Gu et al., Gerontechnology (2024) 23:1
https://doi.org/10.4017/gt.2024.23.1.842.02

Older adults' awareness, motivation, and behavior changes by wearable activity trackers before and during the COVID-19 pandemic

Xiuzhu Gu PhD*, Sahar Hamido PhD, Kenji Itoh PhD

*Department of Industrial Engineering and Economics, School of Engineering, Tokyo Institute of Technology, Tokyo, Japan; *Corresponding author: xiuzhu.g.aa@m.titech.ac.jp*

Abstract

Background: Advanced sensor technology, such as commercial wearable activity trackers, is expected to be useful for improving public health in an aging society. However, its effects on psychological and behavioral changes in older adults have not been thoroughly investigated.
Objective: This study aimed to clarify the effects of wearable activity trackers on psychological and behavioral changes in older adults before the pandemic and to confirm whether the effects were maintained during the pandemic.
Method: Thirty Japanese older adults wearing Fitbit trackers for 12 weeks (i.e., six weeks before the pandemic and six weeks during the onset of the pandemic) in a real-life setting participated in this study. Participants' perceptions of physical activity (PA) and monitoring were measured weekly using a questionnaire in addition to the pre-monitoring survey (baseline).
Results: Significant positive effects of activity trackers were observed on participants' awareness of the benefits of PA and motivation toward monitoring from the first week, and high levels were maintained until the end of the study, regardless of the pandemic. Accordingly, an approximately 3,000-steps/day increase was observed in the first week and maintained before the pandemic; although PA levels decreased during the onset of the pandemic, they remained higher than at baseline. The decrease in the number of steps and activity calories in COVID-19-non-affected participants was 2%. In the affected participants, an 11% decrease in steps and an 8% decrease in activity calories were observed, indicating that 3% was compensated by other activities.
Conclusion: Positive effects of activity trackers were observed on older adults' awareness of PA benefits. Thus, future studies are required to verify the effects of increased PA benefits awareness on older adults' long-term activity levels for their health.

Keywords: psychological change, physical activity, behavior change theories, wearable activity tracker, COVID-19 pandemic

Introduction

Aging is an urgent global concern. According to the 2022 Revision of World Population Prospects published by the United Nations (2022), older adults (aged 65 years or older) will represent 16% of the world's population by 2050. The aging population poses substantial social and financial challenges. For instance, it has pushed the world's healthcare costs to rise to trillions of dollars annually (World Health Organization, 2020). Japan is the world's fastest-aging country due to the long life expectancy and low birth rate among its population (D'Ambrogio, 2020; The World Bank, 2022). According to the Japanese Statistics Bureau, Japan has become a "super-aged" society, with over 29% of its population aged 65 years or above in 2021 (Statistics Bureau of Japan, 2021). For good quality of life in older adults, it is of vital importance to ensure a healthy lifestyle during aging (Hamer et al., 2014). Physical activity (PA) has been encouraged due to its correlation with good physical and mental health in older adults (Garatachea et al., 2009; Hansen et al., 2020; Persson & While, 2012; Song et al., 2015), and it reduces the risk of cognitive decline, dementia, and chronic diseases (McPhee et al., 2016). However, physical inactivity is prevalent in older adults as people aged 60 years or older have been reported to spend approximately 80% of their awake time on sedentary behaviors (Seol et al., 2020). A longitudinal study also reported an overall increase in sedentary time and a decrease in average PA among older adults (Hagstromer et al., 2015).

Currently, advanced sensor technology, such as commercial activity trackers, is expected to be a useful technique for behavior change to improve public health (Lyons et al., 2014). Wearable activity trackers provide users with real-time feedback on biometric and PA measures, such as walking steps, burned calories, sleeping time, and heart rate. However, existing studies related to wearable activity trackers in older adults have mainly focused on the adoption (Zhang et al., 2017) and sustained use of trackers (Kononova et al., 2019). They have addressed older adults' acceptance and user experience of wearable trackers (Fang & Chang, 2016; McMahon et al., 2016), including mental effort, usability, technical affinity, and habit formation (Peng et al., 2021; Talukder et al., 2021). Surprisingly, few studies have measured the changes in older adults' PA levels and health outcomes by the tracker's intervention (Cadmus-Bertram et al., 2015; Hodgson et al., 2021; Sookhai et al., 2015). Furthermore, the outcome assessment of the interventions has focused only on the physical effects but not on the mental and psychological effects. Therefore, wearable activity trackers may be useful for older adults, but the effects have not been well investigated.

Many researchers who conducted studies on PA intervention explored changes in behavior but often neither measured changes in attitudes nor awareness (Albarracin & Shavitt, 2018). Similarly, to date, very few studies have focused on the effects of wearable activity trackers on psychological changes in older adults, that is, whether their awareness of the impact of PA on a healthier lifestyle increases (Hodgson et al., 2021). To achieve a long-term commitment to PA, people should be aware of its benefits for their lifestyle and health (Haskell et al., 2007). Based on behavior change theories, one significant factor for a person to perform a behavior is the person's beliefs about this behavior (Ajzen & Fishbein, 2005). This is consistent with the Health Belief Model (Janz & Becker, 1984) that if people perceive benefits to their health, then they are motivated to engage in health-promotion behavior. Thus, we hypothesize that wearable activity trackers may positively impact users' awareness of PA and health beliefs, contributing to higher levels of PA. Therefore, the effects of activity trackers should be evaluated in older adults not only in terms of behavioral changes by PA levels but also in terms of psychological changes by awareness and motivation toward PA and monitoring.

The present study commenced before the COVID-19 outbreak in Japan and ended during the 2020 pandemic, which resulted in worldwide implementation of restrictive measures to reduce social contact and viral spread. The measures varied by country but generally involved restrictions on nonessential movement and have resulted in approximately 10%–50% PA decrease (Hamasaki, 2021; McCarthy et al., 2021). In addition, even under no restrictions, some people consciously changed their lifestyle— particularly PA. Studies have expressed concerns about the negative impact of reduced PA during the pandemic and the importance of maintaining PA (Jiménez-Pavón et al., 2020; Suzuki et al., 2020) as sedentary behavior and low levels of PA may have negative physical and psychological effects on older adults (Ekelund et al., 2019). Performing light PA may help alleviate some of the negative mental health impacts that older adults experience while being isolated and adhering to government guidelines during the pandemic (Callow et al., 2020). Wearable activity trackers might have been promising in encouraging PA during the pandemic; thus, studies are also required to confirm the effects of activity trackers on older adults during this special period.

Based on the aforementioned background, this study had two main objectives. The first was to clarify the effects of wearable activity trackers on psychological and behavioral changes in older adults. The second was to confirm whether the effects were maintained during the pandemic compared to before. The main contributions of this study to the literature are as follows: (1) it explores the effects of wearable activity trackers on older adults' psychological changes, on which very few studies have focused; (2) rather than merely making comparisons before and after wearing the activity trackers, as in most existing studies, this study examines time-series physical and psychological changes; and (3) the effects of activity trackers are compared for older adults with different characteristics and under different situations.

Methods

Research design

Focusing on time-series changes, particularly psychological ones, we adopted a quasi-experimental approach. Older adult participants were required to wear Fitbit trackers for 12 weeks in a real-life setting between January 20 and April 12, 2020. An overview of the research design is presented in *Figure 1*. All questionnaires were self-reported. A few weeks after the study commenced, the COVID-19 pandemic began. Therefore, as the first national restrictive measure in Japan (i.e., school closure) started on March 2, the 12 monitoring weeks were divided into two periods: before the pandemic (weeks 1–6) and during the onset of the pandemic (weeks 7–12). This study was conducted following the procedures approved by the Ethics Committee of the researchers' university (Approval No. 2019130).

Participants

Participants were recruited via an agency for older adults (KOUREISHA Co., Ltd.). Those who registered in the agency were randomly selected and invited. The inclusion criteria were as follows: aged >65 years, owned a smartphone, had an active e-mail address, and had an Internet connection. The exclusion criteria were as fol-

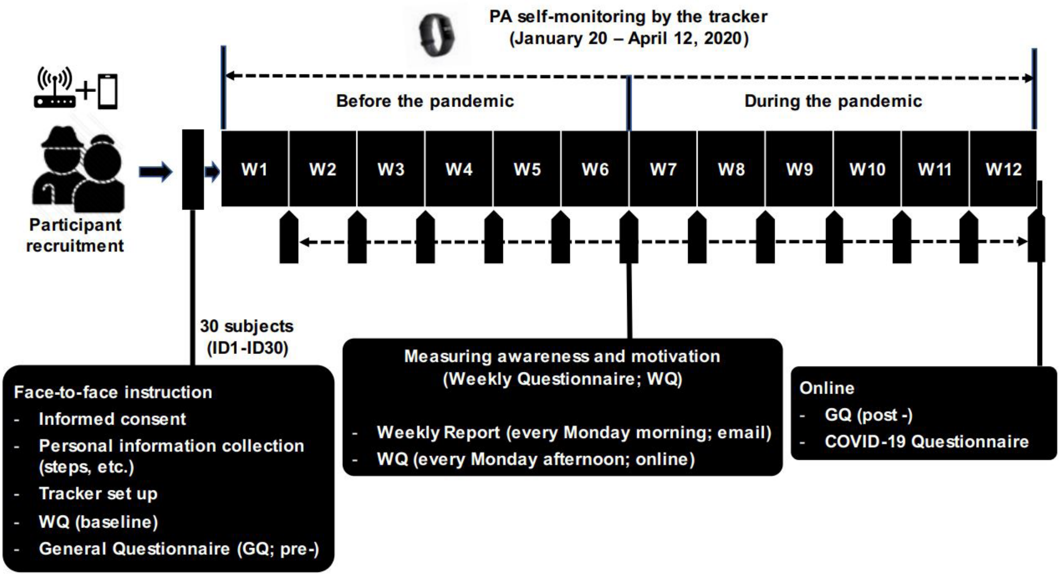

Figure 1. An overview of the research design

lows: inability to perform activities of daily living due to health issues, cognitive impairment or dementia, and mobility disorder. Thirty-two older Japanese adults meeting the criteria agreed to participate, two of whom were excluded because the tracker's setup on their smartphone devices failed. Therefore, 30 participants were included in this study.

Awareness and motivation measurement

To capture the change trends in participants' awareness and motivation toward PA and monitoring by the tracker, we used a Weekly Questionnaire including 20 items for four factors (*Appendix I*). The questionnaire was developed and its reliability and validity were validated in a previous study on young adults (Hamido et al., 2021). As the questionnaire was administered repeatedly by participants to detect weekly changes, a 7-point Likert scale ranging from 1 (strongly disagree) to 7 (strongly agree) was used to make the measurement sensitive. Examples of the items were *"PA/exercise does not contribute to my health condition"* and *"PA results in physical and psychological improvements"*. Participants were asked to respond to this questionnaire before wearing the tracker and at the end of every week during the 12-week monitoring period.

PA measurement

We collected the participants' PA data using a Fitbit tracker (Fitbit Charge) because it is reported as the most reliable type of tracker, particularly for measuring the number of steps (Ferguson et al., 2015) and for older adults (Paul et al., 2015). The tracker is a wristband-type tracker that provides real-time feedback via its screen, mobile app, and website personal account. The tracker's default daily goal is 10,000 steps per day, although we suggested 6,500 for the participants before monitoring, as recommended by the Japanese Ministry of Health, Labour, and Welfare (2013). However, participants were free to change their goals at any time before or during the self-monitoring period. In this study, the number of steps and activity calories were used as PA indicators. The number of steps is considered a reliable estimate of PA level (Tudor-Locke et al., 2002). As a simple, low-impact PA, walking is particularly beneficial for older adults, whose daily step counts are highly associated with all-cause mortality and cardiovascular disease morbidity (Hall et al., 2020). Activity calories interpret activity levels based on the calories burned while walking, doing housework, or undertaking other PA. To determine the baseline values, before self-monitoring by the tracker, participants were asked to report their own steps per day. However, to assure reliability, it was instructed that only those who knew their steps report the data. The number of steps could be obtained from a traditional pedometer or a default smartphone pedometer used by the participant.

Impact of the short-term COVID-19 pandemic

To measure the impact of COVID-19 on the participants' daily lives, attitudes toward activity monitoring, and efforts regarding PA performance during the short-term pandemic, we designed a questionnaire (COVID-19 Questionnaire). In general, participants were asked whether their life/work style had changed because of COVID-19, and the following main section included 16 items (refer to *Appendix*

II) using a 5-point Likert scale from 1 (strongly disagree) to 5 (strongly agree). Participants were asked to complete the questionnaire at the end of this study.

Health status and quality of life (QOL) measurement
Participants' health status and QOL were selfreported using another questionnaire (General Questionnaire) before and after the 12-week monitoring period. It comprised 13 items (refer to *Appendix III*) measured on a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). The first eight items on health status and PA were adopted from a previous young adult study (Hamido et al., 2021). The remaining five items on psychological QOL were adopted from the reliable and validated WHOQOL-BREF scale developed by the WHO (2012).

Research procedures
Before the 12-week monitoring period, we conducted face-to-face instruction, informing each participant about the purpose, procedures, activity tracker usage, ethical issues, and how to respond online questionnaire. Relevant materials were also provided, such as the document for experiment instructions and the Fitbit user manual. After signing the consent form, each participant was assigned an ID number to be used throughout the study period. Each participant then completed a personal information sheet (including self-reported steps per day for those who had the information as baseline data), the Weekly Questionnaire (as baseline), and the General Questionnaire (pre-). Subsequently, the researchers helped each participant download the app and set up the tracker. During the 12-week monitoring period, the participants were asked to keep wearing the tracker except during battery charge and shower time, but they were allowed to change the settings as they liked. A weekly report summarizing the participant's activity level for the previous week was sent to the participant every Monday morning by email. The online link to the Weekly Questionnaire was sent in the afternoon, and the participants were asked to fill out the questionnaire on the same day. After the 12-week monitoring period, the participants were asked to fill out the online COVID-19 Questionnaire and the General Questionnaire again (post-).

Statistical analysis
Awareness and motivation
We first conducted analyses to capture the change trends in older adults' awareness and motivation using four factors: (I) awareness of PA benefits, (II) satisfaction with monitoring, (III) motivation toward monitoring, and (IV) normative feeling for PA. Internal reliability, as assessed by Cronbach's alpha (α = 0.876, 0.836, 0.714, and 0.635), was high enough at > 0.70 (Nunnally, 1978) or at an acceptable level at > 0.60 (Hair, 2010). As normal distribution was not met due to a small sample size, we applied non-parametric analyses; in addition, we used the Friedman and Wilcoxon signed-rank tests to explore the weekly changes in the impacts of PA monitoring and the short-term pandemic. We then divided the 30 participants into three groups (COVID-19-affected, non-affected, and neutral) based on their responses to the COVID-19 Questionnaire and compared change trends between the affected and non-affected groups. In addition, we conducted comparisons by sex, body mass index (BMI) (overweight or not), presence of chronic disease, and regular performance of PA (i.e., engaging in regular PA such as walking or other sports/exercise activities at least once a week) using the Mann-Whitney test.

PA levels
Subsequently, we conducted analyses to capture the change trends in the participants' PA levels and evaluated valid daily activity data using the monitoring (>21 h/day) and three sigma limits. The tracker's non-wearing time for each participant was calculated using the duration of no heart rate data for each day. We removed daily PA records from the analysis sample if a participant did not wear the tracker for three hours or longer on that day. Based on this criterion, 7% of the data were excluded. In addition, we eliminated a daily record outside 3σ (three times the standard deviation; SD) from the participant's 84-day mean score; thus, another 1% of the data were invalid and removed. Then, for each participant, we calculated the weekly mean from Monday to Sunday from the daily sample for each PA indicator, that is, the number of steps and activity calories. We applied analyses of awareness and motivation data to the PA data to explore weekly changes as the impacts of PA monitoring and the short-term pandemic.

Detailed impacts of the short-term pandemic and pre-to-post general changes
To explore the different impacts of COVID-19 on affected and non-affected participants, we applied the Mann-Whitney test to the responses collected by the COVID-19 Questionnaire. Finally, we used the Wilcoxon signed-rank test to examine the participants' health statuses and QOL changes according to their pre- and postresponses to the General Questionnaire. All statistical analyses were performed using IBM SPSS Statistics 26 (Chicago, IL, USA).

Results

Participant characteristics
This study included 30 participants (10 women and 20 men) with a mean age of 71.7 (67–75) years. Their mean BMI was 23.1 (17.4–30.1) kg/

Table 1. The overall change trends of awareness, motivation and PA (N=30)

Measures	Baseline	Self-monitoring period: Before the pandemic (Week 1-Week 6)	Self-monitoring period: During the pandemic (Week 7-Week 12)	p_1
Awareness and motivation factors				
I. Awareness of PA benefits	5.66 (0.72)	6.10 (0.70)	6.19 (0.75)	**
p_2 (between weeks)	NA	**		
II. Satisfaction with monitoring	4.96 (0.87)	5.24 (1.02)	5.22 (1.11)	
p_3	NA			
III. Motivation towards monitoring	4.33 (0.84)	5.27 (0.87)	5.45 (0.93)	***
p_4	NA			
IV. Normative feeling for PA	4.40 (1.10)	4.54 (1.16)	4.67 (1.21)	
p_5	NA			
PA levels				
Number of steps (/day) (Baseline obtained N=17)	7529 (2035)	10963 (3717)	9953 (3962)	***
p_6	NA			
Number of steps (/day) (In total N=30)	NA	10789 (3313)	9777 (3466)	**
p_7	NA		**	
Activity calories (kcal/day)	NA	1057 (391)	985 (412)	*
p_8	NA		*	

PA: Physical activity. NA: Not applicable.
Figure: Mean (standard deviation).
*: $p < 0.05$; **: $p < 0.01$; ***: $p < 0.001$.
p_1: Significance level of difference between baseline, before and during the pandemic by the Friedman test or Wilcoxon signed-rank test.
p_2-p_8: Significance level of difference between 6 weeks (Week 1-6 or Week 7-12) by the Friedman test.

m2, and seven participants were overweight (BMI ≥ 25 kg/m2). Half of the participants had a chronic disease, and 23 performed PA regularly (i.e., engaging in regular PA such as walking or other sports/exercise activities at least once a week). In addition, although half the participants had pedometer usage experience, none had experience using wearable activity trackers. Regarding lifestyle changes due to COVID-19, 24 participants agreed or slightly agreed (affected group) with the change; five participants disagreed or slightly disagreed (non-affected group), and the remaining one participant had a neutral response as neither agreed nor disagreed.

Change trends of awareness and motivation

Overall change trends

Table 1 shows the transitions of the four awareness and motivation factor scores for all 30 participants in terms of the baseline, before the pandemic, and during the short-term pandemic. The results of the Friedman test showed significant differences in two out of the four factors. Overall, participants' awareness of PA benefits and their motivation toward monitoring significantly increased after PA monitoring, and the high level was maintained throughout the 12-week monitoring period even during the short-term pandemic. For the comparisons between weeks, the only significant difference was observed in participants' awareness of PA benefits between the six weeks before the pandemic, as shown in *Table 1*. This difference was because of a significant increase from week 1 to week 2 (mean = 5.98 versus 6.15; $p < 0.05$ by the Wilcoxon signed-rank test). For the detailed weekly transitions, please refer to *Figure 2*.

Comparisons by participant characteristics

For each week of the four factors, we compared the COVID-19-affected and non-affected groups, and the results of the Mann-Whitney test showed no significant differences. The weekly transitions of the two groups are shown in *Figure 2*. In addition, participants' awareness and motivation were compared by sex, BMI, presence of chronic disease, and participation in regular PA. We only observed significant differences in the BMI category (BMI < 25; BMI ≥ 25) and mostly for their awareness of PA benefits ($p < 0.05$). However, although the lower BMI group (5.84 for baseline, 6.25 before the pandemic, and 6.36 during the short-term pandemic) had higher awareness than the overweight group (5.07, 5.61, and 5.63, respectively), the two groups shared the overall change trends.

Change trends of PA

Overall change trends

Seventeen participants reported the number of steps before monitoring. Thus, these reported 17 data were used as baseline data, and the remaining 13 participants' baseline were dealt with as missing values. We did not observe significant differences between those who reported and those who did not for each of the following 12 weeks ($p > 0.05$ by the Mann-Whitney test). *Table 1* shows the transitions of the participants' PA for daily number of steps and burned activity calories for all 30 participants in terms of the baseline, before the pandemic, and during the short-term pandemic. Compared with the baseline, we observed a significant increase (approximately 3,000 steps/day) in the 17 participants' daily steps after monitoring, and the steps remained constant during the six weeks before the pandemic started;

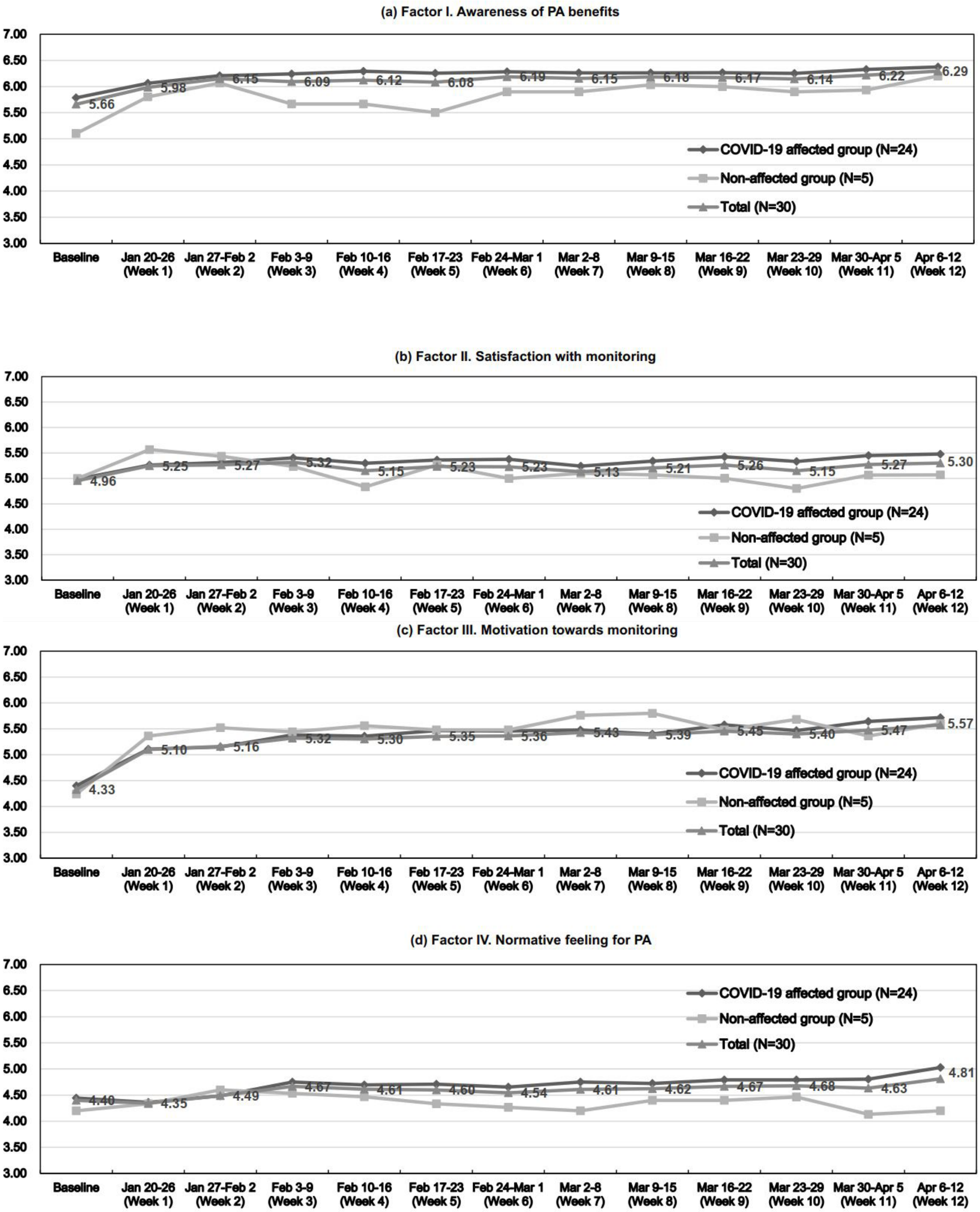

Figure 2. The weekly change trends of awareness and motivation

then, we observed a decrease in steps due to the pandemic, although it remained higher than that at baseline. For all 30 participants, the overall change trend was observed similarly as no significant difference during the six weeks before the pandemic, and then a decrease because of the pandemic. Due to the restrictive measures during the short-term pandemic, participants' steps changed significantly between the six weeks. For the detailed weekly transitions and the restrictive measures, refer to *Figure 3*. Regarding the activity calories, the change trend was almost consistent with that of the number of steps. However, during the short-term pandemic, we observed a decrease in activity calories (7%) smaller than that in steps (9%; *Table 2*).

Comparisons by participant characteristics

As shown in *Figure 3*, the COVID-19-affected and non-affected groups shared a trend before

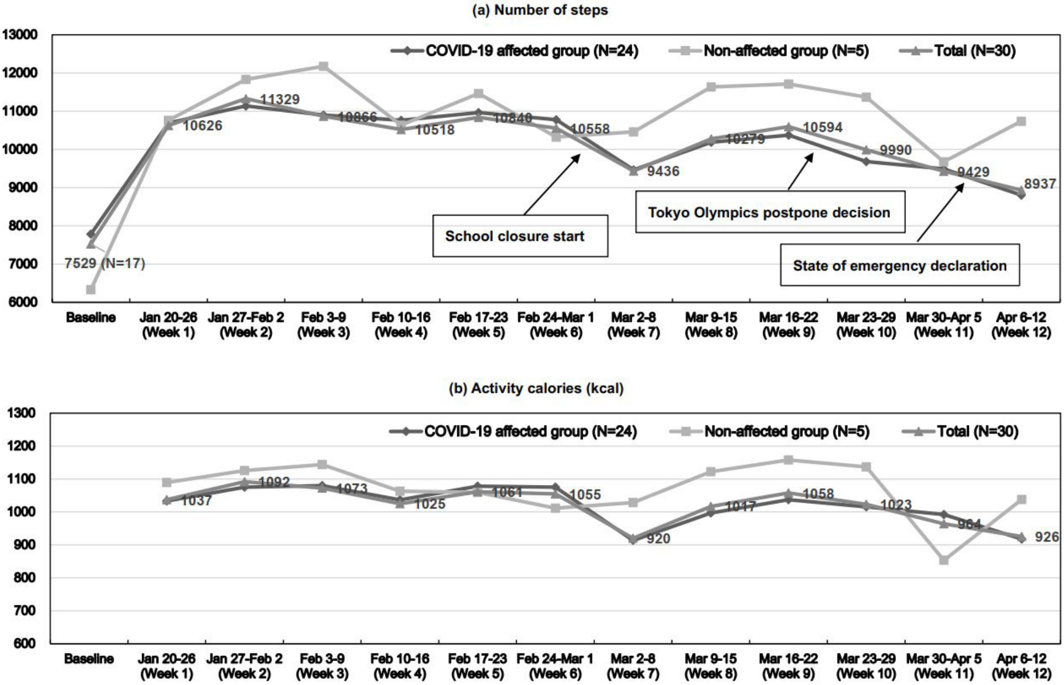

Figure 3. The weekly change trends of physical activity

the pandemic but differed during the short-term pandemic. The decrease in steps and activity calories in the non-affected group was 2%; in the affected group, we observed an 11% decrease in steps and an 8% decrease in activity calories (*Table 2*). In addition, we compared the participants' PA change trends by sex, BMI, presence of chronic disease, and regular PA participation. As shown in *Table 2*, although PA levels differed, all groups shared the change trends, in that the tracker had positive effects. Furthermore, during the short-term pandemic, we observed a slightly smaller decrease in activity calories (4%–10%) than that in steps (6%–14%) for each group.

Detailed impacts of the short-term pandemic

We examined the detailed impact of the shortterm pandemic on participants using the COVID-19 Questionnaire, the results of which are shown in *Table 3*. In both the COVID-19-affected and non-affected groups, we observed positive attitudes toward PA monitoring during the short-term pandemic. However, we identified significant differences in the impact of the shortterm pandemic on their daily lives and efforts regarding PA. No participant in the non-affected group perceived the activity level to decrease significantly, as opposed to 42% in the affected group (I-6). However, a larger percentage of the affected-group participants attempted to make substantial efforts, such as shortening their sitting time (38%; I-4) and engaging in indoor activities to compensate for insufficient outdoor activities (71%; I-15). All these results are consistent with the results of awareness, motivation, and PA level changes.

Health status and QOL pre-to-post changes

Changes in the participants' health condition and QOL were investigated using their pre- and post-responses to the General Questionnaire. Their health condition and QOL did not change even after the short-term pandemic. Only a single item showed a significant change at the 10% level ($p = 0.052$) by the Wilcoxon signed-rank test. More participants (increased from 43% to 63%) were confident in their health condition after monitoring.

Discussion

Increased awareness, motivation, and improved PA

This study's findings showed that wearable activity tracker usage increased participants' awareness of PA benefits, and the trends matched their PA behavior change (before the pandemic). In addition, increased PA resulted in higher confidence in their health condition. Thus, promoting PA awareness, motivation, and behavior using activity trackers is well supported by behavior change theories. Furthermore, because of the increased awareness of PA benefits on lifestyle and health, achieving a long-term commitment to PA could be expected (Haskell et al., 2007); however, further studies are required to verify the long-term effects. The positive effects observed in this study may be attributed to wearable trackers combined with self-regulatory tech-

Table 2. Changes of PA by participants' characteristics

Characteristics	PA indicators	Baseline[a]	Self-monitoring period: Before the pandemic (Week 1-Week 6)	Self-monitoring period: During the pandemic (Week 7-Week 12)	Changes by pandemic (%)
COVID-19					
Affected (N=24)	Number of steps	7786 (1847)	10872 (3434)	9668 (3628)	-11%
	Activity calories (kcal)	NA	1063 (413)	979 (438)	-8%
Non-affected (N=5)	Steps	6333 (2887)	11199 (2732)	10931 (2644)	-2%
	Activity calories	NA	1082 (333)	1056 (323)	-2%
Sex					
Man (N=20)	Steps	8500 (1261)	11244 (3259)	10268 (3639)	-9%
	Activity calories	NA	1238 (320)	1150 (381)	-7%
Woman (N=10)	Steps	5200 (1605)	9880 (3401)	8822 (2990)	-11%
	Activity calories	NA	695 (239)	662 (231)	-5%
BMI					
<25 kg/m^2 (N=23)	Steps	7542 (2137)	10590 (3185)	9595 (3278)	-9%
	Activity calories	NA	1041 (388)	967 (390)	-7%
≥25 kg/m^2 (N=7)	Steps	7500 (2000)	11446 (3899)	10382 (4254)	-9%
	Activity calories	NA	1110 (426)	1040 (509)	-6%
Chronic disease					
Yes (N=15)	Steps	7850 (1510)	11645 (3961)	10970 (4161)	-6%
	Activity calories	NA	1114 (424)	1068 (476)	-4%
No (N=15)	Steps	7071 (2684)	9934 (2342)	8566 (2191)	-14%
	Activity calories	NA	1000 (361)	900 (336)	-10%
Regular PA					
Yes (N=23)	Steps	7643 (1737)	11560 (3269)	10455 (3612)	-10%
	Activity calories	NA	1136 (391)	1053 (417)	-7%
No (N=7)	Steps	7000 (3606)	8258 (2035)	7605 (1566)	-8%
	Activity calories	NA	797 (272)	763 (315)	-4%
Total (N=30)					
	Steps	7529 (2035)	10789 (3313)	9777 (3466)	-9%
	Activity calories	NA	1057 (391)	985 (412)	-7%

PA: Physical activity. NA: Not applicable. [a]: The baseline data were from 17 participants.
Figure: Mean (standard deviation) per day. Changes by pandemic (%) = (Mean of Week 7-12 – Mean of Week 1-6)/Mean of Week 1-6

niques (i.e., self-monitoring, real-time feedback, and goal setting) that enhance self-efficacy for PA, which is a direct predictor of participation in PA (Gualtieri et al., 2016; Wu et al., 2023; Zhang et al., 2022). For many people, PA is a deeply ingrained habit, and choosing PA over inactivity tends to occur without awareness (Phillips & Gardner, 2016). This lack of conscious scrutiny is one of the main reasons why it is difficult to change sedentary habits. People are not always good at monitoring their behavior, especially when it is unintentionally executed (Wilson, 2002). Supporting self-monitoring abilities by providing timely and relevant feedback on behaviors has proven to be a successful strategy for disrupting the automaticity of deeply engrained habitual behaviors such as inactivity and making them available for conscious scrutiny (Hermsen et al., 2016). This real-time feedback could also help sustain the PA level by providing a convenient method to continuously observe its measurements (Chung et al., 2017). In addition to self-monitoring, a meta-analysis suggested that goal setting is another most effective mHealth strategy that leads to more success in PA interventions (Eckerstorfer et al., 2018). The trackers increased participants' self-efficacy by providing a tangible, visible reminder of their commitment to increasing PA and immediate feedback on PA data and progress toward a daily PA goal (Gualtieri et al., 2016). This could be one of the reasons why the increased number of steps observed in this study was higher than that reported (1,297 daily steps) in a self-monitoring systematic review and meta-analysis study (Larsen et al., 2019), in which PA monitors were accelerometers and pedometers with no goalsetting function.

Furthermore, the positive effects observed in this study may be due to the social value perceived by the participants. Social value has been reported as one of the most important motivators of older adults' continued wearable health technology use (Kononova et al., 2019; Talukder et al., 2021). The social connection and recognition associated with wearable trackers contribute to positive emotions, and it is an important motivator for continuous use and behavior change.

Different effect patterns of wearable activity tracker during the pandemic

Regarding attitudes during the pandemic, some older adults tried to maintain their lifestyles, while others changed (Suzuki et al., 2020). In addition, restrictions against the COVID-19 outbreak created different situations. Our findings revealed that all participants maintained high levels of awareness and motivation for PA during the short-term pandemic. Although the effects of activity trackers on PA had different patterns (i.e., engaging in outdoor activities or making more efforts in indoor activities), participants in this study had

Table 3. Detailed impacts of the short-term COVID-19 pandemic

Question items (during the pandemic)	Affected group (N = 24)	Non-affected group (N = 5)	Total (N = 30)
Attitudes to monitoring			
I-1. It is meaningless to monitor PA by tracker.	0%	0%	0%
I-11. I disliked checking PA score, as I mostly stayed at home.	0%	0%	0%
I-12. I was reluctant to monitor PA.	0%	0%	0%
I-14. I wish the monitoring was extended to compensate for the inactive period.	29%	20%	27%
Pandemic impacts on daily life			
I-2. I stopped taking walks or reduced the number of times.	25%	0%	23%
I-5. We should stay at home as much as possible.	83%	80%	83%
I-6. My daily PA decreased greatly. (*)	42%	0%	33%
I-8. It cannot be helped that daily PA level became lower. (*)	67%	20%	57%
I-9. My sleeping quality was degraded.	17%	0%	13%
I-3. The fear of corona virus became stronger than at the beginning.	96%	80%	93%
I-16. I tried to live as usual as possible.	63%	100%	70%
Efforts for PA			
I-4. I tried to make continuous sitting time as short as possible. (*)	38%	0%	30%
I-7. I should have tried to maintain my PA level.	42%	40%	40%
I-10. I tried to achieve my goal of walking steps every day.	71%	60%	67%
I-15. I consciously tried to engage in indoor activities to compensate for insufficient outdoor PA. (*)	71%	20%	60%
I-13. I plan to do more exercise/PA after pandemic. (*)	79%	40%	73%

PA: Physical activity.
Figure: % agreed or strongly agreed.
*: $p < 0.05$ between affected and non-affected group by the Mann-Whitney test.

a low-level PA decrease during the short-term pandemic as it was reported that the pandemic led to approximately a 10%–50% PA decrease (Hamasaki, 2021). Overall, the positive effects of wearable activity trackers during the short-term pandemic also align with behavior change theories. In particular, the effects on awareness and PA during the no-restriction period could be expected in the following COVID-19 era.

Promoting the use of wearable activity trackers

The present study showed that commercial activity trackers are promising for older adults' PA awareness, motivation, and behavioral change. Although other invasive interventions may be more effective at increasing PA levels in older adults, activity trackers may offer a less resourceintensive approach that could be implemented on a larger scale (Brickwood et al., 2021; Larsen et al., 2019).

Wearable devices are mostly designed and produced considering younger people's physical and mental characteristics, as older adults' capacity to acknowledge the importance of and properly use these devices remains a challenge (Teixeira et al., 2021). In particular, older adults require greater mental effort to install apps and connect to activity trackers (Rasche et al., 2015). Therefore, to recommend the use of activity trackers in older adults' daily lives, initial setup support is suggested, as was done in this study. The Fitbit device was used in this study because it has been widely used in research and evaluated as acceptable, useful, and easy to use by older adults (Alharbi, et al., 2019; Zhang et al., 2022). Other wearable trackers have also been approved with adequate accuracy for measuring PA in older adults and for ease of use (Zhang et al., 2022). In addition to the Fitbit, Garmin Vivosmart and Samsung Galaxy Fit are recommended for older adults. However, with fast-paced technological developments, new continuous devices, frequent upgrades, and redesigned versions are being released. Thus, up-to-date reviews and research are required to verify the validity and reliability of these wearable trackers (Alharbi et al., 2019; Teixeira et al., 2021).

Behavior change theories suggest that behavior change is possible if feedback is not only delivered but also embedded in larger interventions with clear target behaviors and action plans. The combined use of activity trackers with other health apps, participation in a therapeutic regimen, and the use of the app and web-based platform that accompany the activity tracker may be seen as an operationalization of this concept of integration (Hermsen et al., 2017). Lined mobile apps also enable users to share health-related information with friends and healthcare providers for various purposes. If an effective healthcare system involving wearable activity trackers is constructed, health problems due to physical inactivity will decrease, and the burden of healthcare costs will decline (Hamasaki, 2021).

Limitations

This study had four main limitations: (1) the small sample size limited the power of the statistical analysis results; (2) it had selection bias because only older adults who had an Internet connection and a smartphone were selected. This could be due to the population having a pre-interest in the technology and already leading an active life, therefore having a higher PA or being able to realize an increased PA more easily. Based on statistical data from the Japanese Ministry of Internal Affairs and Communications in 2022, 87% of the population in their 60s and 66% in their 70s had an Internet connection, and 74% in their 60s and 47% in their 70s used a smartphone; this trend is increasing (MIC, 2022). Therefore, we believe our findings could be generalizable to a large proportion of older adults. Even so, future studies are required to investigate the effects of wearable activity trackers on different types of older adults; (3) the data on the baseline PA levels were inadequate. The main reason for not measuring the objective PA levels is that this study focused more on older adults' psychological changes. Potential influences other than those of the tracker monitoring were eliminated. However, we believe that the results of the increase in older adults' PA levels in this study are reliable as they are consistent with existing self-monitoring studies (Larsen et al., 2019). In addition, the change trends in the participants' PA levels fully matched their awareness and motivation (before the pandemic). Nevertheless, we acknowledge that this is a limitation, and better approaches to obtain baseline PA levels need to be considered in future studies. For instance, a tracker could be used to measure baseline PA levels, but the screen would be hidden to prevent the participants from knowing the data; (4) the monitoring duration was determined to be 12 weeks based on the literature review result of the median number of weeks for intervention length (Larsen et al., 2019). However, the duration should be longer to investigate the effects of the pandemic. As the pandemic was unexpected, and critical timings could not be anticipated, it was difficult to adjust the original plan. The study duration should also be longer—independent of the pandemic—to evaluate the duration of behavioral change in general. Accordingly, the long-term effects could be verified. All the limitations of this study are to be addressed in future studies.

Conclusions

In this study, we evaluated the effects of wearable activity trackers on older adults' awareness of and motivation for PA and their actual PA levels. We examined the effects of their change trends in a 12-week real-life setting by comparing the periods before and during the onset of the COVID-19 pandemic.

The main findings were four: (1) we observed significant positive effects of activity trackers on participants' awareness of PA benefits and motivation toward monitoring from the first week and almost maintained until the end of the study, even during the pandemic; (2) consistent with the awareness change, we observed an approximately 3,000-steps/day increase from the first week and maintained before the pandemic. Subsequently, the short-term pandemic had an impact on the decrease in PA level; however, the level remained higher than the baseline. Compared to before the pandemic, the decrease in steps and activity calories in COVID-19-nonaffected participants was 2%. In affected participants, we observed an 11% decrease in steps and an 8% decrease in activity calories, which indicates that 3% was compensated by their efforts for other activities; (3) participants with different demographic characteristics showed similar trends; (4) as a general effect, compared with before the monitoring, although the pandemic had started, participants became more confident in their health conditions after the 12-week monitoring.

We observed that wearable activity trackers had positive effects on older adults' awareness of PA benefits. Thus, using activity trackers could be a promising technique for improving older adults' long-term activity levels for their health. Future studies are required to verify the long-term effects of these devices.

Acknowledgments

This study was supported by the Japan Society for the Promotion of Science (grant number 18H01654). We are grateful to all the older adults participating in the experiment.

References

Ajzen, I., & Fishbein, M. (2005). The influence of attitudes on behavior. Erlbaum.

Albarracin, D., & Shavitt, S. (2018). Attitudes and attitude change. Annual Review of Psychology, 69, 299-327. https://doi.org/10.1146/annurevpsych-122216-011911

Alharbi, M., Straiton, N., Smith, S., Neubeck, L., & Gallagher, R. (2019). Data management and wearables in older adults: A systematic review. Maturitas, 124, 100-110. https://doi.org/10.1016/j.maturitas.2019.03.012

Brickwood, K. J., Ahuja, K. D. K., Watson, G., O'Brien, J. A., & Williams, A. D. (2021). Effects of activitytracker use with health professional support or telephone counseling on maintenance of physical activity and health outcomes in older adults: Randomized controlled trial. JMIR mHealth and uHealth, 9(1), e18686. https://doi.org/10.2196/18686

Cadmus-Bertram, L. A., Marcus, B. H., Patterson, R. E., Parker, B. A., & Morey, B. L. (2015). Randomized trial of a Fitbit-based physical activity intervention for women. American Journal of Preventive Medicine, 49(3), 414-418. https://doi.org/10.1016/j.amepre.2015.01.020

Callow, D. D., Arnold-Nedimala, N. A., Jordan, L. S., Pena, G. S., Won, J., Woodard, J. L., & Smith, J. C. (2020). The mental health benefits of physical activity in older adults survive the COVID-19 pandemic. American Journal of Geriatric Psychiatry, 28(10), 1046-1057.

https://doi.org/10.1016/j.jagp.2020.06.024
Chen, C., Ding, S., & Wang, J. (2023). Digital health for aging populations. Nature Medicine, 29(7), 1623-1630. https://doi.org/10.1038/s41591-023-02391-8
Chung, A. E., Skinner, A. C., Hasty, S. E., & Perrin, E. M. (2017). Tweeting to health: a novel mHealth intervention using Fitbits and Twitter to foster healthy lifestyles. Clinical Pediatrics, 56(1), 26-32. https://doi.org/10.1177/0009922816653385
D'Ambrogio, E. (2020). Japan's ageing society. European Parliamentary. https://www.europarl.europa.eu/RegData/etudes/BRIE/2020/659419/EPRS_BRI(2020)659419_EN.pdf
Eckerstorfer, L. V., Tanzer, N. K., Vogrincic-Haselbacher, C., Kedia, G., Brohmer, H., Dinslaken, I., & Corcoran, K. (2018). Key elements of mHealth interventions to successfully increase physical activity: Meta-regression. JMIR mHealth and uHealth, 6(11), e10076. https://doi.org/10.2196/10076
Ekelund, U., Tarp, J., Steene-Johannessen, J., Hansen, B. H., Jefferis, B., Fagerland, M. W., . . . Lee, I. M. (2019). Dose-response associations between accelerometry measured physical activity and sedentary time and all cause mortality: Systematic review and harmonised meta-analysis. British Medical Journal, 366, l4570. https://doi.org/10.1136/bmj.l4570
Fang, Y.-M., & Chang, C.-C. (2016). Users' psychological perception and perceived readability of wearable devices for elderly people. Behaviour and Information Technology, 35(3), 225-232. https://doi.org/10.1080/0144929X.2015.1114145
Ferguson, T., Rowlands, A. V., Olds, T., & Maher, C. (2015). The validity of consumer-level, activity monitors in healthy adults worn in free-living conditions: A cross-sectional study. International Journal of Behavioral Nutrition and Physical Activity, 12, 42. https://doi.org/10.1186/s12966-015-0201-9
Garatachea, N., Molinero, O., Martinez-Garcia, R., Jimenez-Jimenez, R., Gonzalez-Gallego, J., & Marquez, S. (2009). Feelings of well-being in elderly people: Relationship to physical activity and physical function. Archives of Gerontology and Geriatrics, 48(3), 306-312. https://doi.org/10.1016/j.archger.2008.02.010
Gualtieri, L., Rosenbluth, S., & Phillips, J. (2016). Can a free wearable activity tracker change behavior? The impact of trackers on adults in a physicianled wellness group. JMIR Research Protocols, 5(4), e237. https://doi.org/10.2196/resprot.6534
Hagstromer, M., Kwak, L., Oja, P., & Sjostrom, M. (2015). A 6-year longitudinal study of accelerometer-measured physical activity and sedentary time in Swedish adults. Journal of Science and Medicine in Sport, 18(5), 553-557. https://doi.org/10.1016/j.jsams.2014.07.012
Hair, J., Black, W. C., Babin, B. J., & Anderson, R. E. (2010). Multivariate data analysis (7th ed.). Pearson Education International.
Hall, K. S., Hyde, E. T., Bassett, D. R., Carlson, S. A., Carnethon, M. R., Ekelund, U., . . . Fulton, J. E. (2020). Systematic review of the prospective association of daily step counts with risk of mortality, cardiovascular disease, and dysglycemia. International Journal of Behavioral Nutrition and Physical Activity, 17(1), 78. https://doi.org/10.1186/s12966-020-00978-9
Hamasaki, H. (2021). Daily physical activity and sleep measured by wearable activity trackers during the coronavirus disease 2019 pandemic: A lesson for preventing physical inactivity during future pandemics. Applied Sciences, 11(21), 9956. https://doi.org/10.3390/app11219956
Hamer, M., Lavoie, K. L., & Bacon, S. L. (2014). Taking up physical activity in later life and healthy ageing: The English longitudinal study of ageing. British Journal of Sports Medicine, 48(3), 239-243. https://doi.org/10.1136/bjsports-2013-092993
Hamido, S., Gu, X., & Itoh, K. (2021). The impact of self-monitoring physical activity on the awareness and behaviour of university students. Journal of Japan Industrial Management Association, 72(2E), 134-148. https://doi.org/10.11221/jima.72.134
Hansen, B. H., Dalene, K. E., Ekelund, U., Wang Fagerland, M., Kolle, E., Steene-Johannessen, J., . . . Alfred Anderssen, S. (2020). Step by step: Association of device-measured daily steps with all-cause mortality - A prospective cohort Study. Scandinavian Journal of Medicine and Science in Sports, 30(9), 1705-1711. https://doi.org/10.1111/sms.13726
Haskell, W. L., Lee, I. M., Pate, R. R., Powell, K. E., Blair, S. N., Franklin, B. A., . . . Bauman, A. (2007). Physical activity and public health: updated recommendation for adults from the American College of Sports Medicine and the American Heart Association. Medicine and Science in Sports and Exercise, 39(8), 1423-1434. https://doi.org/10.1249/ mss.0b013e3180616b27
Hermsen, S., Frost, J. H., Renes, R. J., & Kerkhof, P. (2016). Using feedback through digital technology to disrupt and change habitual behavior: A critical review of current literature. Computers in Human Behavior, 57, 61-74. https://doi.org/10.1016/j.chb.2015.12.023
Hermsen, S., Moons, J., Kerkhof, P., Wiekens, C., & De Groot, M. (2017). Determinants for sustained use of an activity tracker: Observational study. JMIR mHealth and uHealth, 5(10), e164. https://doi.org/10.2196/mhealth.7311
Hodgson, W., Kirk, A., Lennon, M., & Paxton, G. (2021). Exploring the use of Fitbit consumer activity trackers to support active lifestyles in adults with type 2 diabetes: A mixed-methods study. International Journal of Environmental Research and Public Health, 18(21). https://doi.org/10.3390/ijerph182111598
Janz, N. K., & Becker, M. H. (1984). The Health Belief Model: A decade later. Health Education Quarterly, 11(1), 1-47. https://doi.org/10.1177/109019818401100101
Japan Ministry of Health, Labor and Welfare. (2013). Physical activity and exercise. https://www.mhlw.go.jp/www1/topics/kenko21_11/b2.html
Jiménez-Pavón, D., Carbonell-Baeza, A., & Lavie, C. J. (2020). Physical exercise as therapy to fight against the mental and physical consequences of COVID-19 quarantine: Special focus in older people. Progress in Cardiovascular Diseases, 63(3), 386-388. https://doi.org/10.1016/j.pcad.2020.03.009
Kononova, A., Li, L., Kamp, K., Bowen, M., Rikard, R. V., Cotten, S., & Peng, W. (2019). The use of wearable activity trackers among older adults: Focus group study of tracker perceptions, motivators, and barriers in the maintenance stage of behavior change. JMIR mHealth and uHealth, 7(4), e9832. https://doi.org/10.2196/mhealth.9832

Larsen, R. T., Christensen, J., Juhl, C. B., Andersen, H. B., & Langberg, H. (2019). Physical activity monitors to enhance amount of physical activity in older adults - A systematic review and meta-analysis. European Review of Aging and Physical Activity, 16, 7. https://doi.org/10.1186/s11556-019-0213-6

Lyons, E. J., Lewis, Z. H., Mayrsohn, B. G., & Rowland, J. L. (2014). Behavior change techniques implemented in electronic lifestyle activity monitors: A systematic content analysis. Journal of Medical Internet Research, 16(8), e192. https://doi.org/10.2196/jmir.3469

McCarthy, H., Potts, H. W. W., & Fisher, A. (2021). Physical activity behavior before, during, and after COVID-19 restrictions: Longitudinal smartphonetracking study of adults in the United Kingdom. Journal of Medical Internet Research, 23(2), e23701. https://doi.org/10.2196/23701

McMahon, S. K., Lewis, B., Oakes, M., Guan, W., Wyman, J. F., & Rothman, A. J. (2016). Older adults' experiences using a commercially available monitor to self-track their physical activity. JMIR mHealth and uHealth, 4(2), e35. https://doi.org/10.2196/mhealth.5120

McPhee, J. S., French, D. P., Jackson, D., Nazroo, J., Pendleton, N., & Degens, H. (2016). Physical activity in older age: Perspectives for healthy ageing and frailty. Biogerontology, 17(3), 567-580. https://doi.org/10.1007/s10522-016-9641-0

Ministry of Internal Affaires and Communications (MIC). Survey results regarding the Information and Communication Technology Services Usage in 2022. https://www.soumu.go.jp/johotsusintokei/statistics/statistics05.html

Nunnally, J.C. (1978). Psychometric theory (2nd ed.). McGraw-Hill.

Paul, S. S., Tiedemann, A., Hassett, L. M., Ramsay, E., Kirkham, C., Chagpar, S., & Sherrington, C. (2015). Validity of the Fitbit activity tracker for measuring steps in community-dwelling older adults. BMJ Open Sport and Exercise Medicine, 1(1), e000013. https://doi.org/10.1136/bmjsem-2015-000013

Peng, W., Li, L., Kononova, A., Cotten, S., Kamp, K., & Bowen, M. (2021). Habit formation in wearable activity tracker use among older adults: Qualitative study. JMIR mHealth and uHealth, 9(1), e22488. https://doi.org/10.2196/22488

Persson, A., & While, A. (2012). Physical activity among older people and related factors. Health Education Journal, 71(2), 144-153. https://doi.org/10.1177/0017896910396760

Phillips, L. A., & Gardner, B. (2016). Habitual exercise instigation (vs. execution) predicts healthy adults' exercise frequency. Health Psychology, 35(1), 69-77. https://doi.org/10.1037/hea0000249

Rasche, P., Wille, M., Theis, S., Schäefer, K., Schlick, C. M., & Mertens, A. (2015, October 26-28). Activity tracker and elderly: Usability and motivation of mobile healthcare in the context of elderly people. The IEEE International Conference on Computer and Information Technology; Ubiquitous Computing and Communications; Dependable, Autonomic and Secure Computing; Pervasive Intelligence and Computing, Liverpool, United Kingdom. https://ieeexplore.ieee.org/document/7363255

Seol, J., Abe, T., Fujii, Y., Joho, K., & Okura, T. (2020). Effects of sedentary behavior and physical activity on sleep quality in older people: A cross-sectional study. Nursing and Health Sciences, 22(1), 64-71. https://doi.org/10.1111/nhs.12647

Song, J., Lindquist, L. A., Chang, R. W., Semanik, P. A., Ehrlich-Jones, L. S., Lee, J., . . . Dunlop, D. D. (2015). Sedentary behavior as a risk factor for physical frailty independent of moderate activity: Results from the osteoarthritis initiative. American Journal of Public Health, 105(7), 1439-1445. https://doi.org/10.2105/AJPH.2014.302540

Sookhai, L., Coppola, J. F., & Gaur, C. (2015, May 1). Intergenerational activity tracker program: Impact with health related outcomes on older adults. 2015 Long Island Systems, Applications and Technology, Farmingdale, NY, United States. https://ieeexplore.ieee.org/document/7160218

Statistics Bureau of Japan. (2021). Statistical handbook of Japan. https://www.stat.go.jp/english/data/handbook/pdf/2021all.pdf#page=23

Suzuki, Y., Maeda, N., Hirado, D., Shirakawa, T., & Urabe, Y. (2020). Physical activity changes and its risk factors among community-dwelling Japanese older adults during the COVID-19 epidemic: Associations with subjective well-being and health-related quality of life. International Journal of Environmental Research and Public Health, 17(18). https://doi.org/10.3390/ijerph17186591

Talukder, M. S., Laato, S., Islam, A. N., & Bao, Y. (2021). Continued use intention of wearable health technologies among the elderly: An enablers and inhibitors perspective. Internet Research, 31(5), 1611-1640. https://doi.org/10.1108/INTR-10-2020-0586

Teixeira, E., Fonseca, H., Diniz-Sousa, F., Veras, L., Boppre, G., Oliveira, J., . . . Marques-Aleixo, I. (2021). Wearable devices for physical activity and healthcare monitoring in elderly people: A critical review. Geriatrics, 6(2), 38. https://doi.org/10.3390/geriatrics6020038

The World Bank. (2022). Fertility rate dataset. https://data.worldbank.org/indicator/SP.DYN.TFRT.IN

Tudor-Locke, C., Williams, J. E., Reis, J. P., & Pluto, D. (2002). Utility of pedometers for assessing physical activity: Convergent validity. Sports Medicine, 32(12), 795-808. https://doi.org/10.2165/00007256-200232120-00004

United Nations. (2022). 2022 Revision of world population prospects. https://population.un.org/wpp/

Wilson, T. D. (2002). Strangers to ourselves - Discovering the adaptive unconscious. Belknap Press of Harvard University Press.

World Health Organization. (2012). WHOQOL: Measuring quality of life. https://www.who.int/tools/whoqol/whoqol-bref

World Health Organization. (2020). World health statistics 2020: Monitoring health for the SDGs, sustainable development goals. https://apps.who.int/iris/handle/10665/332070

Wu, S., Li, G., Du, L., Chen, S., Zhang, X., & He, Q. (2023). The effectiveness of wearable activity trackers for increasing physical activity and reducing sedentary time in older adults: A systematic review and meta-analysis. Digital Health, 9,1-23. https://doi.org/10.1177/20552076231176705

Zhang, M., Luo, M., Nie, R., & Zhang, Y. (2017). Technical attributes, health attribute, consumer attributes and their roles in adoption intention of healthcare wearable technology. International Journal of Medical Informatics, 108, 97-109. https://doi.org/10.1016/j.ijmedinf.2017.09.016

Zhang, Z., Giordani, B., Margulis, A., & Chen, W. (2022). Efficacy and acceptability of using wearable activity trackers in older adults living in retirement communities: A mixed method study. BMC geriatrics, 22, 231. https://doi.org/10.1186/s12877-022-02931-w

Appendix I – Weekly questionnaire items

(-): Item labeling a reversed meaning.

Factor I. Awareness of physical activity benefits (Cronbach's α = 0.876)
Q7. Physical activity/exercise does not contribute to my health condition. (-)
Q20. I do not need physical activity in my life. (-)
Q18. I get no benefit from the feedback of my daily activity scores. (-)
Q5. Physical activity results in physical and psychological improvements.
Q4. I will continue to carry out my physical activity as much as possible.
Q9. When I have time, I try to perform physical activity.

Factor II. Satisfaction with monitoring (α = 0.836)
Q19. I would recommend this tracker to my friends and family.
Q11. Wearing this tracker on my wrist bothers me. (-)
Q12. It is nice to see how many steps I have taken.
Q1. I am satisfied that I can get information about my daily physical activity.
Q14. I feel satisfied when I have achieved my daily step goal.
Q3. When the tracker tells me that I require slightly more steps (e.g., 100 steps) to achieve my goal at the end of the day, I try to do so.

Factor III. Motivation towards monitoring (α = 0.714)
Q10. I check how much I have slept every day.
Q15. I am aware of how many hours I sleep every day.
Q6. It is difficult to spend time on daily exercises due to other activities. (-)
Q8. I seldom check how many steps I have taken during the day. (-)
Q13. I often check indicators other than step count, such as calories burned and heart rate.

Factor IV. Normative feeling for physical activity (α = 0.635)
Q2. I think I must walk a bit more than I currently do for my health.
Q17. If I have not achieved my goal, I will try to walk more the next day.
Q16. I want to brag to my friends/family about the number of steps I have taken.

Appendix II – COVID-19 questionnaire items

I-1. It is meaningless to monitor physical activity by tracker during the pandemic.
I-2. Because of the pandemic, I stopped taking walks or reduced the number of times.
I-3. The fear of coronavirus became stronger than at the beginning.
I-4. During the pandemic, I tried to make continuous sitting time as short as possible.
I-5. We should stay at home as much as possible to protect ourselves from corona virus.
I-6. Due to the fear of corona virus, my daily physical activity decreased greatly.
I-7. I should have tried to maintain my physical activity level even during the pandemic.
I-8. It cannot be helped that daily physical activity level became lower during the pandemic.
I-9. Because of the pandemic, my sleeping quality was degraded.
I-10. I tried to achieve my goal of walking steps every day even during the pandemic.
I-11. I disliked checking physical activity score, as I mostly stayed at home because of the pandemic.
I-12. I was reluctant to monitor physical activity during the pandemic.
I-13. I plan to do more exercise/physical activity after pandemic.
I-14. I wish the monitoring was extended to compensate for the inactive period because of the pandemic.
I-15. During the pandemic, to compensate for insufficient outdoor physical activities, I consciously tried to engage in indoor activities like stretching, cleaning and TV gymnastics.
I-16. I tried to live as usual as possible even during the pandemic.

Appendix III – General questionnaire items

1. My daily physical activity level is higher than the average people in my age.
2. I take better care of my health than others do.
3. I like exercise/physical activity more than average people in my age.
4. It's important for me to find time for daily exercise.
5. I intend to use the activity tracker (even after this research).
6. I need to do more physical activities than I do now.
7. I am confident in my health condition.
8. It's annoying to monitor activity with a tracker.
9. I enjoy my life very much.
10. My life is very meaningful.
11. I am able to concentrate whenever I have to.
12. I accept my physical appearance.
13. I am very satisfied with myself.