Final Technical Report

for

Research Project

The Knowledge and Tool Development for Depressive Symptoms Screening in Thai Elderly from Passive Sensing Data of Smartphones or Smartwatches

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Final Report

The Knowledge and Tool Development for Depressive Symptoms Screening in Thai Elderly from Passive Sensing Data of Smartphones or Smartwatches

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Executive Summary

Geriatric depression often goes unnoticed due to recall bias and overlapping symptoms with normal aging when using questionnaire screening tools. Consequently, this study aims to explore the associations between passive sensing parameters, such as physical activity and sleep characteristics from smart devices, and depression screening scores to validate their efficacy as detection tools for the Thai elderly. Moreover, the acceptability of wearable devices as a mental health monitoring tool in Thai elderly will be evaluated.

The prospective cohort study was conducted from July to September 2023. One hundred and seventy-seven elderly individuals were purposefully selected from the main district of each province across five regions in Thailand. Participants were required to wear an Actigraph wGT3X-BT on the non-dominant wrist for one month, collecting information on physical activity and sleep characteristics. Demographic information was surveyed at the beginning, and the depression questionnaire (PHQ-9) was screened every two weeks. Univariate and multivariate linear regression were applied to identify associations between passive sensing parameters and PHQ-9, adjusting for baseline scores and demographics in two-week period. Moreover, the Technology Acceptance Questionnaire was applied at the end of the study, with fourteen participants selected for the focus group discussion. Thematic analysis was used to classify into themes such as ease of use, equipment characteristics, privacy concerns, and intentions to use in the future.

The results found an association between physical activity parameters and depression scores. A one-unit increase of VM CPM showed a statistically significant reduction of 0.00037 in PHQ-9 scores during the second half period (95% CI =

0.00022; P-value = 0.094). Additionally, a one-unit increase in daily step count resulted in a statistically notable reduction of PHQ-9 scores, ranging from 0.00007 (95% CI = 0.00004; P-value = 0.084) to 0.00008 (95% CI = 0.00003; P-value = 0.068) in both periods. Regarding sleep parameters, a one-unit increase in WASO significantly reduced PHQ-9 scores by 0.021 (95% CI = 0.012; P-value = 0.080) in the first half period while other sensing parameters were not shown association. Additionally, participants living in Bangkok, being older, living alone or being divorced or widowed, smoking or using substances, having mental illness, and being dependent in daily living tended to have higher depression scores. For the technology acceptance, the device was acceptable by participants and would gain further approved with multipurpose functionality including screening results, waterproofing, and recommendations from health experts.

There is potential to apply passive sensing data from wearable devices, especially using physical activity and sleep parameters, for depression screening in the elderly. However, there are limitations in sample selection, wear-time validity, and study duration. The potential of passive sensing data, especially through smart devices in addressing mental health issues in Thailand is recognized, emphasizing the need for interoperability of data systems and data standardization. The future direction involves enhancing smartwatch technologies for mental health monitoring by integrating data with other sources, such as facial and voice recognition, and questionnaires. This integration aims to aid in the early detection and better management of mental well-being.

Introduction

The global demographic landscape is shifting towards an aging society, characterized by a population where individuals aged 60 years or older account for more than 10% of the overall population (1). Specifically, in Thailand, the demographic of individuals classified as elderly, aged 60 years and above, has reached a staggering 13 million in 2023, constituting approximately 19.8% of the nation's total population of 66.1 million (2). Consequently, Thailand has entered the category of a "complete aging society." While aging individuals often experience a decline in physical function, mental health tends to receive less attention in comparison to physical illnesses (3). Depressive disorders accounted for the largest proportion of DALYs in mental disorder accounting for 37.3% of all mental illnesses in 2019 [95% Confidence Interval; 95%CI = 32.3 – 43.0] (4). Notably, in Thailand, approximately one-third of the elderly population is susceptible to mental health issues, with depression ranking among the top five prevalent mental illnesses within this group (5).

In Thailand, geriatric depression is often overlooked and undetected as a result of some complexities and lack of access in screening by using questionnaires. Depressive symptoms in older adults can also be attributed to normal aging or physical illnesses, leading to misinterpretation by both patients and clinicians (6). For instance, the overlapping depressive symptoms and normal aging includes loss of appetite, insomnia, and psychomotor retardation (7). Cognitive impairment can hinder the accurate diagnosis of depression because it's often challenging to differentiate whether cognitive symptoms such as apathy and difficulty concentrating are attributable to dementia or a major depressive episode (6).

Accordingly, screening questionnaires may yield poorer accuracy due to cognitive impairment and recall bias in the elderly (8). The national prevalence of Depressive Disorder among Thai elderly, as reported by the Department of Mental Health, Ministry of Public Health, was 4.1% in 2008 (9). Various studies in Thailand have shown a prevalence of depression ranging from 6.5% to 36.9%, depending on settings and screening tools (10, 11). Despite the latest surveillance activity in 2022 covering 68% of Thai elderly, only 0.4% were found to be at risk for depression using the 2Q screening questionnaire (Thai version of the Patient Health Questionnaire-2; PHQ-2) (12, 13). Additionally, the existing number of depressed older patients was 3.5% in 2019 (14). Consequently, there exists a gap in the screening of depression among the elderly through traditional methods.

Due to the challenges of screening in the elderly, passive sensing with smartphones and wearables is a rapidly growing area in healthcare, capable of capturing multiple dimensions of human behavior encompassing physical, mental, and social aspects of well-being (15). Passive sensing data collection also has the potential to be a more accurate and less burdensome approach to detection when compared with traditional screening tools (16). A survey by the National Statistical Office showed that Thai older adults have a decent degree of familiarity with technology since around 68.3% of them reported to be smartphone users in 2021 and 74.5% in 2022 (as of 10 million of mobile phone users) (17). Also, Thai elderly aged 60-70 years and nearly-elderly aged 50-59 years old also have moderate and high digital literacy, respectively in 2021 (18). It is speculated that the number of elderlies with digital access and literacy will continue to rise in the future. Hence, it is possible that passive sensing data from smartphones and smartwatches can

potentially fill the above-mentioned gap in the elderly population through its automatic data collection properties and their initial accessibility.

There are numerous studies exploring the potential benefits of using passive sensing data in mental health. Two systematic reviews propose the plausibility that features on smart devices, such as smartphones and wearables, could play an important role as proxies for mental health (19, 20). In another systematic review of literature concerning the use of passive sensing data in smartphones or smartwatches for screening depression in the elderly between 2012 and 2022, we found 16 studies conducted in Western countries, accounting for 21 studies in total (21). The most prevalent passive sensing data were sleep and physical activity parameters, measured using wearable devices (21). Regarding sleep characteristics, Wakefulness after sleep onset (WASO) was found to be related to depressive symptoms with a potential exacerbating effect over time when the duration of WASO exceeded one hour (22-24). The physical activity has a negative relationship with depressive symptoms; for example, studies by O'Brien et al. (2017) showed that the physical activity in a form of movement data like acceleration magnitude was considerably lower ($t = 3.63$, $p = 0.001$) with depression when compared to the control group (25). On the other hands, other sleep characteristics such as sleep efficiency, sleep latency, and long wake episodes yielded mixed results in terms of statistical significance as same as step count and level of physical activity. Thus, passive sensing data for both sleep, and physical activity parameters especially WASO and activity count from wearable devices can be a potential proxy for depression detection.

Nevertheless, there is still a lack of literature on the use of passive sensing data for depressive symptoms screening in elderly in low-income contexts

especially in Thailand (21). This highlights the need for research to identify associations between passive sensing parameters, like physical activity and sleep characteristics, and depression screening scores to validate its efficacy as a detection tool among Thai elderly. Furthermore, exploring technology acceptance aims to ensure the acceptability of wearable devices as mental health monitoring tools for this demographic. It is anticipated that employing digital health technology will enhance comprehensive depression screening, ensuring early detection and access to care alongside the existing surveillance system.

Objectives

- To explore the association between passive sensing parameters, such as physical activity and sleep characteristics, and depression screening scores in Thai elderly.
- To evaluate the acceptability of wearable devices as a mental health monitoring tool for Thai elderly.

Methodology

The prospective cohort study was conducted from July to September 2023 to collect data from Thai elderly individuals across all regions within a month. Ethical approval had been granted by The Institute for the Development of Human Research Protections (HSRI 809/2565), and participants were informed and gave written consent before the research team commenced the project.

Data collection

The survey and wearable devices were used as data collection methods every two weeks for objective 1. For objective 2, a survey and focus group discussion were applied at the end of the study.

In objective 1, a sample size of 183 participants was calculated using a correlation formula designed for an infinite population for the survey, see detailed calculations in the Annex II. Participants were purposively selected from provinces in each region with limited access to depression treatment among the elderly (14) including Bangkok (Capital), Saraburi (Central), Loei (North-Eastern), Phuket (Southern), and Lampang (Northern), elderly clubs in city districts of each province were purposively chosen. Forty elderly individuals from each club were recruited using quota sampling. The inclusion criteria required participants to be aged 60 years or older, socially active, and free from diagnoses of cognitive impairment and mental health disorders, except for depression.

For the focus group interview in objective 2, we purposively selected fifteen elderly participants from the cohort study based on a mix of criteria including age, gender, socioeconomic status, and comorbidity. Each group comprised four to five participants from three provinces (Phuket, Lampang, Bangkok).

Data measurement

Participants were required to wear an Actigraph wGT3X-BT, a wrist-worn device designed to collect movement data in three axes, enabling the identification of physical activity and sleep characteristics (26). This device had to be worn on the non-dominant wrist for a duration of one month, with the recommendation to wear it at all times, except for removal during water-related activities such as

bathing or washing. The raw data of 3-axis accelerations were sampled at a frequency of 30 Hz, referring to recorded data at every 1/30 of a second (27).

At the beginning, demographic information was collected, encompassing age, gender, education, occupation, marital status, and income. Additionally, other factors associated with depression, such as family members, alcohol and tobacco use, drug use, comorbidities, and medical history, level of dependence (Instrumental Activities of daily living; IADL), were recorded, see details of questionnaire in Annex III-VI. The depression screening process occurred every two weeks (week 2 and 4), employing the PHQ-9 questionnaire, consisting of nine questions related to depressive symptoms scored from 0 to 27 (28). Participants with mild depression scores or those expressing suicidal thoughts were referred for further treatment.

At the end of the data collection, a technology acceptance survey and an interview guide in the focus group, adapted from Puri et al. (2017), were administered to gauge participants' perceptions toward this device (29). This assessment covered several aspects: ease of use, equipment characteristics, privacy concerns, facilitating and barrier conditions, subjective norms, and intentions to use. The survey utilized a Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree) for the survey, and open-ended questions were developed in the focus group discussion to gain further insight.

Data analysis

Exploring the demographics of the loss follow-up group aims to identify potential selection bias. The valid wearing time was defined as wearing the device for more than four days within a week and for more than 10 hours per day (29).

Non-wear time was identified and subsequently excluded from the analysis using Choi (2011) (30). The raw data was analyzed into activity counts every 60 seconds (60 epochs), which were then utilized to generate variables.

Physical activity and sleep parameters were categorized as independently continuous variables. Physical activity level was calculated to variables such as Vector Magnitude Count per Minute (VM CPM: a summary of three-axis activity count in square root in a minute) (31), daily step counts, and total time in each physical activity level (sedentary, light, moderate, vigorous) (28). Meanwhile, sleep/wake period was identified by Cole-Kripke (1992) and Tudor-Locke (2014) (32, 33). classified into parameters such as Total Sleep Time (TST), Wakefulness After Sleep Onset (WASO: total minutes of wakefulness after sleep onset), Sleep Efficiency (SE: the percentage of sleep minutes relative to the total number of minutes the subject was in bed), and Sleep Fragmentation Index (SFI: the percentage reflecting restlessness during the sleep period) (34). All independent variables were calculated in mean of each two-week period.

The PHQ-9 score was continuous variable defined as a dependent variable. Summary in this score were analyzed every two weeks (survey round 2; week 2 and survey round 3; week4) compared to baseline PHQ score at the beginning (survey round 1). Confounding variables included age, gender, education, occupation, marital status, income, household members, alcohol, tobacco and drug use, comorbidities, medical history, and IADL which were analyzed as categorical variables.

The study period was divided into two halves, the first and second half of a two-week period. The demography of participant was descriptively analyzed in minimum, median, interquartile range (IQR), and maximum values among

continuous variables and was classified as category. The inferential analysis involved applying linear regression to identify associations between physical activity, sleep characteristics, and PHQ-9 scores in both periods, adjusting for confounding variables, including baseline PHQ-9. Only variables that showed statistical significance in the univariate analysis and identify association in previous literature were included in the multivariate analysis.

The technology acceptance questionnaire was subject to descriptive analysis, including measures of minimum, median, interquartile range (IQR), and maximum values. For the focus group interview, deductive thematic analysis was applied in addition to explain perspectives from the survey.

Results

I. Demographic characteristics of participants

A total of 177 Thai elderly participants were included in the study, as depicted in Figure 1. The demographics of included and loss follow-up participants were shown in Annex VII and did not display significant differences. The highest proportion of participants was in the Northern region, while the lowest proportion was in the North-Eastern and Central regions, accounting for 23.2% and 18.1%, respectively. The majority of participants were women (84.7%), with a median age of 68.9 years old (min = 60.1; IQR = 8.8; max = 85.9), see Figure 2. Most had a primary education level (41.2%) and were either unemployed or retired (65.5%), as illustrated in Figures 3 and 4. The median income was 8,500 Baht (approximately 243 USD) per month (min = 0; IQR = 21,900; max = 300,000). More than half were married (54.8%), followed by those who were divorced or widowed (37.9%), detailed in Figure 5. Concerning household composition, participants usually lived with mixed generations, such as children and grandchildren (54.8%), as depicted in Figure 6. Less than ten percent of participants was dependent elderly defined by less than full score of IADL (8.5%).

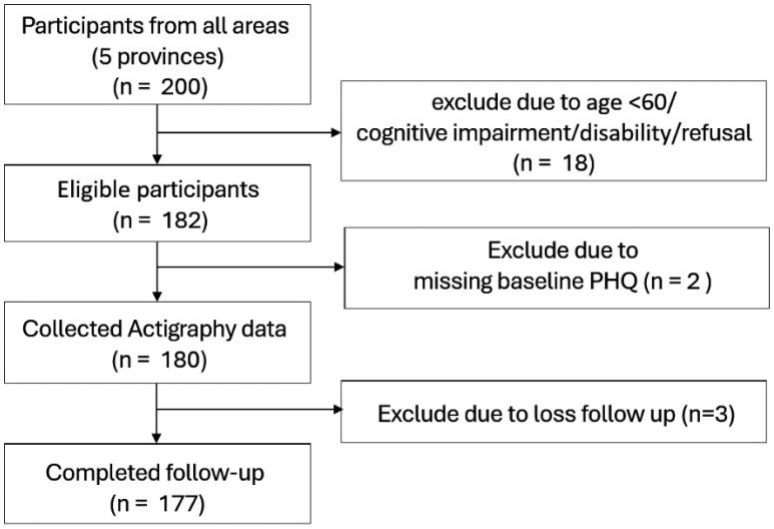


Figure 1 Flow chart of participant recruitment

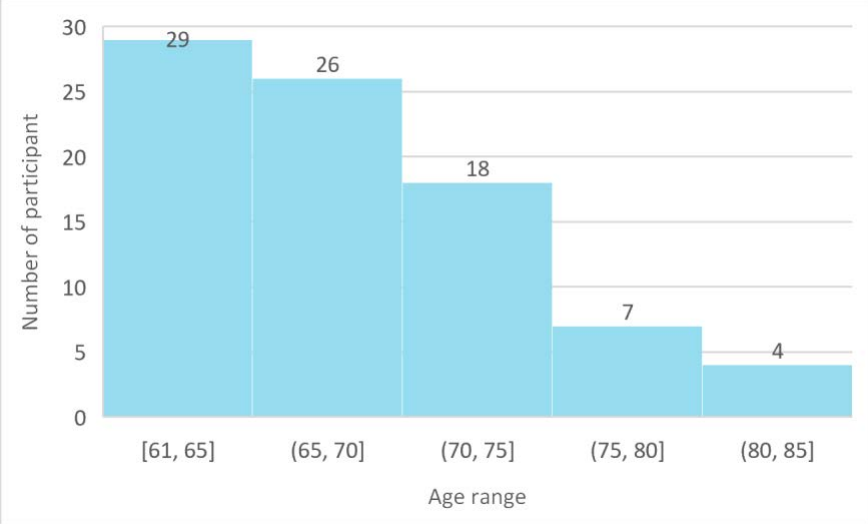


Figure 2 Histogram of participants classified by age

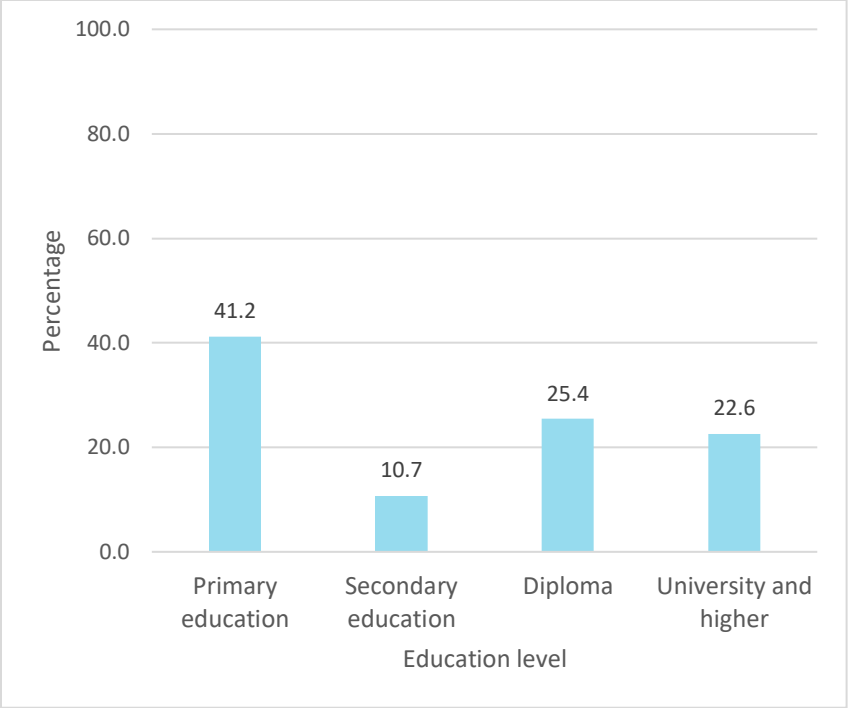


Figure 3 Percentage of participants classified by education level

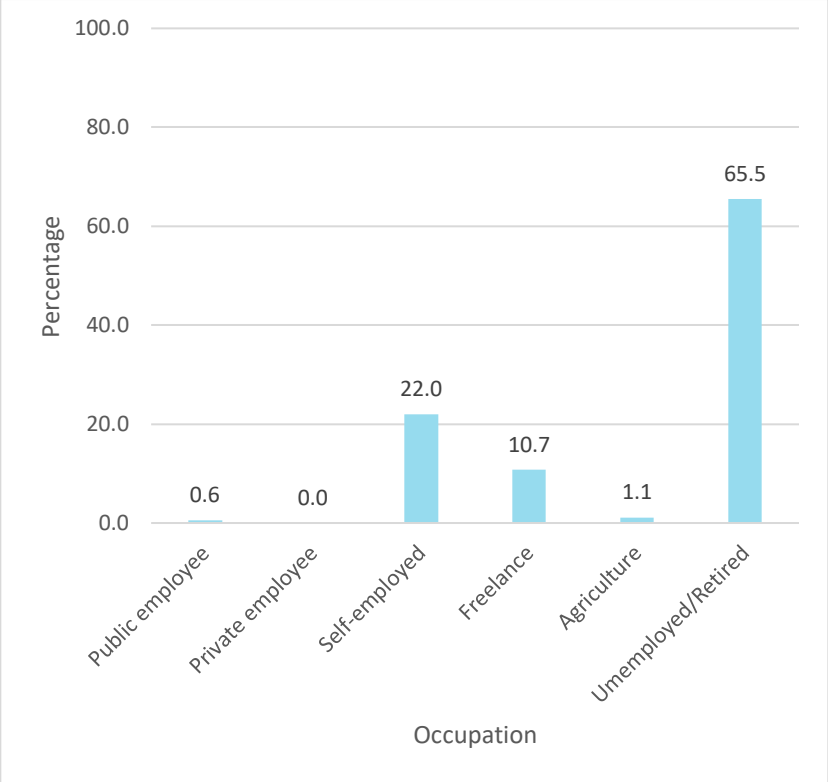


Figure 4 Percentage of participants classified by occupation

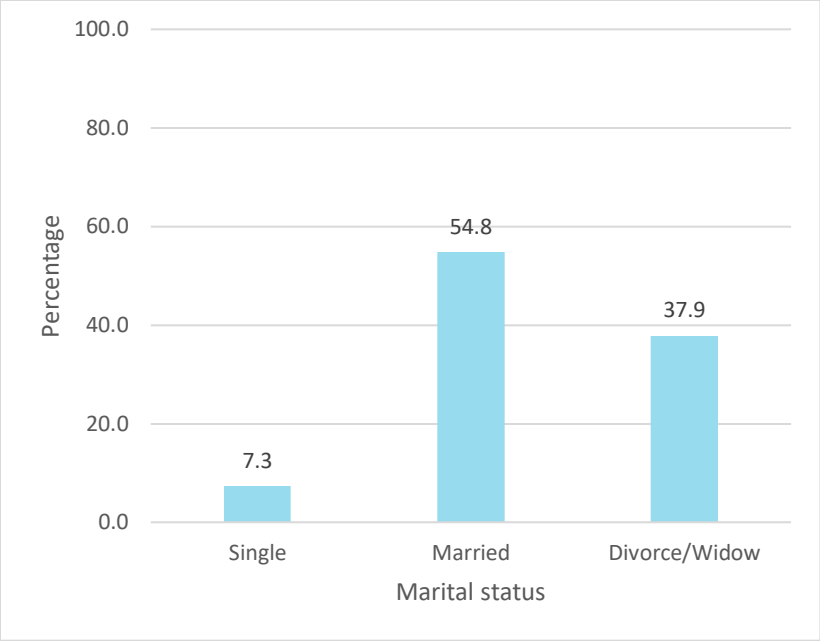


Figure 5 Percentage of participants classified by marital status

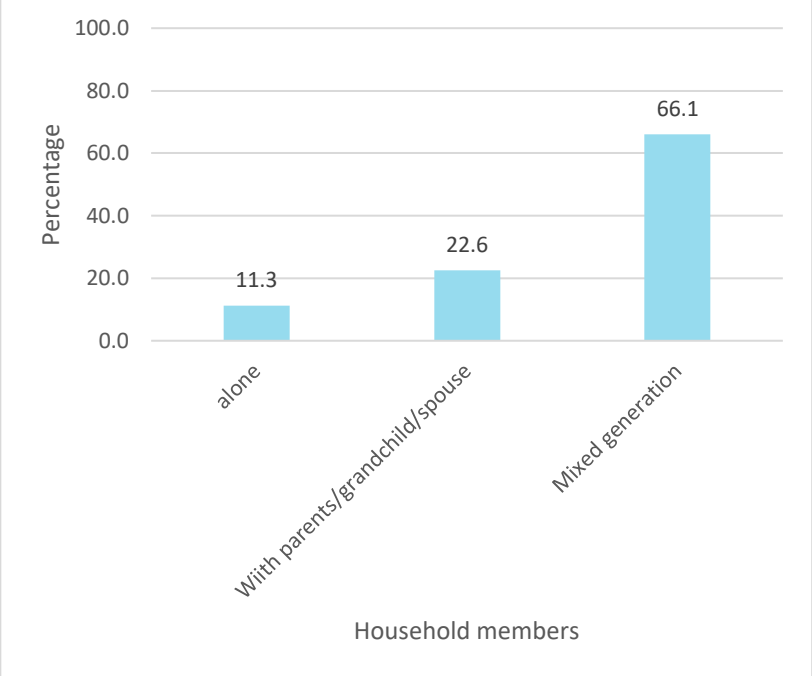


Figure 6 Percentage of participants classified by household members

Regarding risk behavior, a large proportion of participants reported not smoking (98.3%), abstaining from alcohol consumption (88.7%), and refraining from drug use (94.9%) in the past 12 months. Notably, a significant number of participants had cardiovascular diseases (CVD) such as hypertension,

hyperlipidemia, diabetes, and heart disease (60.5%), but only 8.5% of them took regular medications affecting sleep and movement, as shown in Figure 7. Moreover, most participants did not report any mental illnesses (94.4%), as illustrated in Figure 8.

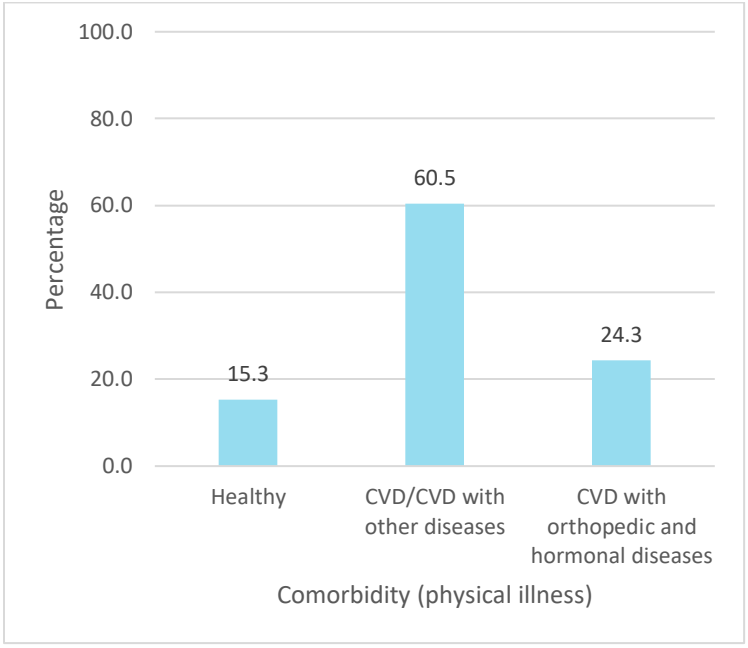


Figure 7 Percentage of participants classified by type of comorbidity (physical illness)

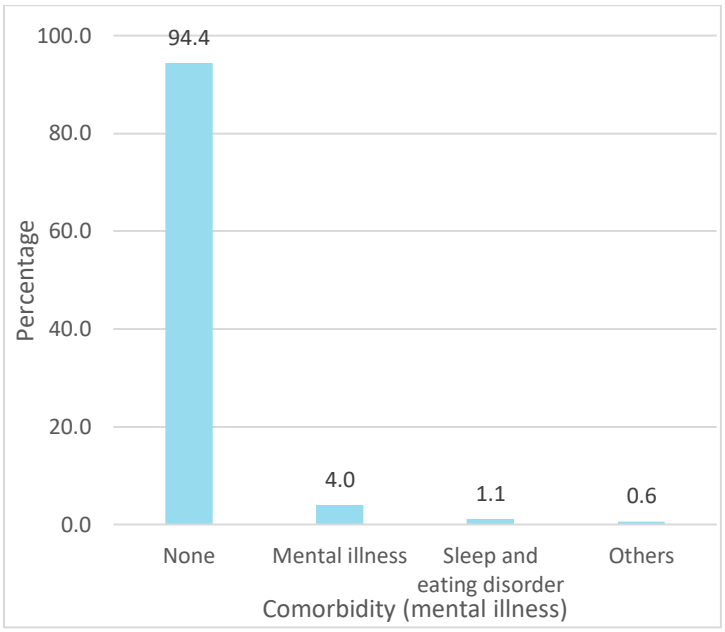


Figure 8 Percentage of participants classified by type of comorbidity (mental illness)

II. PHQ-9 score of participants during the study period

The median PHQ-9 score at the beginning was one (min = 0; IQR = 3; max = 14), remaining consistent at week 2 (min = 0; IQR = 2; max = 16) and week 4 (min = 0; IQR = 2; max = 14), as depicted in Figure 8. When considering the change in PHQ-9 scores (rounds 2 and 3) compared to the baseline (round 1), it was observed that in the first two weeks, 35.6% of participants showed a increasing trend in PHQ-9 scores, followed by a neutral trend (32.8%) and an decreasing trend (31.6%), as shown in Figure 9. In the second half of the study, the percentage of participants with a neutral trend increased to 40.1%, followed by those with a decreasing trend (35.0%) and an increasing trend (24.9%).

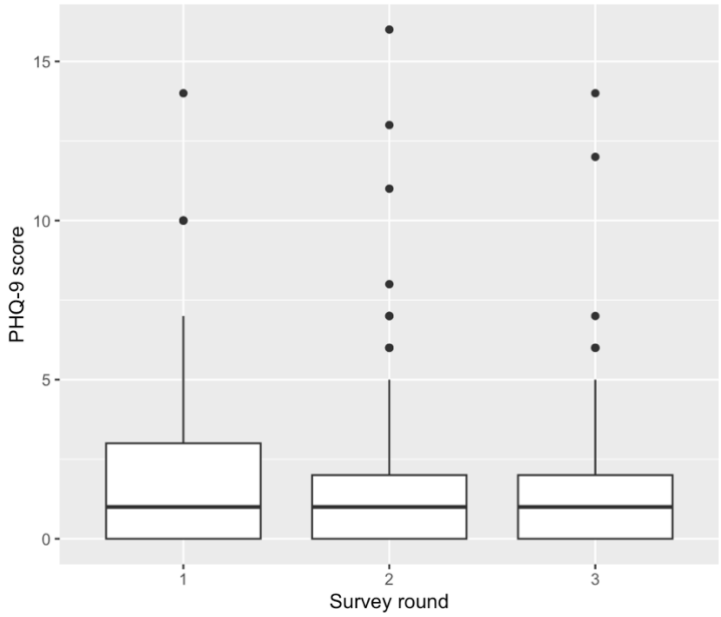


Figure 9 Summary of PHQ-9 score at survey round 1 (week 0; baseline), round 2 (week 2) and round 3 (week 4)

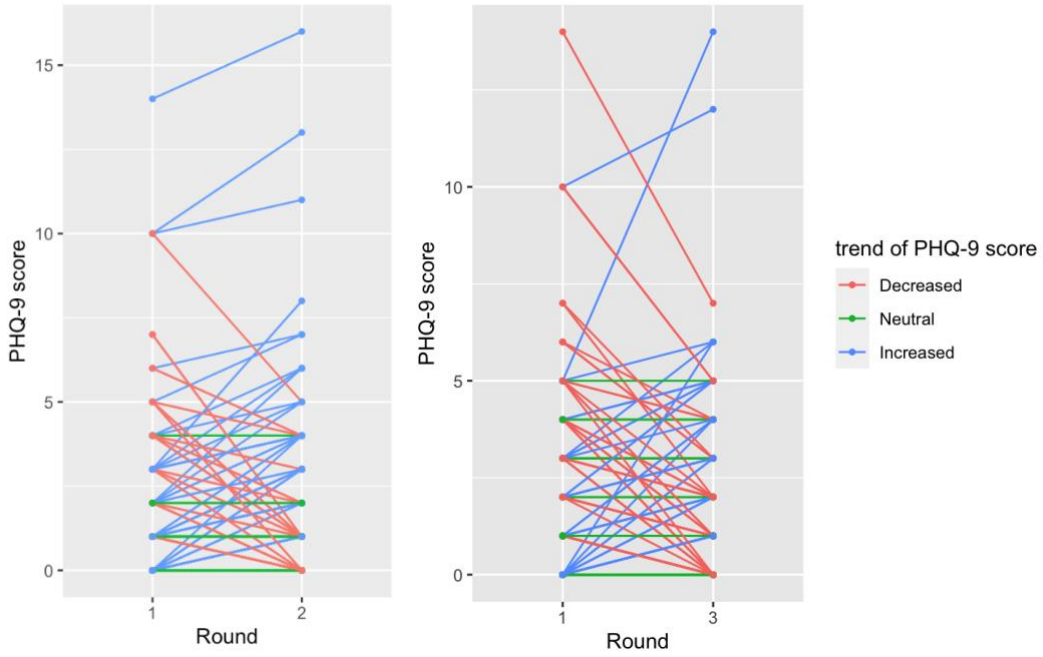
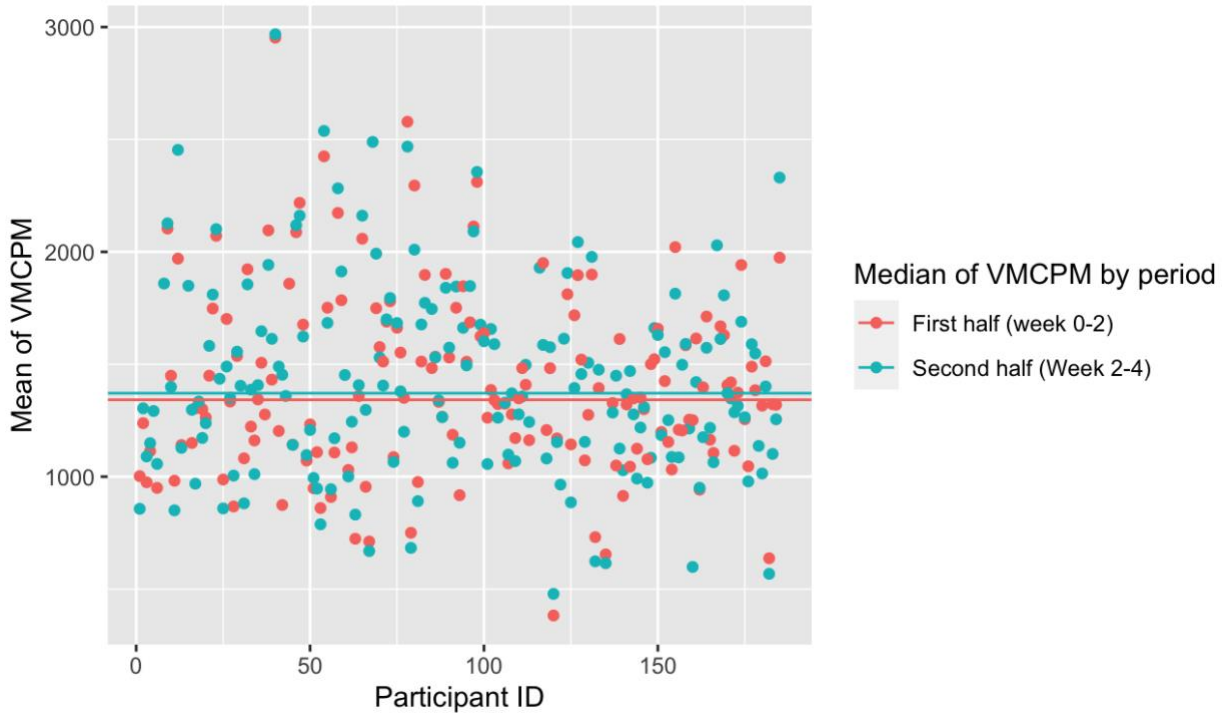


Figure 10 The individual trend of PHQ-9 score change in survey round 2 (week 2) and round 3 (week 4) compared to round 1 (week 0; baseline)

III. Physical activity and sleep parameters of participants during the study period

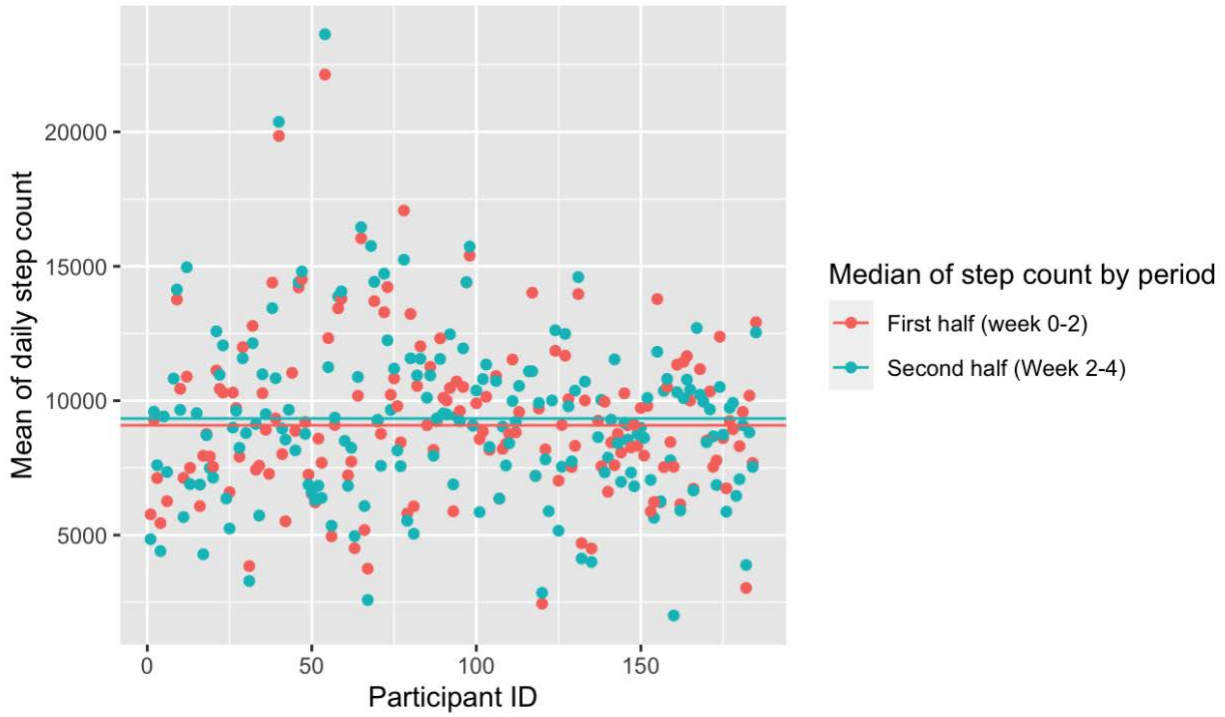
The median of average vector magnitude (count per minute) during week 0 to 2 was 1,342 (min = 383; IQR = 502; max = 2,953), see Figure 10. During week 2 to 4, the median of an average vector magnitude (count per minute) marginally increased accounting for 1,371 (min = 479; IQR = 525; max = 2,968). The median of average step counts during week 0 to 2 was 9,083 (min = 1,952; IQR = 4,321; max = 22,729). During week 2 to 4, the median of average step counts slightly increased accounting for 9,336 (min = 126; IQR = 4,490; max = 24,307), see Figure 11. Finally, the median of minute in moderate intensity level during week 0 to 2 was 110 (min = 15; IQR = 92.5; max = 518). During week 2 to 4, the median of average step counts

slightly increased accounting for 114 (min = 1; IQR = 87.5; max = 440), see Figure 12.



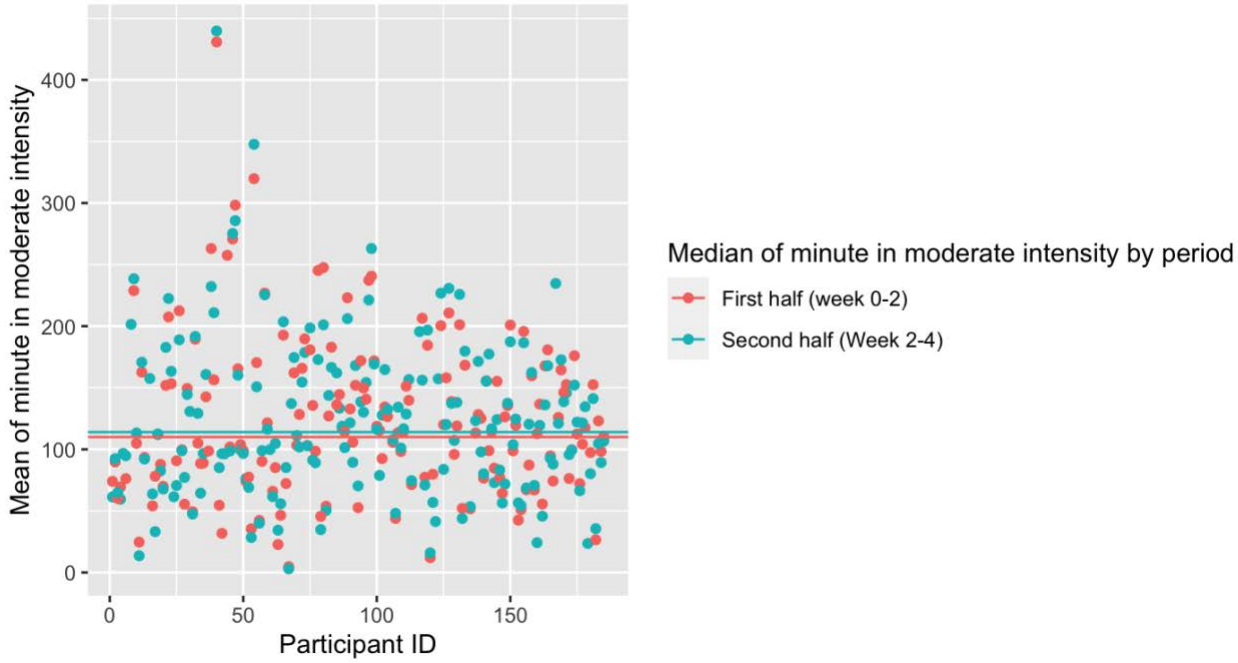
Note: outlier was excluded from Figure in first half period (ID116 = 17; ID 122 = 24) and second half period (ID 44 = 6,853)

Figure 11 Mean of individual vector magnitude (count per minute) during week 0-2 (n=164) and 2-4 (n=175) and median of each period



Note: outlier was excluded from Figure in first half period (ID116 = 407; ID 122 = 565) and second half period (ID 44 = 43,292)

Figure 12 Mean of individual daily step count during week 0-2 (n=164) and 2-4 (n=175) and median of each period



Note: outlier was excluded from Figure in first half period (ID116 = 0; ID 122 = 0) and second half period (ID 44 = 667)

Figure 13 Mean of individual minute in moderate intensity level during week 0-2 (n=164) and 2-4 (n=175) and median of each period

The median average minutes of wake after sleep onset (WASO) during weeks 0 to 2 was 27.1 (min = 2.1; IQR = 14.4; max = 72.9). Between weeks 2 to 4, the median of average WASO minutes reduced to 24.9 (min = 5.3; IQR = 13.0; max = 70.3), as depicted in Figure 13. The median of average sleep efficiency during weeks 0 to 2 was 91.6 (min = 77.9; IQR = 4.6; max = 98.7), experiencing a minimal decrease to 91.5 (min = 78.6; IQR = 14.9; max = 98.0) from weeks 2 to 4, as illustrated in Figure 14. Moreover, the median of the average sleep fragmentation index from weeks 0 to 2 was 23.8 (min = 4.9; IQR = 9.9; max = 47.7), which declined to 23.5 (min = 6.1; IQR = 11.2; max = 91.2) in the subsequent period, shown in Figure 15.

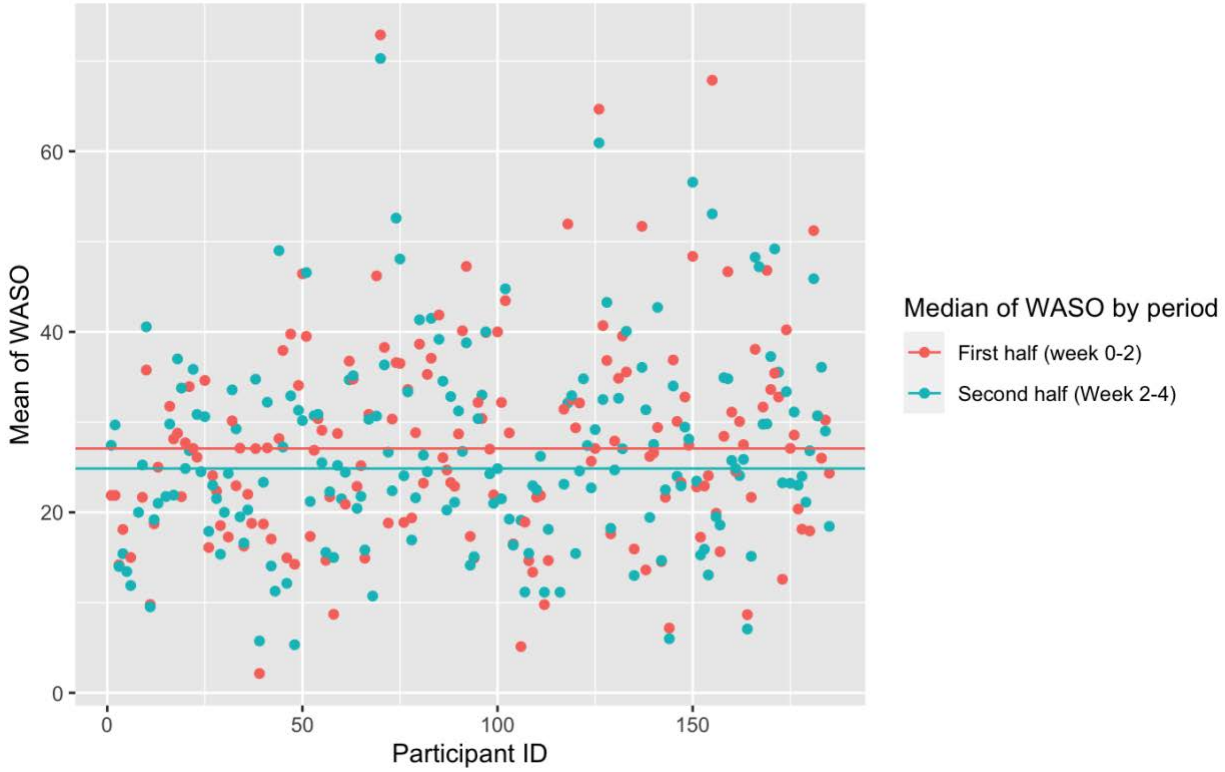


Figure 14 Mean of individual WASO during week 0-2 and 2-4 during week 0-2 (n=164) and 2-4 (n=176) and median of each period

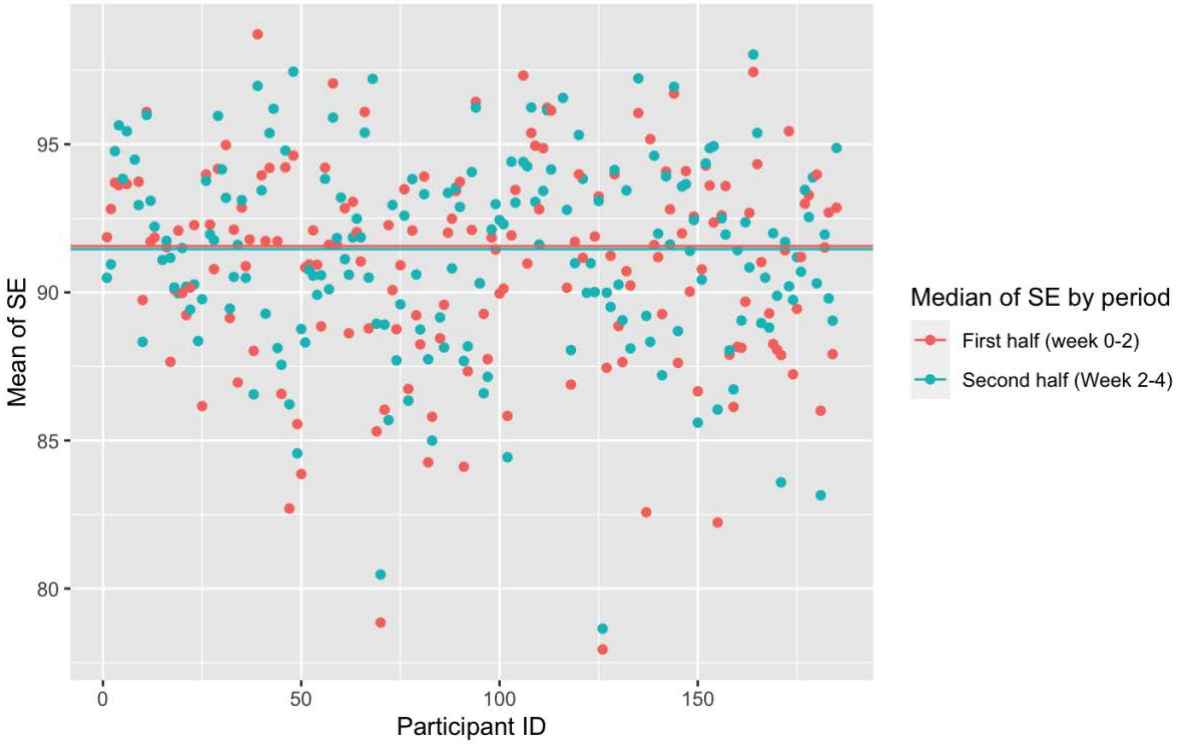


Figure 15 Mean of individual SE during week 0-2 and 2-4
during week 0-2 (n=164) and 2-4 (n=176) and median of each period

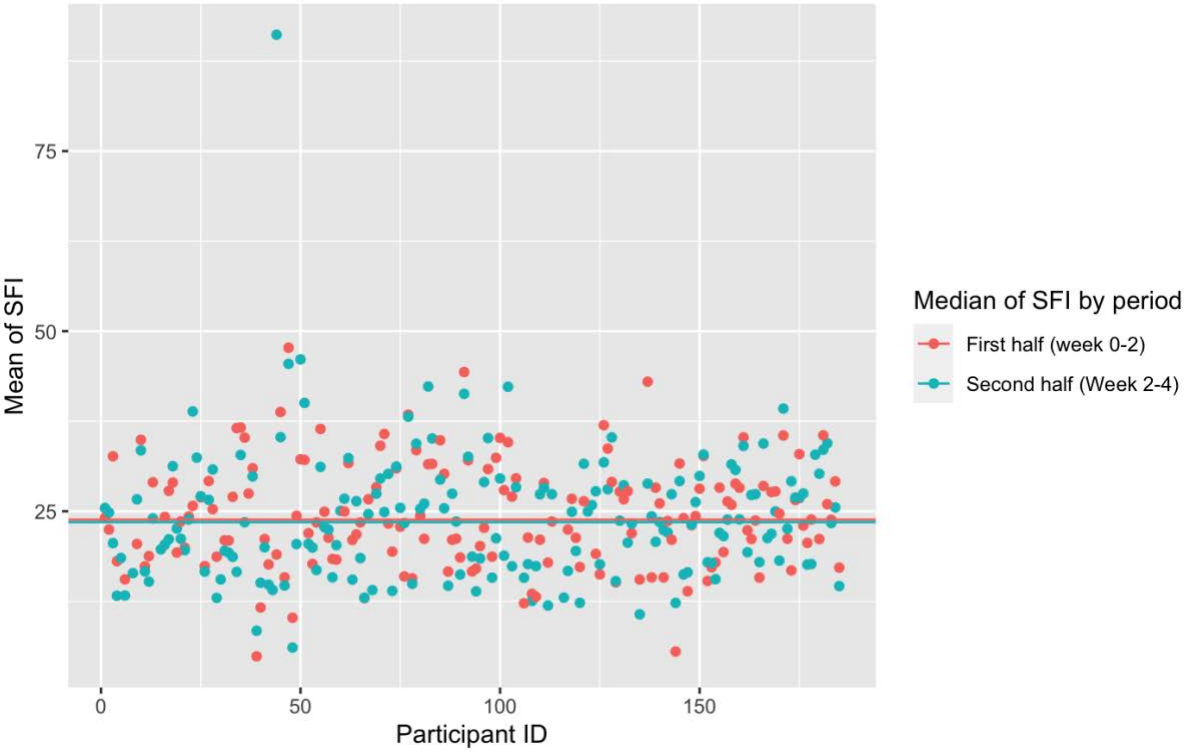


Figure 16 Mean of individual SFI
during week 0-2 (n=164) and 2-4 (n=176) and median of each period

IV. Association between physical activity/sleep parameters and PHQ-9 score

The significant variables associated with PHQ-9 scores in univariate analysis from two rounds were included in multivariate analysis, see Annex VIII. In the multivariate analysis, a one-unit increase of VM CPM showed a statistically significant reduction of 0.00037 in PHQ-9 scores during the second half period (95% CI = 0.00022; P-value = 0.094), as shown in Table 1. Additionally, a one-unit increase in daily step count resulted in a statistically notable reduction of PHQ-9 scores, ranging from 0.00007 (95% CI = 0.00004; P-value = 0.084) to 0.00008 (95% CI = 0.00003; P-value = 0.068) in both periods, see Table 2. Regarding sleep parameters, a one-unit increase in WASO significantly reduced PHQ-9 scores by 0.021 (95% CI = 0.012; P-value = 0.080) in the first half period, see Table 3, while SE did not show an association with PHQ-9 scores, see Table 4.

The analysis across all tables highlighted significant correlations between other confounders and PHQ-9 scores. Participants living outside Bangkok were more likely to have lower PHQ-9 scores, ranging from 0.867 to 0.949 compared to those living in Bangkok (95% CI = 0.351-0.353; P-value = 0.008-0.015) in the first half period. Moreover, for each one-year increase in age, PHQ-9 scores tended to increase by 0.041 to 0.046 in the first half round (95% CI = 0.021-0.022; P-value = 0.032-0.068). Furthermore, individuals who lived alone or had been divorced or widowed tended to have higher PHQ-9 scores by 0.433 to 0.496 (95% CI = 0.258-0.262; P-value = 0.060-0.096) in the first round. Those who smoked or used substances were also more likely to have higher PHQ-9 scores, scoring around 1.704 to 1.850 (95% CI = 0.984-0.988; P-value = 0.062-0.081) compared to non-smokers in the first half period and around 1.045 to 1.303 (95% CI = 0.581-0.591;

P-value = 0.028-0.079) compared to non-substance users in both rounds. Moreover, the elderly with mental illness had higher PHQ-9 scores, ranging from 0.949 to 1.121 (95% CI = 0.587-0.589; P-value = 0.058-0.110) compared to those without a diagnosed mental illness in the first round. Lastly, participants who were dependent in daily living tended to have higher PHQ-9 scores, ranging from 0.761 to 0.846 (95% CI = 0.457-0.464; P-value = 0.063-0.099) in the second half period.

Table 1 Multivariate analysis of between VM CPM and PHQ-9 score (Round 2 and 3) adjusted with confounders

Independent/confounding variables	PHQ-9 score (Round 2)			PHQ-9 score (Round 3)		
	Correlation coefficient	95% confident interval	P-value	Correlation coefficient	95% confident interval	P-value
VM CPM	-0.00050	0.00030	0.104	-0.00037	0.00022	0.094*
Baseline PHQ-9	0.631	0.060	<0.001**	0.549	0.057	<0.001**
Province (BKK vs non BKK)	-0.924	0.351	0.009**	-0.303	0.347	0.384
Age	0.046	0.021	0.033**	0.019	0.021	0.372
Education (primary & secondary vs diploma & university)	-0.002	0.275	0.994	-0.035	0.266	0.896
Marital status (married vs single/divorce/widow)	0.433	0.258	0.096*	-0.251	0.252	0.321
Current smoking (no vs yes)	1.730	0.986	0.081*	-0.310	0.995	0.755
Current substance used (no vs yes)	1.267	0.582	0.031**	1.081	0.585	0.067*
Mental illnesses (no vs yes)	1.121	0.588	0.058*	0.595	0.533	0.265
IADL (independent vs dependent)	0.190	0.468	0.685	0.761	0.459	0.099*

Note: *confidence interval at 90%; **confidence interval at 95%

Table 2 Multivariate analysis of between daily step count and PHQ-9 score (Round 2 and 3) adjusted with confounders

Independent/confounding variables	PHQ-9 score (Round 2)			PHQ-9 score (Round 3)		
	Correlation coefficient	95% confident interval	P-value	Correlation coefficient	95% confident interval	P-value
Daily step count	-0.00007	0.00004	0.084*	-0.00006	0.00003	0.068*
Baseline PHQ-9	0.629	0.060	<0.001**	0.547	0.057	<0.001**
Province (vs BKK vs non BKK)	-0.949	0.352	0.008**	-0.329	0.349	0.347
Age	0.046	0.021	0.032**	0.018	0.021	0.403
Education (primary & secondary vs diploma & university)	0.020	0.272	0.941	-0.021	0.265	0.935
Marital status (married vs single/divorce/widow)	0.436	0.258	0.092*	-0.256	0.252	0.311
Current smoking (no vs yes)	1.704	0.986	0.086*	-0.360	0.995	0.718
Current substance used (no vs yes)	1.273	0.581	0.030**	1.098	0.585	0.062*
Mental illnesses (no vs yes)	1.117	0.587	0.059*	0.583	0.532	0.274
IADL (independent vs dependent)	0.245	0.465	0.600	0.778	0.457	0.091*

Note: *confidence interval at 90%; **confidence interval at 95%

Table 3 Multivariate analysis of between WASO and PHQ-9 score (Round 2 and 3) adjusted with confounders

Independent/confounding variables	PHQ-9 score (Round 2)			PHQ-9 score (Round 3)		
	Correlation coefficient	95% confident interval	P-value	Correlation coefficient	95% confident interval	P-value
WASO	-0.021	0.012	0.080*	-0.001	0.012	0.953
Baseline PHQ-9	0.640	0.060	<0.001**	0.554	0.058	<0.001**
Province (vs BKK vs non BKK)	-0.867	0.351	0.015**	-0.177	0.342	0.606
Age	0.041	0.022	0.068*	0.026	0.022	0.244
Education (primary & secondary vs diploma & university)	0.054	0.273	0.843	0.027	0.266	0.918
Marital status (married vs single/divorce/widow)	0.476	0.261	0.070*	-0.273	0.254	0.284
Current smoking (no vs yes)	1.850	0.984	0.062*	-0.091	0.997	0.927
Current substance used (no vs yes)	1.280	0.584	0.030**	1.057	0.590	0.075*
Mental illnesses (no vs yes)	0.974	0.587	0.099*	0.571	0.539	0.291
IADL (independent vs dependent)	0.214	0.468	0.648	0.846	0.464	0.070*

Note: *confidence interval at 90%; **confidence interval at 95%

Table 4 Multivariate analysis of between WASO and PHQ-9 score (Round 2 and 3) adjusted with confounders

Independent/confounding variables	PHQ-9 score (Round 2)			PHQ-9 score (Round 3)		
	Correlation coefficient	95% confident interval	P-value	Correlation coefficient	95% confident interval	P-value
SE	0.057	0.038	0.133	-0.017	0.040	0.672
Baseline PHQ-9	0.637	0.060	<0.001**	0.552	0.058	<0.001**
Province (vs BKK vs non BKK)	-0.904	0.353	0.011**	-0.165	0.343	0.631
Age	0.045	0.022	0.043**	0.029	0.021	0.178
Education (primary & secondary vs diploma & university)	0.060	0.274	0.827	0.026	0.266	0.922
Marital status (married vs single/divorce/widow)	0.496	0.262	0.060*	-0.273	0.254	0.283
Current smoking (no vs yes)	1.795	0.988	0.071*	-0.062	0.995	0.951
Current substance used (no vs yes)	1.303	0.587	0.028**	1.045	0.591	0.079*
Mental illnesses (no vs yes)	0.949	0.589	0.110	0.601	0.541	0.268
IADL (independent vs dependent)	0.224	0.469	0.633	0.864	0.461	0.063*

Note: *confidence interval at 90%; **confidence interval at 95%

V. The Technology Acceptance

From the Technology Acceptance Questionnaire, the main themes included perceived ease of use, perceived usefulness, equipment characteristics, privacy concerns, facilitating conditions, subjective norms, and intention to use ranged from strongly disagree (1) to strongly agree (5). Participants totally agreed that the device was easy to use (median = 5; min = 1; IQR = 0; max = 5), see Figure 16. They mostly perceived the device as useful, with the majority agreeing that monitoring activity for 24 hours could be a good thing (median = 5; min = 1; IQR = 1; max = 5). However, they believed that using the device was less likely to help them improve overall health (median = 1; min = 1; IQR = 2; max = 5).

Regarding equipment characteristics, participants felt that they were able to perform their daily tasks as usual while wearing the device (median = 5; min = 3;

IQR = 0; max = 5), and they were also willing to wear the tool at night (median = 5; min = 1; IQR = 0; max = 5). They also agreed that the battery life met their needs (median = 5; min = 1; IQR = 1; max = 5).

Privacy concerns were generally low, with most participants not expressing concern when using the device (median = 1; min = 1; IQR = 0; max = 4). They did not feel the need for assistance from others when using this tool (median = 1; min = 1; IQR = 0; max = 5) and did not feel embarrassed to wear the device (median = 1; min = 1; IQR = 0; max = 5). Lastly, they were willing to continue using the tool in the future (median = 4; min = 1; IQR = 2; max = 5).

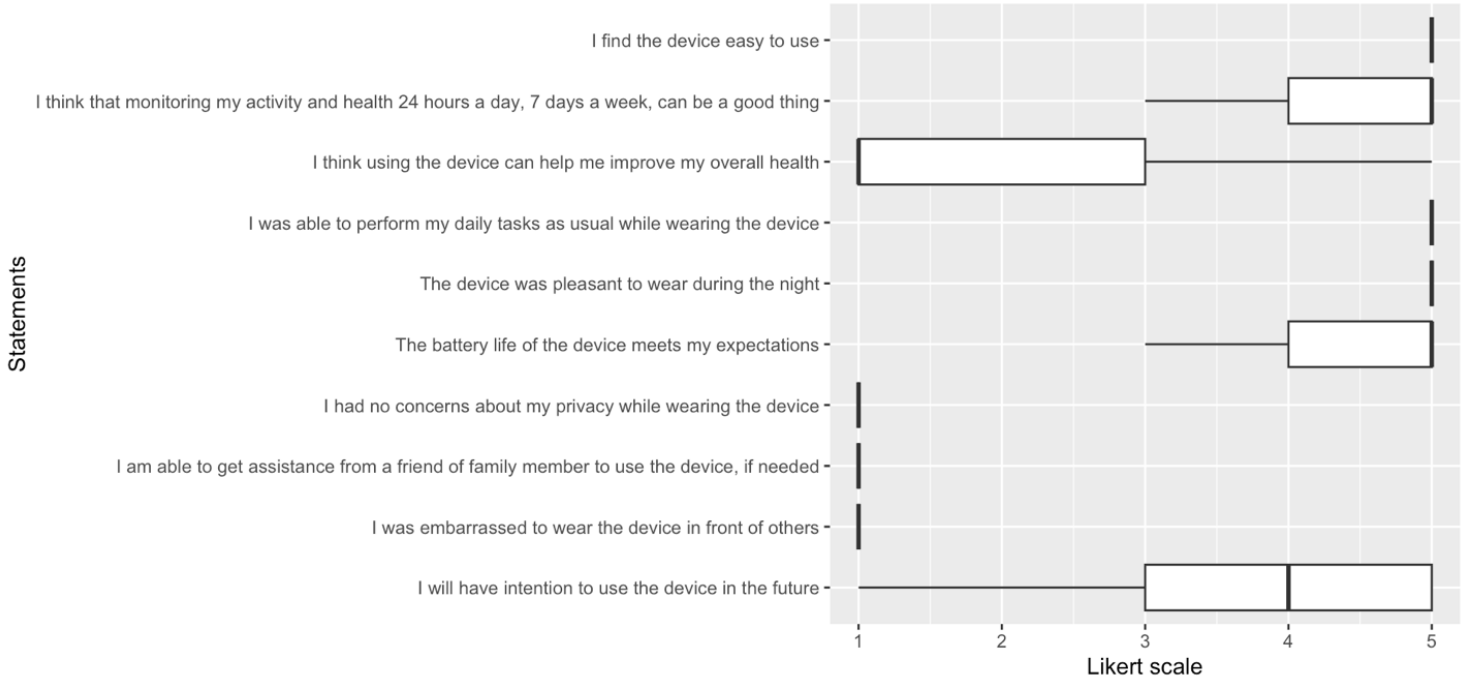


Figure 17 Summary of technology acceptance score

The focus group interviews were conducted to gain deeper insights into each dimension of technology acceptance. The characteristics of the 14 participants, encompassing a mix of gender, age, occupation, and comorbidity, are presented in Table 5. The results encompassed the themes, outlined as follow:

Table 5 The characteristics of participants in focus group

No.	ID	Province	Gender	Age	Occupation	Comorbidity
1	35	Bangkok	Male	76	Self-employed	Yes
2	36	Bangkok	Male	73	Unemployed	Yes
3	48	Bangkok	Female	62	Unemployed	No
4	58	Bangkok	Female	64	Freelance	No
5	61	Bangkok	Female	82	Unemployed	Yes
6	106	Phuket	Male	86	Unemployed	Yes
7	108	Phuket	Female	75	Unemployed	Yes
8	116	Phuket	Female	71	Unemployed	Yes
9	138	Phuket	Female	66	Self-employed	No
10	149	Lampang	Female	64	Freelance	Yes
11	159	Lampang	Male	65	Unemployed	Yes
12	169	Lampang	Female	65	Public employee	Yes
13	170	Lampang	Female	64	Self-employed	Yes
14	176	Lampang	Female	69	Unemployed	No

Theme 1: Understanding of why the device was given

The degree to which participants perceived the experience of receiving the device was examined. Most participants did not fully understand the objective of this study, and some were not aware or unsure about the reasons for receiving the device. They thought this device was used for measuring general health indicators such as blood pressure and heart rate. However, some recognized its role in tracking physical activity, exercise, and sleep. Additionally, only a few of them remembered that this device could assist in screening for depression.

"I do not know the information. I do not know how the devices record data …I do not know how they (researchers) collect data when wearing the device." (ID 35)

"They asked us to wear it for monitor our health in general." (ID 176)

"It records our daily activities - what do we do during the daytime, and our sleep at night." (ID 48)

"I would explain that it is a tool for research purposes, and data will be analyzed to see if this device can screen for depression or not." (ID 106)

Theme 2: Perception of depression

The degree to which they have perception or knowledge about depression. Their opinions towards depression were divided into three groups: 1) not aware at all; 2) aware of symptoms like overthinking, feeling depressed, or experiencing social exclusion; and 3) aware of causes related to environmental factors such as family or social problems.

"How does one become depressed? What leads to it? What are the causes? I do not know." (ID 61)

"The symptoms of depression include lack of refreshment, feelings of loneliness, and sleepiness. The most apparent symptom is fatigue. Upon waking up, they feel unwilling to leave bed and still feel sleepy." (ID 106)

"The cause is linked with family, especially the elderly who live alone without children or grandchildren." (ID 170)

Theme 3: Perception of device's characteristics

The degree to which participants perceived the device's characteristics and their feelings while wearing it was assessed. Most participants expressed satisfaction with the device's general appearance However, some participants noted that the device is too large and not waterproof, leading to occasional inconvenience during housework, such as washing clothes or dishes. In addition, the participants said the device should have a display screen showing results to make them aware of their health status.

"The device looks cool because the red and black colors suit me well. The appearance is good, especially for the elderly." (ID 138)

"It is not waterproof, so if it gets hit by something just a little bit, water might get in." (ID 108)

"It would be good if there were a display showing results compared with standards." (ID 106)

Theme 4: Perceived usefulness

The degree to which they have perception of device's usefulness. Most participants were uncertain about the benefits of wearing the device; however, some believed that the device might be beneficial to their health. One interviewee

took into account the potential public benefits when they participated in this research project.

"'I do not know how it is useful to us…however, we are an example for data collection, and it will be beneficial for the public." (ID 106)

"At the beginning, I wore it because it was advised by them (researcher), but I think it might have a positive effect on health." (ID 138)

" (ID 106)

When considering its perceived usefulness in increasing awareness of mental health or detecting depressive symptoms, only some of the participants believed the device could detect or raise awareness of the disease. Conversely, others held the belief that depression could not occur to them and therefore could not be detected.

" Researcher: Do you think this device can detect depression?

Participant: We cannot know if anyone has depression or not. We only find out when they visit a doctor or post something on social media, so it's difficult to detect this disease." (ID 169)

"It (wearing the device) does not cause us concern (about depression) because I prefer to be happy and not experience sadness (do not have any risk of depressive disorder)." (ID 58)

"If you are depressed, you will feel like you do not want to move. So, I believe that if I move more, I will not get depressed." (ID 149)

Theme 5: Perceived ease of use and non-interference

The degree to which a participant believed that using a device would be free of effort. Most participants considered it is an easy-to-use device without any effort and did not find it inconvenient to use due to its similarity to a wristwatch.

"I usually wear a watch, so I feel indifferent." (ID 36)

“Wherever I go and whatever I do, I just wear it and there are not any problems.” (ID 61)

Theme 6: Facilitators to use the device

The degree to which a person believes that using the device would be free of effort. Interviewees shared strategies to avoid forgetting to wear the device throughout the day. For instance, they mentioned placing it in open, visible areas where they often frequent, such as next to their pillows, on the dressing table, and at the dining room table.

"What I have forgotten is placing the device in the wrong spot previously. So, when I take them off, I need to put them in a place where I can easily see or in the usual spot." (ID 106)

Theme 7: Barriers to use the device

The degree to which the device encounters obstacles during usage. Some individuals initially believed it could negatively impact their bodies, but eventually found it had no side effects. Most participants expressed concerns about potential water damage due to the device not being waterproof. Additionally, some were anxious about physical damage to the device.

"At first, I thought it might have an impact on our bodies…but it would not affect just one person, it will affect us all." (ID 58)

"It is annoying to take it off and put it back on time after time." (ID 58)

"I am worried that it might get wet and concerned that the device will be damaged." (ID 36)

Theme 8: Privacy concern

The degree to which the device was perceived to protect personal information varied. Most participants did not express concerns about privacy issues. They clarified that the device's characteristics or functions did not allow the capture of personal information. Additionally, they were informed by the research team that personal information would not be exposed. Furthermore, participants perceived health information as not being a privacy issue.

"It is impossible for this device to collect this kind of data (privacy data)." (ID 149)

"They (researchers) take several steps to contact us through elderly club, so I trust." (ID 116)

"Only conversations constitute privacy data, but health data does not, as hypertension and heart disease are common in everyone." (ID 36)

However, only a few participants expressed concern about their personal information due to a lack of understanding or uncertainty about the data collection process.

"I am afraid that our voices will be recorded during phone calls." (ID 138)

Theme 9: Social norm

The degree to which individuals were influenced by others regarding the use of the device varied. The majority of participants disclosed that others had a

positive opinion about the device, so they felt good to wear. However, some participants gave interesting comments. They expressed concerns that wearing the device could be seen as a symbol of someone experiencing depression, and they didn't want to wear it due to potential stigma associated with it.

"Other people also want to wear this device. Some ask where I bought it." (ID 48)

“I am reluctant to wear the device if it indicated to others that I am experiencing depression. I accept myself but others might perceive me in a negative way.” (ID 106)

Theme 10: Intention to use in the future

The degree to which they want to use this device in the future. Most participants mentioned that they would be happy to wear it if it offered health benefits, integrated with smartwatch functions to detect a wide range of diseases, and if it were waterproof. Furthermore, if this device were recommended by health personnel, people would be more inclined to wear it.

"If it is not useful, I don't want to wear it." (ID 106)

"If everyone knows the reason why they wear it and if our health status is displayed on the device, I think more people would want to wear it too." (ID 58)

"I wish it could be more useful if integrated into a single device like a smartwatch, as it has a clock and can monitor other diseases." (ID 159)

“If the doctor advises us to wear it, we wear it to collect data. It is beneficial for us and allows the doctor to read the information.” (ID36)

In summary, the data on technology acceptance gathered from both questionnaires and focus group discussions could be combined to gain deeper insights. Regarding perceptions of depression and the device's purpose, most participants exhibited a lesser understanding of the device's objective and showed less interest in depression screening compared to physical illnesses. They found the device easy to use without requiring assistance, and its non-interference during both daytime and nighttime resembled that of a smartwatch. However, they mentioned that they would be more pleased to wear it if the device were waterproof and smaller in size. Although most perceived the device's health benefits, it did not make them aware of their mental health due to the lack of a display screen. Regarding privacy concerns, most participants were not worried, considering health data not to be privacy sensitive. Social norms did not influence their decision to wear the device, except it was known as device for individuals with depression. Finally, participants shared similar views on future device use if they perceived health benefits, received recommendations from health professionals, and if the device had multipurpose functions, such as telling the time and detecting other diseases.

Discussion

The study's findings revealed associations between physical activity, sleep parameters (daily step count, VM CPM, and WASO), and depression scores. Additionally, participants living in Bangkok, being older, living alone or being divorced or widowed, smoking or using substances, having mental illness, and being dependent in daily living tended to have higher depression scores. Regarding participants' acceptance of the device, there was a lack of understanding about its

purpose for detecting depression compared to physical health. While they found it user-friendly, akin to a smartwatch, they desired a waterproof, smaller design. Despite recognizing health benefits, the device didn't increased awareness of mental health due to the absence of a screen. Minimal impact was observed on privacy concerns and social norms, and future usage depended on perceived health benefits and professional recommendations.

Evidence suggests a correlation between physical activity parameters and depression, consistent with findings from O'Brien et al. (2017) and Gruenenfelder-Steiger et al. (2017) among elderly populations. These studies revealed that lower physical activity, measured as acceleration magnitude, was associated with depression compared to control groups (25). Another study demonstrated a 14 percent reduction in daily depressive mood with a one-unit increase in standardized daily step count (35). This finding was corroborated by a meta-analysis of cohort studies until 2017, confirming that reduced physical activity triggered depression in the elderly (adjusted odds ratio=0.83, 95% CI=0.79, 0.88; I2=0.00) (36). The predominance of somatic symptoms compared to mood symptoms to in late-life depression (37) may explain why physical activity can be an indicator in individuals with depression.

In this study, only WASO among sleep characteristics exhibited an association with depressive symptoms, potentially explained by the common appearance of somatic symptoms, including insomnia, in late-life depression (37). Interestingly, our findings revealed a reverse relationship between WASO and depression score, contrary to previous studies linking increased WASO with more depressive symptoms (22-24). Utilizing an analysis algorithm to identify sleep periods from Actigraph might introduce errors in data collection and analysis

compared to the standardized sleep monitoring of polysomnography (38). Moreover, not all sleep parameters, such as sleep efficiency, consistently correlated with depressive symptoms in the elderly. This suggests the necessity for further exploration in subsequent studies of appropriate device, and data measurement and analysis.

There is an ongoing initiative to promote the utilization of smart devices, such as smartphones and wearables, for detecting depressive disorders. Wearables, known for collecting and analyzing biomarkers like heart rates, physical activities, sleep patterns, blood oxygen levels, and respiratory rates, have gained popularity, particularly among the elderly (21, 39). While smart devices are advocated as tools for detecting depression, it should be complimented with other data sources, such as neuroimaging data and traditional diagnostic methods like self-report questionnaires or interviews, to gain a more comprehensive understanding of a patient's condition (35). Previous feasibility studies on wearables reported high participant satisfaction, citing ease of use, support in goal setting, motivation, and self-monitoring benefits (40, 41). Similar to this study, high device acceptance was linked to ease of use and non-interference, akin to a smartwatch. However, additional features like multipurpose functionality, waterproofing, screening results, and recommendations from health experts could further encourage future use. In conclusion, wearable devices possess the potential to become integrated tools in mental health monitoring, but robust evidence and technology development are necessary to ensure accuracy and acceptability in implementation.

Despite being the first study of passive sensing data and depression in Thailand, it has several limitations. The sample selection might be biased due to

quota sampling across regions, creating a non-probability sample where participants in each region have an equal chance of being selected, potentially impacting the sample's representativeness. Additionally, participants need to remove the Actigraph during water-related activities, potentially affecting the validity of wearing time. However, efforts were made to mitigate this by asking participants to wear the device as soon as possible after such activities, ensuring sufficient wearing time for evaluation (more than 10 hours per day and 4 days per week). Lastly, the study's short duration might limit its ability to capture significant changes in physical activity and sleep parameters, including the PHQ-9 score. Further studies should consider longer durations, encompass participants with a wide range of PHQ-9 scores, such as patients, and incorporate devices used in their daily lives, like smartwatches.

In Thailand, there is potential to leverage passive sensing data for mental health issues, yet challenges exist at the population level, resulting in most technologies being in the form of self-assessments, such as the Mood Delight application from the Department of Mental Health (42). Emerging technologies for mental health detection using passive sensing data are in progress like the DMIND application developed by the Faculty of Medicine and the Faculty of Engineering at Chulalongkorn University, focusing on screening for depression through facial and voice detection (43). Smart devices, especially smartwatches, have the capability to collect such data, but consent approval is necessary, and a tool is required for extracting data from these devices (44). Integration of smartwatch data with electronic health records, clinicians could access patients' mental health data from their smartwatches to provide response and inform clinical assessments, treatment plans, and the evaluation of treatment efficacy (45). The future direction of using

smartwatches for mental health monitoring should focus on interoperability of system and methodology in data analysis based on strong evidence.

Conclusion

In this research, the objective was to tackle the underdiagnosis of geriatric depression in Thailand by investigating the correlation between data collected from smart devices (such as physical activity and sleep patterns) and depression scores. A cohort study was carried out with 177 elderly individuals from diverse regions, monitoring their activity and sleep using Actigraph devices for a month, with depression scoring every two weeks. The findings indicated connections between increased vector magnitude count per minute (a measure of physical activity) and daily step count, and decreased depression scores. Additionally, Wakefulness After Sleep Onset (a measure of minute of wakefulness after sleep), a sleep parameter, showed reverse association with depression scores. Furthermore, the device appears to be acceptable and is likely to gain further acceptance when equipped with multipurpose functionality including screening results, waterproofing, and recommendations from health experts. This implies the potential use of passive sensing data for mental health in Thailand. For the integration of this smart device data into public health policies, interoperable system and standardization of data is crucial for ensuring comparability.

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Annex

Annex I: Informed consent form

Informed Consent Form

Research Title: The Knowledge and Tool Development for Depressive Symptoms Screening in Thai Elderly from Passive Sensing Data of Smartphones or Smartwatches

Date of Consent: Date……. Month ……. Year…….

Before signing this conformed consent, I have been explained by the researcher and have a thorough understanding of the purpose, objectives, methodology, risks, and benefits that may arise from this research.

The researcher certifies to willingly clarify all my doubts and concerns, without any concealment, until I am satisfied.

I have the right to withdraw my participation in this research at any time without penalty and I am willing to participate in this research. My participation withdrawal will not affect my own initial treatment(s) and legal rights and I am not required to give a reason.

The researcher certifies that all personal information will remain anonymous and confidential. It shall only be disclosed in the form of research findings or for the relevant parties who support and supervise research project.

The researcher certifies that, if any harm arises from this research, I will be compensated for electronic device damage or information loss. The compensation would not cover any damages that caused by user devices and user behaviors violating rules and regulations. I could contact Dr Hathairat Koyisaporn (the principal investigator) via mobile at 0-8763-1314 for compensation details.

If I would like to ask for information and submit complaints, I may contact the International Health Policy Program (IHPP), Address: 88/20 Satharanasuk 6 Alley, Talat Khwan, Mueang Nonthaburi, Nonthaburi, 11000, Telephone: 0-2590 2366-7 or Fax: 0-2590 2385. Alternatively, I may contact the Human Research Ethics Committee. Institute for Research Protection Development in Humans Address Office of Human Research Protection Development (OCPB), Address: Building 8, Floor 7, Room 702, Department of Medical Sciences Ministry of Public Health Tiwanon Road, Talat Khwan, Mueang Nonthaburi, Nonthaburi, 11000, Telephone: 0-2591-3876, 0-2591 3517 or Fax: 0-2591-4125.

I have read the above-mentioned message and have a thorough understanding in all respects and willing to sign this consent form.

Signature: ……. (Consenter) Date: …….

Signature: ……. (Witness) Date: …….

Signature: ……. (Witness) Date: …….

I have described and answered all questions about the purpose, objectives, methodology, risks and benefits of this research in detail to the participants. I have given a copy of this informed consent to the participant.

Signature …….Researcher

Date……..

Annex II: Sample size calculation

The sample size will be calculated using an infinite population of correlation formula as followed:

$$N = [(Z_\alpha+Z_\beta)/0.5 * \ln[(1+r)/(1-r)]]^2 + 3$$

Where, r or coefficient correlation between passive sensing data (GPS) and depression score (PHQ-9) is 0.23*, Z_α is the standard deviation of type I error accounting for 1.96, and Z_β is the standard deviation of type II error accounting for 0.84.

$$N = [(1.96+0.84)/0.5 * \ln[(1+0.23)/(1-0.23)]]^2 + 3$$

Given a 20% non-response rate, the final sample size will be 146*100/80 = 182.5 or 183 participants

* Farhan AA, Yue C, Morillo R, Ware S, Lu J, Bi J, et al., editors. Behavior vs. introspection: refining prediction of clinical depression via smartphone sensing data. 2016 IEE Wireless Health (17); 2016 25-27 Oct. 2016

Annex III: The demographic questionnaire

Questions	Answers
1. Province	1. Saraburi 2. Bangkok 3. Loei 4. Phuket 5. Lampang
2. Date of Birth	……..
3. Gender	1. Male 2. Female 3. Others
4. Weight (Kilogram)	……..
5. Hight (Centimeter)	……..
4. Education	1. Illiterate 2. Primary education 3. Secondary 4. Diploma 5. University and higher
6. Occupation	1. Public employee 2. Private employee 3. Self-employed 4. Freelance 5. Agriculture 6. Unemployed/Retired 7. Others……..
7. Marital status	1. Single 2. Married

Questions	Answers
	3. Divorce/Widow
8. Family members	1. Alone 2. With parents 3. With spouse 4. With children 5. With relatives 6. With grand children but without second generation 7. With non-relatives 8. Others……..
9. Income (Bath per month)	……..
10. Current smoking (in the past 12 months)	1. No 2. Yes
11. Current alcohol used (in the past 12 months)	1. No 2. Yes
12. Current drug used (in the past 12 months)	1. No 2. Yes (Cannabis) 3. Yes (Others) ……..
13. Comorbidity (physical illness)	1. Hypertension 2. Diabetes 3. Hyperlipidemia 4. Heart disease 5. Stroke 6. Chronic lung disease or asthma 7. Cancers 8. Kidney failure or renal impairment 9. Liver failure such as cirrhosis

Questions	Answers
	10. Osteoarthritis of the knee or degenerative spine or cervical spondylosis 11. Gout or rheumatoid arthritis 12. Thyroid disease 13. Others ……..
14. Comorbidity (Mental illness)	1. None 2. Depression 3. Bipolar 4. Anxiety disorder 5. Schizophrenia 6. Dementia/Alzheimer's disease 7. Parkinson's disease 8. Alcoholism/Substance Addiction 9. Sleep disorders such as insomnia 10. Eating disorders such as obsessive-compulsive disorder 14. Others……..
15. Number and name of current medical history	……..

Annex IV: The nine-item Patient Health Questionnaire Depression Scale (PHQ-9)

Over the last 2 weeks, how often have you been bothered by any of the following problems?	Not at all (0)	Several days (1-7 days) (1)	More than half the days (>7 days) (2)	Nearly everyday (3)
1. Little interest or pleasure in doing things				
2. Feeling down, depressed, or hopeless				
3. Trouble falling or staying asleep, or sleeping too much				
4. Feeling tired or having little energy				
5. Poor appetite or overeating				
6. Feeling bad about yourself – or that you are a failure or have let yourself or your family down				
7. Trouble concentrating on things, such as reading the newspaper or watching television				
8. Moving or speaking so slowly that other people could not have noticed. Or the opposite – being fidgety or restless that you have been moving around a lot more than usual				
9. Thoughts that you would be better off dead or of hurting yourself in some way				

Ref: Kroenke K, Spitzer RL, Williams JB. The PHQ-9: validity of a brief depression severity measure. J Gen Intern Med. 2001;16(44):606-13.

Annex V: The technology acceptance questionnaire

Questions	Strongly disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly agree (5)
1. I find the device easy to use					
2. I think that monitoring my activity and health 24 hours a day, 7 days a week, can be a good thing					
3. I think using the device can help me improve my overall health					
4. I was able to perform my daily tasks as usual while wearing the device					
5. The device was pleasant to wear during the night					
6. The battery life of the device meets my expectations					
7. I had no concerns about my privacy while wearing the device					
8. I am able to get assistance from a friend of family member to use the device, if needed					
9. I was embarrassed to wear the device in front of others					
10. I will have intention to use the device in the future					

Ref: Puri A, Kim B, Nguyen O, Stolee P, Tung J, Lee J. User Acceptance of Wrist-Worn Activity Trackers Among Community-Dwelling Older Adults: Mixed Method Study. JMIR Mhealth Uhealth. 2017;5(11):e173.

Annex VI: Instrumental Activities of daily living (IADL) Questionnaire

LAWTON - BRODY
INSTRUMENTAL ACTIVITIES OF DAILY LIVING SCALE (I.A.D.L.)

Scoring: For each category, circle the item description that most closely resembles the client's highest functional level (either 0 or 1).

A. Ability to Use Telephone		**E. Laundry**	
1. Operates telephone on own initiative-looks up and dials numbers, etc.	1	1. Does personal laundry completely	1
		2. Launders small items-rinses stockings, etc.	1
2. Dials a few well-known numbers	1	3. All laundry must be done by others	0
3. Answers telephone but does not dial	1		
4. Does not use telephone at all	0		
B. Shopping		**F. Mode of Transportation**	
1. Takes care of all shopping needs independently	1	1. Travels independently on public transportation or drives own car	1
2. Shops independently for small purchases	0	2. Arranges own travel via taxi, but does not otherwise use public transportation	1
3. Needs to be accompanied on any shopping trip	0	3. Travels on public transportation when accompanied by another	1
4. Completely unable to shop	0	4. Travel limited to taxi or automobile with assistance of another	0
		5. Does not travel at all	0
C. Food Preparation		**G. Responsibility for Own Medications**	
1. Plans, prepares and serves adequate meals independently	1	1. Is responsible for taking medication in correct dosages at correct time	1
2. Prepares adequate meals if supplied with ingredients	0	2. Takes responsibility if medication is prepared in advance in separate dosage	0
3. Heats, serves and prepares meals, or prepares meals, or prepares meals but does not maintain adequate diet	0	3. Is not capable of dispensing own medication	0
4. Needs to have meals prepared and served	0		
D. Housekeeping		**H. Ability to Handle Finances**	
1. Maintains house alone or with occasional assistance (e.g. "heavy work domestic help")	1	1. Manages financial matters independently (budgets, writes checks, pays rent, bills, goes to bank), collects and keeps track of income	1
2. Performs light daily tasks such as dish washing, bed making	1	2. Manages day-to-day purchases, but needs help with banking, major purchases, etc.	1
3. Performs light daily tasks but cannot maintain acceptable level of cleanliness	1	3. Incapable of handling money	0
4. Needs help with all home maintenance tasks	1		
5. Does not participate in any housekeeping tasks	0		
Score		**Score**	
		Total score_____	
A summary score ranges from 0 (low function, dependent) to 8 (high function, independent) for women and 0 through 5 for men to avoid potential gender bias.			

Ref: Graf C. The Lawton instrumental activities of daily living scale. Am J Nurs. 2008 Apr;108(4):52-62; quiz 62-3.

Annex VII: Comparison of demography between recruited and loss follow-up groups

Demographic characteristics	Number of recruited group (%)	Number of loss-follow up group
Province		
Lampang (Northern)	41 (23.2)	0 (0.0)
Phuket (Southern)	35 (19.8)	3 (100.0)
Bangkok	38 (21.5)	0 (0.0)
Saraburi (Central)	31 (17.5)	0 (0.0)
Loei (North-Eastern)	32 (18.1)	0 (0.0)
Gender		
Female	150 (84.7)	3 (100.0)
Male	27 (15.3)	0 (0.0)
Median Age (IQR)	68.9 (8.8)	62.4*
Education		
Primary education	73 (41.2)	0 (0.0)
Secondary education	19 (10.7)	0 (0.0)
Diploma	45 (25.4)	2 (66.7)
University and higher	40 (22.6)	1 (33.3)
Occupation		
Unemployed/Retired	116 (65.5)	1 (33.3)
Self-employed	39 (22.0)	1 (33.3)
Freelance	19 (10.7)	1 (33.3)
Agriculture	2 (1.1)	0 (0.0)
Public employee	1 (0.6)	0 (0.0)
Median income (IQR)	8,500 (21,900)	18,400*
Marital status		
Single	13 (7.3)	0 (0.0)
Married	97 (54.8)	2 (66.7)
Divorce/widow	67 (37.9)	1 (33.3)
Household members		
Alone	20 (11.3)	0 (0.0)
With parents/spouse/grandchildren	40 (22.6)	0 (0.0)
With mixed generations	117 (66.1)	3 (100.0)
Current smoking		
No	174 (98.3)	3 (100.0)
Yes	3 (1.7)	0 (0.0)
Current alcohol used		
No	157 (88.7)	3 (100.0)
Yes	20 (11.3)	0 (0.0)

Demographic characteristics	Number of recruited group (%)	Number of loss-follow up group
Current drug used		
No	168 (94.9)	3 (100.0)
Yes (e.g,. Cannabis)	9 (5.1)	0 (0.0)
Comorbidity (physical illness)		
None	27 (15.3)	1 (33.3)
Cardiovascular-related diseases	107 (60.5)	2 (66.7)
Orthopedic and Hormonal related diseases	43 (24.3)	0 (0.0)
Comorbidity (mental illnesses)		
No	167 (94.4)	3 (100.0)
Yes	10 (5.6)	0 (0.0)
Medication		
None	162 (91.5)	3 (100.0)
Having drugs affecting sleep and movement	15 (8.5)	0 (0.0)
IADL		
Dependent	15 (8.5	0 (0.0)
Independent	162 (91.5)	3 (100.0)
Total	**177 (100.0)**	**3 (100.0)**

*cannot evaluate IQR due to low number of sample

Annex VIII: Univariate analysis between demography, physical activity and sleep parameters, and PHQ-9 score (round 2 and 3) adjusted for baseline PHQ-9 score

Independent/confounding variables	PHQ-9 score (Round 2)			PHQ-9 score (Round 3)		
	Correlation coefficient	95% confident interval	P-value	Correlation coefficient	95% confident interval	P-value
Sex (vs female)						
male	0.386	0.365	0.292	-0.052	0.438	0.906
Province (vs BKK)						
Non-BKK	-1.085	0.315	0.001**	-0.250	0.381	0.514
Age	0.059	0.022	0.007**	0.050	0.025	0.048**
Education (vs lower than diploma and university)						
Equal or higher than diploma and university	-0.290	0.267	0.279	-0.111	0.249	0.656
Occupation (vs Unemployed/Retired)						
Having occupation	-0.079	0.281	0.779	-0.117	0.259	0.653
Income	0.000001	0.000004	0.898	0.0000003	0.0000039	0.931
Household members (vs alone)						
With parents/spouse/grandchildren	0.301	0.487	0.538	-0.600	0.444	0.179
With mixed generations	0.304	0.426	0.477	-0.179	0.393	0.650
Marital status (vs Married)						
Single/divorced/widowed	0.478	0.269	0.078*	0.350	0.249	0.162
Current smoking (vs no)						
Yes	2.226	0.986	0.025**	-0.214	0.951	0.822
Current alcohol used (vs no)						
Yes	-0.122	0.431	0.778	-0.360	0.398	0.368
Current drug used (vs no)						

Independent/confounding variables	PHQ-9 score (Round 2)			PHQ-9 score (Round 3)		
	Correlation coefficient	95% confident interval	P-value	Correlation coefficient	95% confident interval	P-value
Yes (e.g, Cannabis)	1.107	0.617	0.075*	0.873	0.589	0.140
Comorbidity (physical illness) (vs none)						
Cardiovascular-related diseases	0.142	0.384	0.712	-0.261	0.352	0.459
Orthopedic and Hormonal related diseases	0.417	0.435	0.340	-0.034	0.403	0.934
Comorbidity (mental illnesses) (vs none)						
Yes	0.668	0.621	0.284	0.470	0.535	0.381
IADL (vs independent)						
Dependent	0.631	0.477	0.187	0.979	0.434	0.025**
Medicine affecting sleep and movement (vs no)						
Yes	-0.276	0.524	0.599	0.255	0.453	0.574
PA						
VM CPM	-0.00054	0.00031	0.081*	-0.00039	0.00021	0.064*
Step count	-0.00007	0.00004	0.098*	-0.00006	0.00003	0.056*
Moderate intensity level	-0.003	0.002	0.129	-0.003	0.002	0.102
Sleep						
WASO	-0.028	-0.012	0.018**	-0.012	0.011	0.301
SE	0.067	0.038	0.085*	0.008	0.038	0.838
SFI	-0.009	0.018	0.608	0.002	0.013	0.882

Note: *confidence interval at 90%; **confidence interval at 95%

Annex IX: Summary of expert meeting

This meeting was hold on 15th November 2023, 9.00 - 11.00 hrs. with the objective to present the results of the study on the development of a screening tool for depression in Thai elderly using passive sensor data, gather opinions and suggestions from expert towards the study, and develop policy recommendations for tool application in Thailand. There was a total of 15 participants from various agencies covering mental health, digital health and elderly heath experts such as Department of Mental Health and Department of Health (Ministry of Public Health), Faculty of Medicine, Chulalongkorn University, and Medical Devices Research Center (The National Science and Technology Development Agency). The summary of discussion was as follows:

1. Research methodology

- This study was limited to urban area participants due to digital literacy, device accessibility, and it also had a limitation in the non-water-resistant nature of the device.
- The selection criteria should consider specific groups, such as disabled or bedridden patients, who are at a higher risk of depression.
- There were a low number of participants with PHQ scores higher than 7, suggesting consideration of changing the cut-off point to median or third quartile or performing subgroup analysis to reveal more significant results.
- Sleep variables were found unrelated to depression, potentially affected by bias in data analysis. Therefore, variable selection should consider other methods such as LASSO and statistical approaches applied to non-normally distributed data to ensure methodological soundness.

- Recommendations were made to specify analysis on items related to emotions or other sub-questions in PHQ-9.

2. Further research

- Future research recommendations included expanding to include depressed patients, for which the Department of Mental Health could provide information.
- Consideration should be given to studying the intensity of light, which impacts participant behavior like movement, sleep, and device usage.
- Expanding the data collection period to at least four time points was proposed to evaluate hierarchical linear regression models and assess cognitive processes in addition to existing themes in PHQ-9.
- Collaboration with other organizations, such as the Ministry of Digital Economy and Society, was suggested to develop infrastructure for utilizing passive sensor data devices to support policy.

3. Policy implications

- Standardization of devices should be considered due to variations in specifications and algorithms for data collection among different devices in the market.
- If the tool is used in the future, guidelines and protocols should be established to refer those at depression risk for further treatment.