout pregnancy and these activity levels declined further during the third trimester. MVPA decreased considerably in the third

trimester for many women, with women who had previously engaged in high levels of physical activity exhibiting greater decreases.

These findings demonstrate that interventions to promote physical activity in pregnant women need to take individual lifestyle factors into account, such as pregnancy trimester, parity, and employment status. Particularly dramatic decreases in physical activity were observed in primiparas engaged in sedentary work and in women in the third trimester. Prioritized support is required for such women as they have increased health risks. Going forward, a physical activity intervention program tailored to pregnancy trimester needs to be developed and its effects verified.

Methods

Study participants

This study recruited pregnant women attending medical institutions (University of Osaka Hospital, Toyonaka Municipal Hospital, and Osaka General Medical Center) between November 2021 and June 2023. The inclusion criteria were being aged 20 years or older at the time of recruitment, having a singleton pregnancy, being earlier than 25 weeks' gestation, with no contraindication for exercise. Consent was obtained from 332 women during the study period. The study protocol was approved by the Observational Study Institutional Review Board of Osaka University Hospital (approval no.: 21346).

Physical activity measurement with a wearable device

The physical activity of participants was measured using a wearable device with a three-axis acceleration sensor (Active Style Pro, Omron, Kyoto, Japan). This device has a measurement range of ± 6 G and resolution of 3 mG. Two measurement periods were established: the second trimester (week 16 through week 27), and the third trimester (week 28 onward), providing an interval of at least 6 weeks after fitting of the device during the second trimester. Each participant was provided with a wearable device and instructed to wear it for a minimum of 8 h per day for 2 weeks excluding periods of sleeping and bathing. Participants wore the device on the waist or using a study-provided bellyband. Before the study, we measured treadmill walking (inclination: 0°, 3 km/h, 4 km/h, inclination: 12°, 3 km/h) and stair climbing with the wearable device attached to the waist or the bellyband. We confirmed that there were no significant differences in activity intensity measured with the device whether attached to the waist or the bellyband. The mean difference was 0.3 METs, indicating that the placement of the device had minimal impact on the study outcomes. METs per 60 s of data were calculated using the "Activity Measurement Application" associated with the wearable device.

Pregnancy trimester and lifestyle factors (parity and physical activity during work)

Gestational weeks 16 through 27 were classified as the second trimester and gestational week 28 onwards as the third trimester. Based on a questionnaire survey investigating lifestyle factors, not having given birth to a child from gestational week 22 onwards was defined as “primipara,” whereas having given birth to at least one child was defined as “multipara”. For employment status, “unemployed” was defined as not working from the second through the third trimester, “sedentary work” was defined as work involving sitting for more than half of the working time, and “standing work” was defined as work involving standing for more than half of the time spent working.

Data analysis

All data were subjected to zero count data processing based on a combination of zero count probability and continuity using the zero count correction algorithm by Nishiyama et al. [16] Processed data were considered valid and used for analysis if they contained at least three days’ worth of measurement data for 8 h or more per day. According to physical activity classifications in a previous study, sedentary behavior was defined as 1.5 METs or below, LPA as 1.6–2.9 METs, MPA as 3.0–5.9 METs and VPA as 6.0 METs or above [4]. Given the very low proportion of VPA (≤ 0.1%), we analyzed data by combining MPA and VPA as MVPA, defined as 3.0 METs or above.

As the total time spent exercising daily was influenced by total device wearing time, we calculated the percentage of each day spent performing exercise at each intensity level by dividing the total time for each physical activity intensity level by total wearing time. Additionally, since the frequency of each activity intensity per day was affected by total device wearing time, we divided the frequency of each activity level by total wearing time and then multiplied this by 60 to calculate the frequency per hour (times/h) (Figs. 5 and 6).

Statistical analysis

This study evaluated changes in physical activity indices across pregnancy trimesters by calculating intra-individual mean values from multi-day for each participant. Given the repeated measurements on the same participants during different pregnancy periods (second and third trimesters), a paired design was employed. Parity (primipara and multipara) and employment status (unemployed, sedentary work, and standing work) were analyzed as unpaired inter-group comparisons. Prior to analysis, normality was assessed using the Shapiro–Wilk test across all groups. As normality was not observed in all groups, nonparametric procedures were subsequently applied. Main effects and interactions were examined using a generalized linear mixed model (GLMM). In this study, due to repeated measurements being performed on the same participants during various stages of pregnancy, personal identifiers (IDs) were treated as random effects and analysis was performed using a GLMM. Appropriate distribution and link variables were specified for each response variable: binomial distribution with a logit link for sedentary behavior and MVPA percentages, Poisson distribution with a log link for frequency, and gamma distribution with a log link for duration.

To clarify inter-group differences for items that exhibited a significant difference in terms of interactions and employment status (three groups), pairwise comparison based on the estimated average was performed and post-hoc testing applying Tukey's correction was conducted. The level of significant difference was set at 5% for all statistical tests. Data analysis was performed using Python 3.1.1 and R version 4.5.1 (R Foundation for Statistical Computing, Vienna, Austria).

Declarations

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Author contributions:

NN, SK, TK, IO, TY, SY, RH, MM, ME, TK and KN designed and conceived this study. NN and KN collected data. NN, SK and KN analyzed and interpreted the results and drafted the manuscript. SK supported statistical analyses. All authors read and approved the final manuscript.

Competing interests:

The author(s) declare no competing interests.

Data availability:

The dataset generated and analyzed during the current study are available from the corresponding author on reasonable request.

Ethics declaration:

The study protocol was approved by the Observational Study Institutional Review Board of Osaka University Hospital (approval no.: 21346).

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Tables

Tables 1 to 4 are available in the Supplementary Files section.

Figures

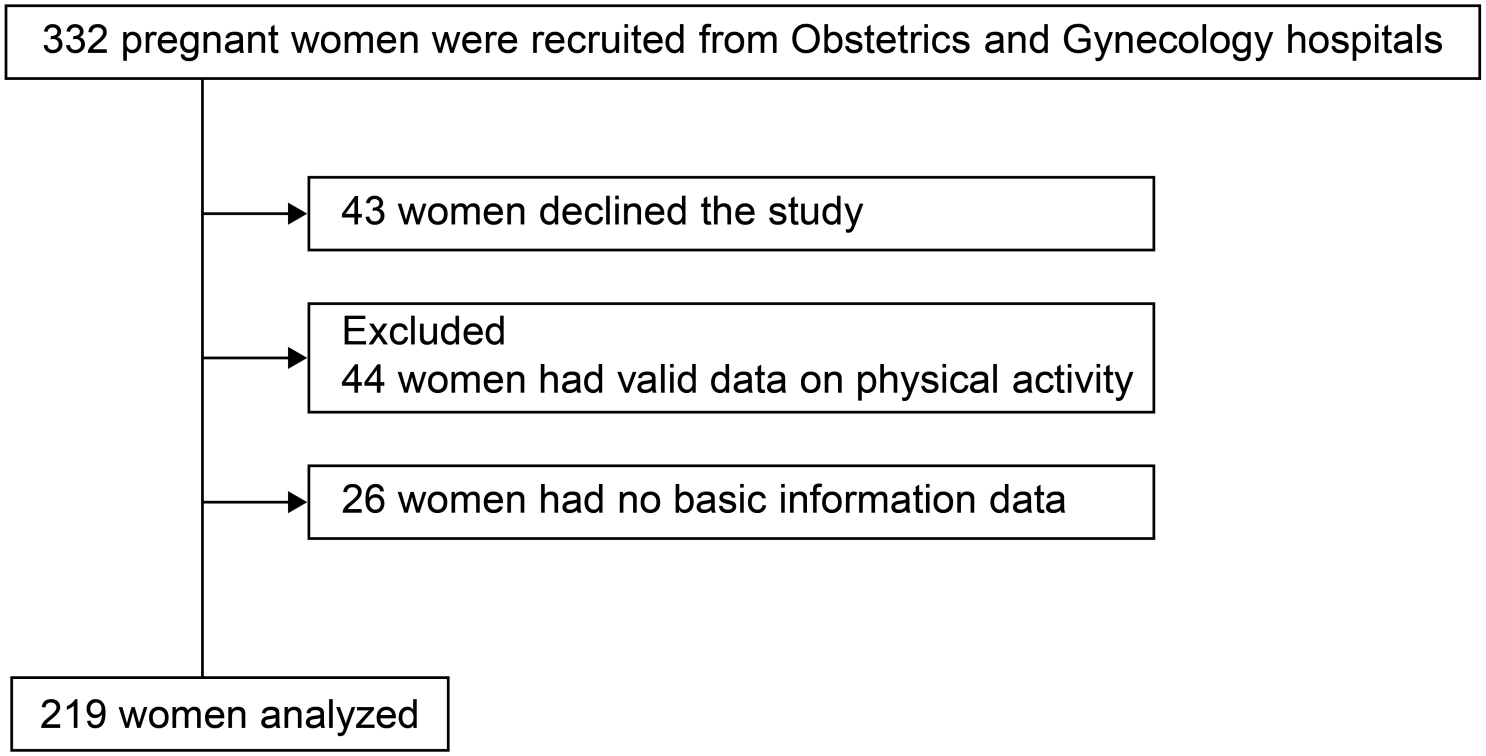


Figure 1

Flowchart showing study participant selection.

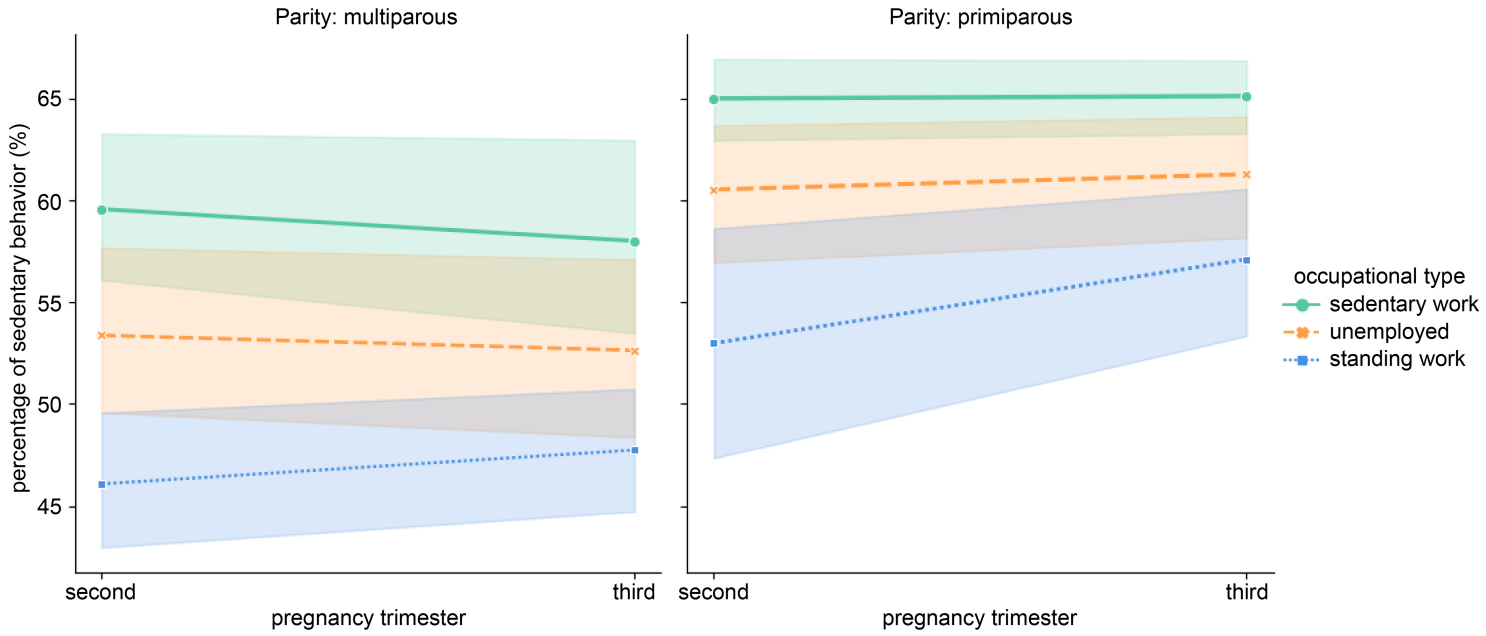


Figure 2

Percentage of sedentary behavior.

Percentage of sedentary behavior (%) as estimated using a GLMM. The figure stratifies the results according to whether participants were primiparous or multiparous. Median values are shown on a line

graph for each occupational type. Line color and shape reflect occupational type while line thickness reflects the magnitude of the percentage of sedentary behavior.

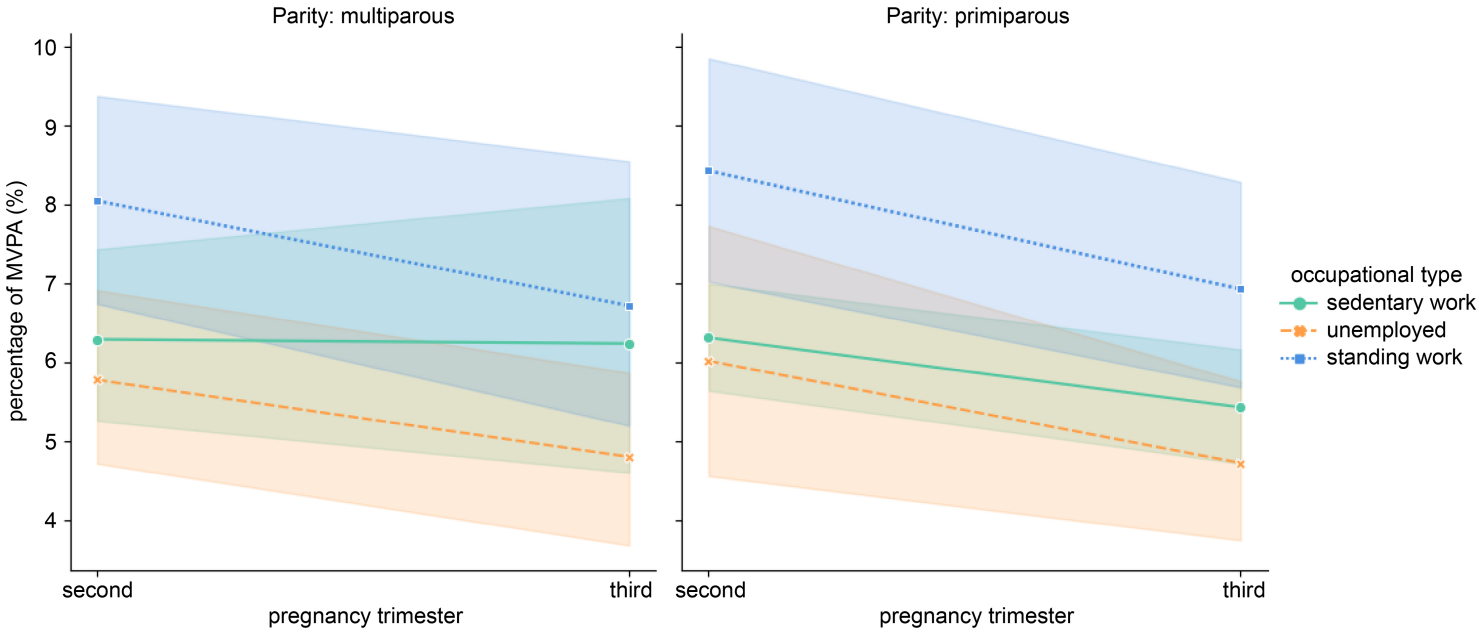


Figure 3

Percentage of MVPA.

Percentage of MVPA (%) as estimated using a GLMM. The figure stratifies results based on whether participants were primiparous or multiparous. Median values are depicted on a line graph for each occupational type, with line color and shape indicating occupational type, while line thickness reflects the magnitude of the percentage of MVPA. MVPA: moderate-to-vigorous physical activity.

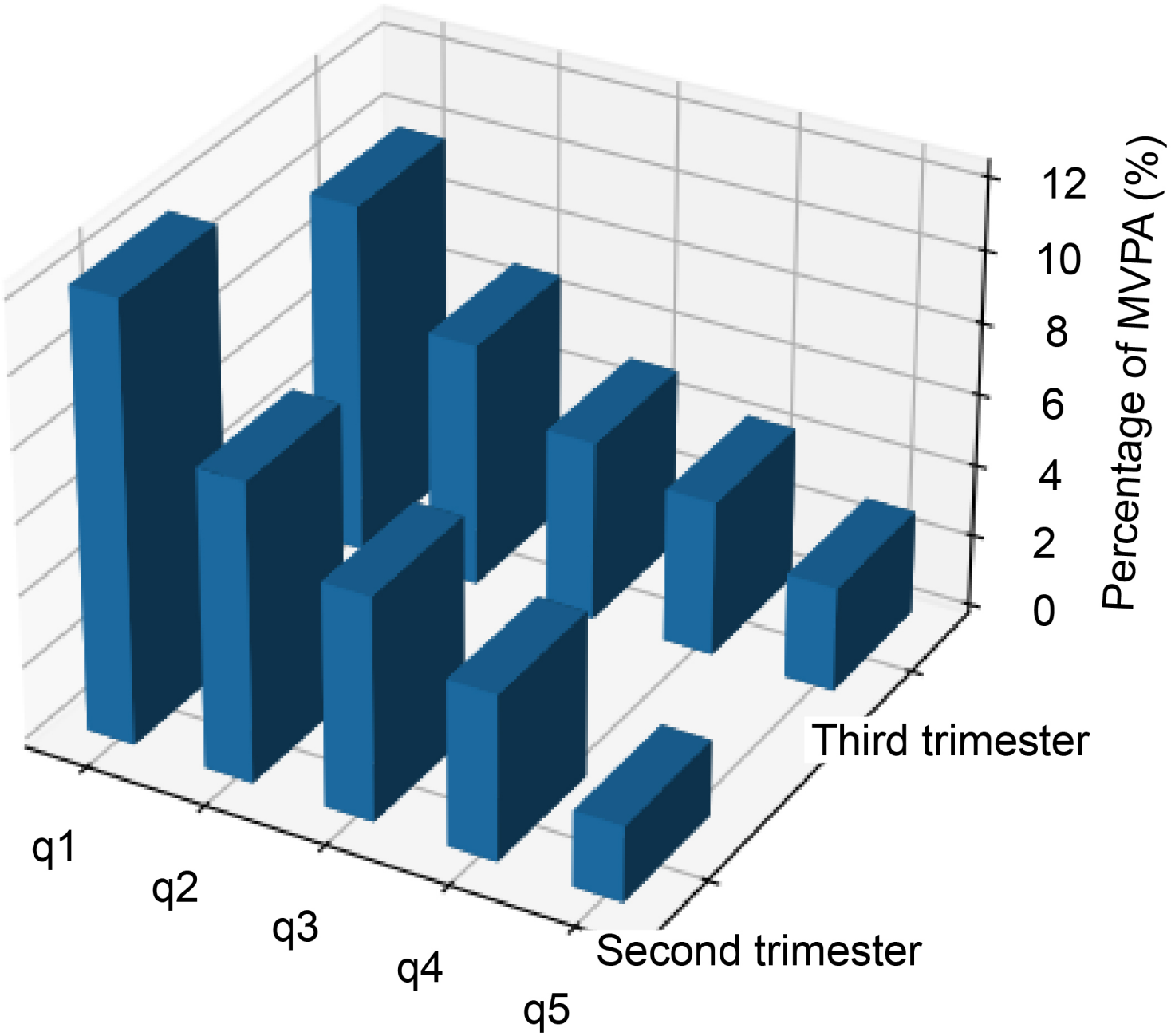


Figure 4

MVPA change rate between the second and third trimesters.

MVPA: moderate-to-vigorous physical activity.

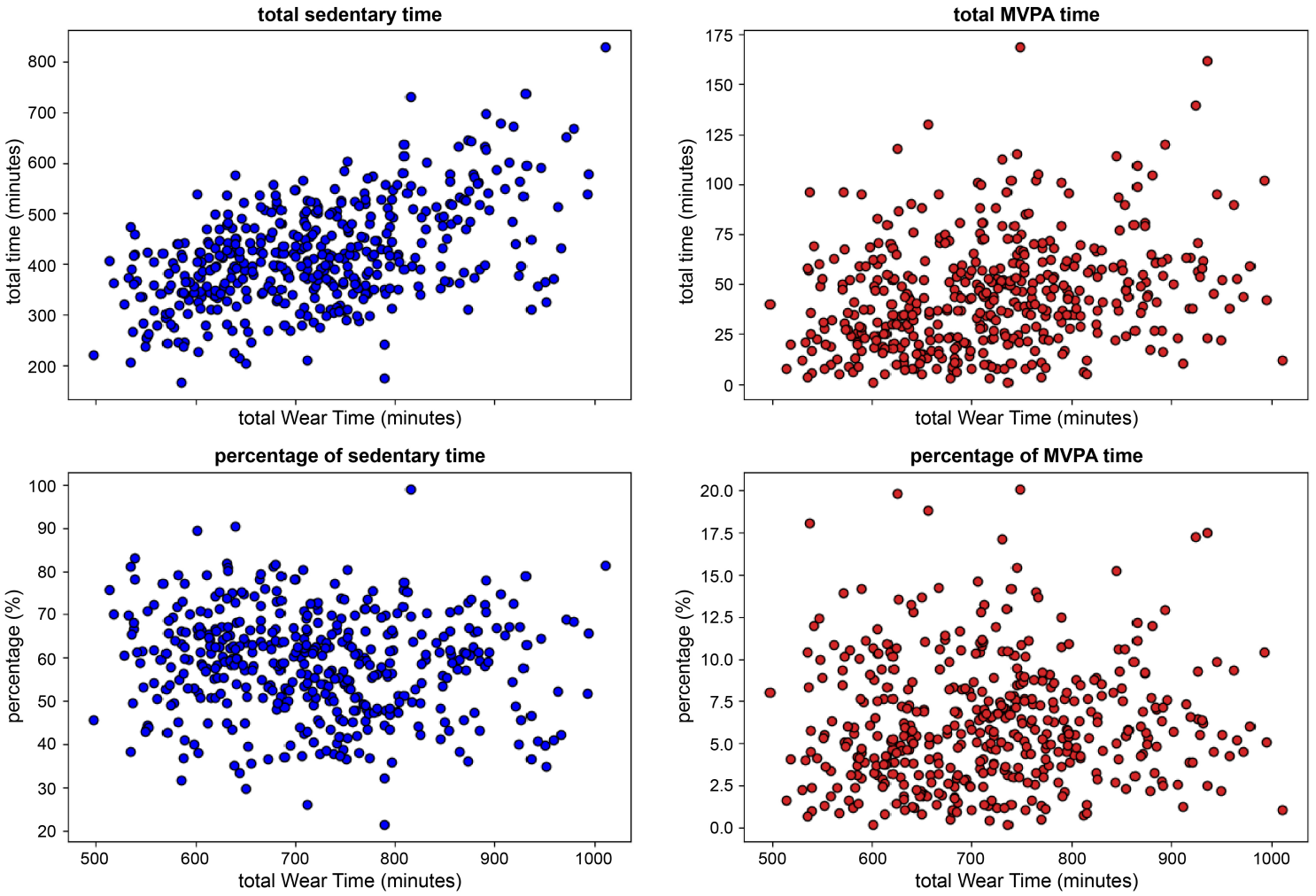


Figure 5

Relationship Between Total Wear Time and Activity Time by Intensity (Sedentary Behavior and MVPA)

Scatter plots illustrating the relationship between total wear time as recorded by wearable devices and the time spent on activities of varying intensities throughout the day: sedentary behavior and MVPA. The top row depicts scatter plots with total wear time on the x-axis and the absolute time spent on each activity on the y-axis, illustrating the total duration of each activity. The bottom row presents scatter plots with total wear time on the x-axis and the proportion of time spent on each activity (activity time divided by total wear time) on the y-axis, indicating the relative distribution of activity intensities throughout the day. The plots are arranged from left to right in order of increasing levels of intensity from sedentary behavior to MVPA. MVPA: moderate-to-vigorous physical activity.

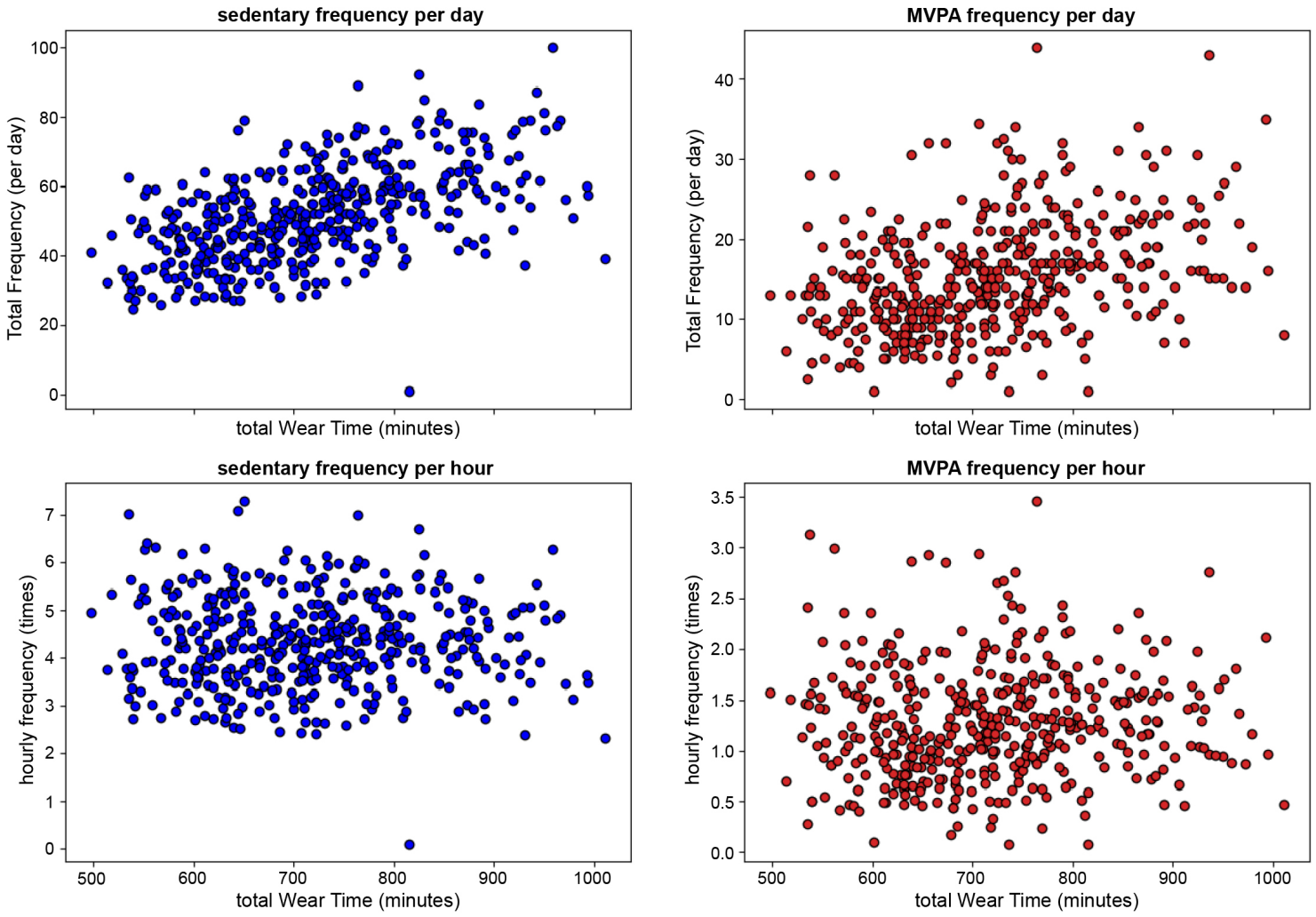


Figure 6

Relationship Between Total Wear Time and Activity Frequency by Intensity (Sedentary Behavior and MVPA)

Scatter plots illustrating the relationship between total wear time recorded by wearable devices and the frequency of daily activities, including sedentary behavior and MVPA. The top row shows scatter plots with total wear time on the x-axis and the total daily frequency (number of occurrences) of each activity on the y-axis, visualizing the absolute number of activity events. The bottom row displays scatter plots with total wear time on the x-axis and the hourly frequency (number of occurrences per hour) on the y-axis, representing a standardized measure of activity frequency per unit time. The plots are arranged from left to right in the order of sedentary behavior and MVPA, reflecting increasing levels of activity intensity. MVPA: moderate-to-vigorous physical activity.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Tables.docx