# Physical Activity Tracker Application in Promoting Physical Activity Behavior Among Older Adults: A 24-month Follow-up Study

**(ACCEPTED VERSION)**

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**Abstract**

Objectives: To investigate whether and how PA tracker application use supports PA behavior among older adults during the first 24 months of use.

Methods: The changes in PA levels (i.e., time spent in different PA intensities) and between PA categories (i.e., low, moderate, or high based on total PA) were examined between three different time points: before taking the application into use (t0), after 12 months of use (t1), and after 24 months of use (t2). The data was collected by using the International Physical Activity Questionnaire modified for the elderly (IPAQ-E).

Results: A statistically significant increase was observed in walking ($\chi^2(2) = 29.741$, $p < 0.001$), moderate PA ($\chi^2(2) = 6.327$, $p = 0.042$), and total PA levels ($\chi^2(2) = 11.489$, $p = 0.003$). The increase was observed between t0 and t1 as well as between t0 and t2. The overall changes between PA categories were statistically significant between t0 and t1 ($\chi^2(3) = 15.789$, $p = 0.001$) as well as between t0 and t2 ($\chi^2(3) = 14.745$, $p = 0.002$). There were more increasingly active (moved to a higher PA category) than decreasingly active (moved to a lower PA category) participants.

Discussion: Overall, the results indicate that PA tracker application use can promote PA behavior among older adults. Stakeholders that work with PA programs and PA promotion, as well as individual users, can utilize digital wellness technologies in supporting PA promotion, especially in exceptional times, like the COVID-19 pandemic, when health care restrictions prevent general gatherings.

**Keywords:** digital wellness technology, physical activity tracker application, mobile application, physical activity, older adults, IPAQ-E, follow-up study

# 1 Introduction

The older population forms a central target group for efforts aiming to promote and support healthy ageing. There are several reasons for this. The proportion of older citizens is rising in practically all countries worldwide, which together with the improving life expectancy at older ages (United Nations, 2019) makes healthy and physically active ageing an increasing priority area for governing bodies and healthcare providers (e.g., Rudnicka et al., 2020). According to the United Nations' (2019) estimate, the global population aged 65 years or older will double to 1.5 billion people by 2050, and whereas a person aged 65 years was expected to live 17 additional years in 2015–2020, by 2045–2050, this will increase to 19 additional years (United Nations, 2019). Hence, actions to support healthier ageing are becoming all the more needed in order to keep the older citizens healthy and active members of the society.

Physical activity (PA) and exercise support healthy ageing in various ways. They have several significant health benefits and contribute to the prevention of non-communicable diseases (World Health Organization [WHO], 2020). Sustained PA in older age is associated with improved overall health, while becoming physically active even at older age is beneficial for health (Hamer et al., 2014). PA also supports maintaining the ability to function in everyday life when a person gets older and helps to protect against age-related illness and frailty (Hoogendijk et al., 2019). PA in middle-age will likely also contribute to being able to stay in the job market for longer and retire later, as it decreases the risk of all-cause disability retirement (Lahti et al., 2013).

Physical inactivity, on the other hand, is a major health risk and a factor for premature death (WHO, 2020). According to an estimate by Ding et al. (2016), physical inactivity accounted for $54 billion in direct health care costs in 2013 alone. In Finland, where the present study was conducted, it was estimated that in 2017 alone, the mean direct and indirect costs associated with low PA were €3.2 billion in total, of which €419 million was from institutional eldercare and €325 million from disability-pension payments related to non-communicable diseases (Kolu et al., 2022). These are further reasons to allocate resources for PA promoting actions and to advance PA policies among older citizens.

The health benefits of PA are well-established (Warburton & Bredin, 2016), and the World Health Organization (WHO) along with several national health organizations provide research-based guidelines and recommendations for PA. For example, the WHO (2020) recommends that older adults should do at least 150–300 minutes of moderate PA or at least 75–150 minutes of vigorous PA per week, or an equivalent combination of these. Balance and muscle-strength exercises should also be conducted regularly. Additional health benefits can be reached with more moderate- and vigorous-intensity PA (WHO, 2020). Overall, there is a wide consensus on the positive health effects of PA and activities to improve muscle strength and balance among older adults. Despite this, insufficient PA is a major issue in all age groups across the globe (WHO, 2020). This issue of insufficient PA has further grown during the past few years due to the COVID-19 pandemic, which has limited the PA and exercise possibilities of older adults and led to a decrease in PA levels among them (Hoffman et al., 2022; Portegijs et al., 2021; Sepúlveda-Loyola et al., 2020; Son et al., 2021). Therefore, innovative solutions, both digital and non-digital, to promote PA among older adults are sorely needed.

One potential solution to promote PA is the use of *digital wellness technologies*. These are "digital technologies that can be used to support different aspects of wellness" (Kari et al., 2021) and comprise various kinds of devices, applications, and services. The use of these technologies for various wellness-related purposes has become common among different user groups with varying PA levels (Kettunen et al., 2017). Their use for PA, health, and social purposes has become more attractive also for older adults (Farivar et al., 2020). However, research on older peoples' use of digital wellness technologies and the associated outcomes has been relatively scarce (Farivar et al., 2020). For example, there is limited knowledge on how digital wellness technology use could promote older adults' PA behavior over a longer period of time, and to the best of our knowledge, no previous study has investigated this in a 24-month follow up. The potential benefits of digital wellness technology use for PA behavior among older adults has been suggested, but more research is called for (e.g., Carlsson & Walden 2017; Larsen et al., 2019; Seifert et al., 2018).

To address this, the present study investigates the following research question: *Whether and how PA tracker application use is related to PA behavior among older adults during the first 24 months of use?* PA is a multifaceted concept and PA behavior covers quite a variety of behaviors (Rhodes & Nigg, 2011), but there is a consensus definition for PA: "any body movement generated by the contraction of skeletal muscles that raises energy expenditure above resting metabolic rate, and is characterized by its modality, frequency, intensity, duration, and context of practice" (Thivel et al., 2018). In the present study, with PA behavior, we refer to walking, moderate PA, vigorous PA, and the subsequent total PA (IPAQ group, 2005a; Hurtig-Wennlöf et al., 2010). By addressing the research question, we contribute to the stream of research on digital wellness technologies and behavior change by providing research-based insights and contributing to the knowledge on how the use of these technologies can stimulate changes in PA behavior among older adults. From the practitioners' perspective, the findings are valuable for different stakeholders working with PA promotion and digital wellness technologies. The study was part of a research program in which older adult (60 years or older) participants used a mobile PA tracker application to track their everyday PA.

## 2 Digital Wellness Technologies in Promoting PA Among Older Adults

The use of digital wellness technologies has become increasingly interesting for older adults (e.g., Farivar et al., 2020). A central reason for them to use digital wellness technologies is the support towards PA behavior and the expected positive effects on health and wellness (e.g., Farivar et al., 2020). Indeed, by using technology, users are receptive to potential changes in their behavior, and the technology can support them towards behavior change (Oinas-Kukkonen, 2013). For example, studies (e.g., Kari et al., 2016a; Karppinen et al., 2016) have shown that the user experiences of using digital wellness technologies can steer PA behaviors in the future. There are several different kinds of features implemented in digital wellness technologies to support PA; these features can be found in devices, applications, and services. Commonly used ones include PA tracking features (e.g., Mendiola et al., 2015; Wang & Collins, 2021), data management features (e.g., James et al., 2019; Suh & Li, 2022), goal-setting features (e.g., Gordon et al., 2019; Kirwan et al., 2013), and some novel solutions even include digital coaching features (e.g., Kari & Rinne, 2018; Kettunen et al., 2020). Besides these utility related features, social support features (e.g., Suh & Li, 2022; Sullivan & Lachman, 2017) are common, as well as gamification (Kari et al., 2016a; Koivisto & Hamari, 2019) and exergaming features (e.g., Kari, 2014; Loos & Zonneweld, 2016), which are typically implemented to make PA more enjoyable. However, technology features alone are not enough for continued digital wellness technology use among older adults, and a successful integration of the used technology as part of the user's daily life is influenced more by the perceived added value to life (Moore et al., 2021). Moore et al. (2021) describe this added value to be formed by the resulting balance of motivators (or lack of motivators), technology features (and their accuracy), ease of use, technology purpose, and user experience.

Digital wellness technologies and the interventions utilizing them can provide efficient PA support for older adults. Several studies have identified their ability to promote not only PA but also related factors such as self-efficacy for exercise (e.g., Changizi & Kaveh, 2017; Kari et al., 2022; Kwan et al., 2020; Larsen et al., 2019; McGarrigle & Todd, 2020; Muellmann et al., 2018; Stockwell et al., 2019; Yerrakalva et al., 2019). For example, Changizi and Kaveh (2017), in a systematic review, showed that mHealth technology use can promote PA behavior, improve self-efficacy, and support self-management among older adults. Kari et al. (2022), in a 12-month follow-up study, found that PA tracker application use can be efficient in promoting self-efficacy for exercise among older adults. Kwan et al. (2020), in a systematic review, showed that eHealth interventions can be effective in increasing overall PA, walking steps, and energy expenditure during PA among older adults. Larsen et al. (2019), in a systematic review, showed that interventions utilizing PA technology are more effective than control interventions among older adults. McGarrigle and Todd (2020), in a review of reviews, showed that mHealth and eHealth technology use can be effective in increasing PA among older adults. Muellmann et al. (2018), in a systematic review, showed that partaking in an eHealth PA promotion intervention leads to increased PA levels among older adults. However, they also note that this evidence only applies to short-term effects and the evidence on long-term effects is lacking. Stockwell et al. (2019), in a systematic review, showed that behavior change interventions with digital technologies can increase PA and physical functioning, as well as reduce sedentary time among older adults. Yerrakalva et al. (2019), in a systematic review, showed that mHealth application-based interventions can promote PA and fitness as well as reduce sedentary time among older adults, but they also highlight the need for studies with longer follow-ups. Here it should be noted that, based on the above-mentioned systematic reviews and the papers reviewed in them, the terms eHealth and mHealth have often been used interchangeably. In general, mHealth (i.e., solutions delivered via mobile technology) can be seen as a sub-category of eHealth which includes electronic technology more comprehensively, but the distinction is not always unambiguous. The studies investigating mHealth/eHealth are also not just restricted to health but also include wellness related factors. In terms of the present study, a mobile PA tracker application falls under both mHealth and eHealth.

Besides the positive outcomes, also negative outcomes and experiences occur during the use of digital wellness technologies (Rockmann, 2019), and when the negative ones outweigh the positive ones, the technology will most likely not be accepted as part of the daily life of the older adult user (Moore et al., 2021). Different kinds of challenges related to the implementation and use also occur. Kari et al. (2020) identified various kinds of such challenges among older adults, and categorized them into technology-based challenges, user-based challenges, and PA-based challenges. When a user faces challenges, negative experiences, or negative outcomes, it increases the likelihood of technology (Kari et al., 2016b) and digital wellness program (Schroé et al., 2022) abandonment, in which case the potential benefits are also less likely to be reached.

In summary, several studies have shown the potential of digital wellness technologies in promoting PA behavior among older adults, but a common conclusion has been that more high-quality and more longitudinal studies are needed.

## 3 Methodology

The present study investigates the following research question: Whether and how PA tracker application use is related to PA behavior among older adults during the first 24 months of use? To investigate the changes in PA behavior over the course of time, we examined the changes in PA levels (i.e., time spent in different PA intensities) and PA categories (i.e., low, moderate, or high based on total PA) between the baseline, that is, before taking the application into use (t0), and two follow-ups: after 12 months of use (t1), and after 24 months of use (t2). This setup was done in order to estimate the sustainability of the possible changes, and to mitigate the influence of seasonal variation. In Finland, the possibilities for PA and exercise can vary a lot between summer and winter, and hence, all data collections for a given participant took place at the same time of the year. Accordingly, the participants in the present study consist of those partaking in the research program and using the application for a at least 24 months.

### 3.1 Research Setting

The present study was part of the DigitalWells research program conducted in Finland during 2019–2022. The purpose of the program was to support older adults in adopting and maintaining sustainable PA routines in their everyday lives and to find out if this could be promoted with a PA tracker application. The focus was on older adults (people aged 60 years or older), because of the possibility for meaningful contributions to healthier ageing. While the definition of older adult is somewhat arbitrary, it is often associated with the age at which one can begin to receive pension benefits. There is no standard numerical criterion, but United Nations has proposed a cut-off of 60 years or older to refer to the older populations (Kowal & Dowd, 2001).

In the program, the participants were provided with a mobile PA tracker application to be used in their everyday lives for tracking PA. The application was developed in the beginning of the program and the design was adapted to the potential needs of the target user group of older adults. By selecting and using an application that was our own design, we could provide the participants with an application that was tailored for this particular user group, and which also allowed us to provide better technical support if needed. The application operated on the Wellmo platform (Wellmo, 2022), where the application features constituted their own entity. That is, the features the participants used formed an independent section inside the Wellmo platform and were readily available for use when opening the application. Wellmo supports the iOS and Android operating systems. The central features of the application were built around the tracking of everyday PA. These included features for tracking the conducted PA and exercise as well as weekly, monthly, and annual reports on these. From each PA or exercise session, activity type, intensity, duration, and date were stored, and kilocalories and metabolic equivalent of task minutes (MET-minutes) calculated. The users could also set a personal weekly goal in MET-minutes, which could be followed in the reports. There was no direct connection from the application to any wearable device, but it was possible to import PA data from external services supported by the Wellmo platform, such as Apple Health, Google Fit, and Polar Flow, which in turn could have derived the PA data from different wearable devices. Though only about 14% of the participants ever used this import feature. The application and its use were free of charge for the participants, but they were required to have an own smartphone. In general, the participants reported that the application was easy to use in everyday life. Based on our communication with the field researchers and participants during the program and the approximate amount of direct support requests, we estimate that less than 5% of the participants experienced usage issues with the application. Support for use and assistance to resolve possible issues was always available.

The first groups of participants joined the research program in June 2019, after which new groups were recruited continuously. The groups were contacted and recruited via the Finnish pensioners' associations, who assisted in advertising the possibility to join the program to their members. No limits except for age (60 years or older) were set for partaking, as we and the pensioners' associations wanted each willing person to have the chance to take part in the program and receive the potential benefits for their PA behavior. In total, 802 participants in 30 different groups joined the program. As different groups could join at different times, those who started earlier had been taking part longer at the end of the research program (February 2022). Each group of participants, typically consisting of 20–30 people, had a designated field researcher who guided the participants in taking the application into use and in using it. This was done in either face-to-face meetings or remotely, depending on the COVID-19 situation. Face-to-face follow-up meetings with the groups were scheduled to be held every six months, but due to the varying COVID-19 restrictions, some of these meeting had to be cancelled or postponed to a later date. Hence, during the first 24 months, each group had four face-to-face meetings organized and run by the field researcher. The participants used the application in their everyday lives and conducted PA according to their own preferences. They were not provided with any specific exercise programs or goals, but instead could freely carry out PA and exercise as much as, how, and when they wanted. In other words, the program largely relied on the PA tracker application in promoting PA. A participant could quit the program any time simply by informing about his or her willingness to do so. The dropout rate was 15% over the program. The local ethical committee was consulted before the start of the research program, which determined that no separate approval was required for the conducted studies. All participants provided a written informed consent when joining the program.

### 3.2 Data Collection

The data was mainly collected by using online surveys, which were created with the LimeSurvey software. At each data collection point (t0, t1, and t2), each participant received a personal survey invitation link to their email and was advised to respond as soon as possible. In the case of the participants who started in the program in June 2019 (approximately 20% of all the participants), the first data collection round (t0) was conducted with printed questionnaires during field meetings that were organized separately with each field group. In all cases, the participants were given instructions on answering. No time limit was set so they could take their time and respond at their own pace.

The data on PA levels were collected by using the International Physical Activity Questionnaire modified for the elderly (IPAQ-E) (Hurtig-Wennlöf et al., 2010), which is a modified version of the short-format IPAQ (Craig et al., 2003; Ekelund et al., 2006). The IPAQ-E has been culturally modified and validated for older populations (Hurtig-Wennlöf et al., 2010). The IPAQ and IPAQ-E are designed to provide a set of well-developed instruments that can be used to obtain comparable estimates of PA (IPAQ group, 2005a). The IPAQ-E collects self-reported PA data on sitting time, walking time, moderate PA time, and vigorous PA time from the period of last seven days. The IPAQ is the most widely validated and used PA questionnaire (Lee et al., 2011; van Poppel et al., 2010). For the present study, the IPAQ-E questionnaire was translated from Swedish to Finnish by following the wording of the Finnish short-format IPAQ. As there were both Finnish and Swedish (official languages in Finland) speaking participants, both language versions were used.

### 3.3 Data Analysis

After the data had been collected and before conducting the analysis, the data was processed as advised in the *Guidelines for the data processing and analysis of the International Physical Activity Questionnaire* (IPAQ group, 2005b). That means that the standard methods for the cleaning and treatment of IPAQ datasets were adopted and applied (IPAQ group 2005b, p. 10–11). We followed the same guidelines as well as the guidelines by Hurtig-Wennlöf et al. (2010) for presenting the results, that is, the results are presented in *median minutes per week* (rather than means) together with the interquartile ranges (25th–75th percentile) (IPAQ group, 2005b) and in *time in minutes spent in different intensities* (instead of converting into MET-values and MET-minutes), except for the total PA which is presented in MET-minutes per week (Hurtig-

Wennlöf et al., 2010, p. 1853). The total PA MET-minutes were calculated by using the formula: 3.3 * walking minutes + 4.0 * moderate PA minutes + 8.0 * vigorous PA minutes (IPAQ group, 2005b).

The participants were also categorized into three PA categories (low, moderate, or high) based on the reported time in combination with a weighting factor for the different activities (for details, see Hurtig-Wennlöf et al., 2010; IPAQ group, 2005b). Hurtig-Wennlöf et al. (2010) note that the used weighting factors correspond to activity-specific MET values in adults, whereas in older adults they might not be fully appropriate. For example, vigorous intensity level of young adults is likely higher than the same intensity level in older adults. Yet, they "can still reflect the proportions of PA intensities and are therefore useful for ranking participants with regard to PA" (Hurtig-Wennlöf et al., 2010, p. 1853).

The analysis was conducted with the IBM SPSS Statistics 26 software. To analyze the changes in the time spent in different types (i.e., intensities) of PA (walking, moderate PA, and vigorous PA) and in sitting, as well as in total PA MET-minutes, the levels between the baseline and the follow-ups were compared. As all the investigated variables were non-normally distributed, non-parametric statistical tests were used. First, the Friedman test (Friedman, 1937) was used as an omnibus test to examine whether the overall change between different time points in each investigated variable was statistically significant. Second, if the Friedman test showed a statically significant change, the Wilcoxon signed-rank test (Wilcoxon, 1945) was used as a post-hoc test to pinpoint which time points in particular differed from each other. To analyze the changes in PA categories, we compared the changes between the baseline and the follow-ups. The statistical significance of the changes in PA categories were analyzed with the McNemar-Bowker test (Bowker, 1948).

The level of statistical significance for all the tests was set to $p < 0.05$. However, because multiple comparisons were conducted (i.e., three comparisons: t0 vs. t1, t0 vs. t2, and t1 vs. t2), to reduce the chance of type 1 error, the level of statistical significance of the Wilcoxon signed-rank test as well as the McNemar-Bowker test was adjusted with the Bonferroni correction (Bonferroni, 1936). This resulted in $p < 0.017$ (0.05 / 3) to be used as the adjusted level of statistical significance. The missing values were handled by using listwise deletion, that is, the responses of a certain participant to a certain item were excluded if the participant had not responded to it in each investigated data collection point. Thus, the exact number of respondents slightly varies between the items. The reasons for missing values include (i) a participant missing a follow-up survey for some reason and (ii) a response being removed from the analysis following the cleaning and treatment of the dataset as advised by the IPAQ group (2005b, p. 10–11).

## 4 Results

In total, 241 research program participants had been taking part for 24 months or longer by the end of the research program (i.e., at the time of the study), and thus, had the possibility to respond to the IPAQ-E at the baseline as well as at the 12-month and 24-month follow-up points. They form the sample of the present study. The descriptive statistics of this sample in terms of gender, age, marital status, and educational attainment are reported in Table 1. In terms of the WHO recommendation that older adults should do at least 150–300 minutes of moderate PA or at least 75–150 minutes of vigorous PA per week, or an equivalent combination of these (WHO, 2020), between 79.5% (at least 600 moderate-to-vigorous MET-minutes per week) and 64.1% (at least 1,200 moderate-to-vigorous MET-minutes per week) of the participants met this recommendation at the baseline. To account for the equivalent combination of moderate PA and vigorous PA, the threshold for meeting the WHO's recommendation was calculated by converting the minutes in each intensity to MET-minutes by using the weighting factors from the IPAQ (IPAQ group, 2005b), which sets the threshold of meeting the recommendation to 600–1,200 moderate-to-vigorous MET-minutes per week.

**Table 1: Descriptive statistics of the sample of this study (N=241)**

| | n | % |
|---|---|---|
| **Gender** | | |
| Male | 92 | 38.2 |
| Female | 149 | 61.8 |
| **Age** (mean 69.8 years – standard deviation 4.2 years) | | |
| Under 65 years | 17 | 7.1 |
| 65–69 years | 94 | 39.0 |
| 70–74 years | 103 | 42.7 |
| 75 years or over | 27 | 11.2 |
| **Marital Status** | | |
| Married | 163 | 69.7 |
| Common-law marriage | 19 | 8.1 |
| Single, divorced, widow/er | 52 | 22.2 |
| N/A | 7 | – |
| **Educational attainment** | | |
| Primary education | 13 | 5.6 |
| Vocational education | 160 | 69.0 |
| University of applied sciences | 17 | 7.3 |
| University | 42 | 18.1 |
| N/A | 9 | – |

### 4.1 Changes in PA levels between different time points

The Friedman test showed that there was a statistically significant change in walking ($\chi^2(2) = 29.741$, $p < 0.001$), moderate PA ($\chi^2(2) = 6.327$, $p = 0.042$), and total PA ($\chi^2(2) = 11.489$, $p = 0.003$) between different time points, and that there was no statistically significant change in sitting ($\chi^2(2) = 0.218$, $p = 0.897$) and vigorous PA ($\chi^2(2) = 1.225$, $p = 0.542$). Table 2 presents the median minutes (or MET-minutes) per week with interquartile ranges at different time points. In addition, Figures 1 and 2 present the median minutes per week at different time points as a graphical illustration. Post-hoc analysis with the Wilcoxon signed-rank test was conducted with a Bonferroni-adjusted significance level of $p < 0.017$[1]. With walking, there was a statistically significant increase in minutes per week between t0 and t1 ($Z = -5.356$, $p < 0.001$) as well as between t0 and t2 ($Z = -3.376$, $p = 0.001$), but no statistically significant change between t1 and t2 ($Z = -2.222$, $p = 0.026$). With moderate PA, although the omnibus test showed a statistically significant change between different time points, the post-hoc tests could not identify which of the time points differed from each other. The time points between which the changes were found to be closest to being statistically significant were t0 and t2 ($Z = -2.000$, $p = 0.045$) as well as t1 and t2 ($Z = -1.804$, $p = 0.071$). With total PA, there was a statistically significant increase in MET-minutes per week between t0 and t1 ($Z = -3.447$, $p = 0.001$) as well as between t0 and t2 ($Z = -3.544$, $p < 0.001$), but no statistically significant change between t1 and t2 ($Z = -0.662$, $p = 0.508$).

**Table 2: Medians and 25th–75th percentiles of PA levels at different time points**

| | | t0 (min/week) | | t1 (min/week) | | t2 (min/week) | | Missing |
|---|---|---|---|---|---|---|---|---|
| | n | Med | 25th–75th | Med | 25th–75th | Med | 25th–75th | |
| **Sitting** | 222 | 2,100 | 1,680–2,730 | 2,100 | 1,680–2,730 | 2,100 | 1,680–2,940 | 19 |
| **Walking** | 217 | 540 | 270–858 | 840 | 420–1260 | 720 | 360–1100 | 24 |
| **Moderate PA** | 222 | 240 | 120–458 | 240 | 90–450 | 240 | 120–540 | 19 |
| **Vigorous PA** | 222 | 60 | 0–240 | 60 | 0–240 | 90 | 0–240 | 19 |
| **Total PA** | 229 | 3,972 | 2,036–6,068 | 4,692 | 2,367–6,978 | 4,617 | 2,961–6,558 | 12 |

The cells represent minutes per week at different time points, except for Total PA, which represents MET-minutes per week. The Missing column represents the number of missing respondents for each item.

[1] Following a suggestion by a reviewer, we also run our analyses by using the Benjamini and Hochberg procedure (Benjamini & Hochberg, 1995), and the results that we obtained were very similar to those that were obtained by using the Bonferroni procedure. The only difference in the results was that in the case of walking, a statistically significant increase in minutes per week was found also between t1 and t2.

**Figure 1: Median minutes per week of walking, moderate PA, and vigorous PA at different time points**

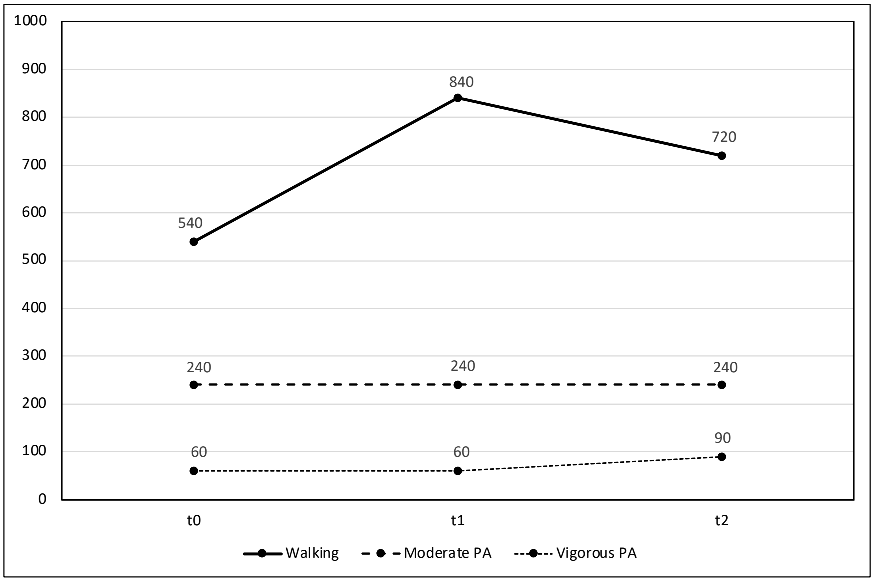
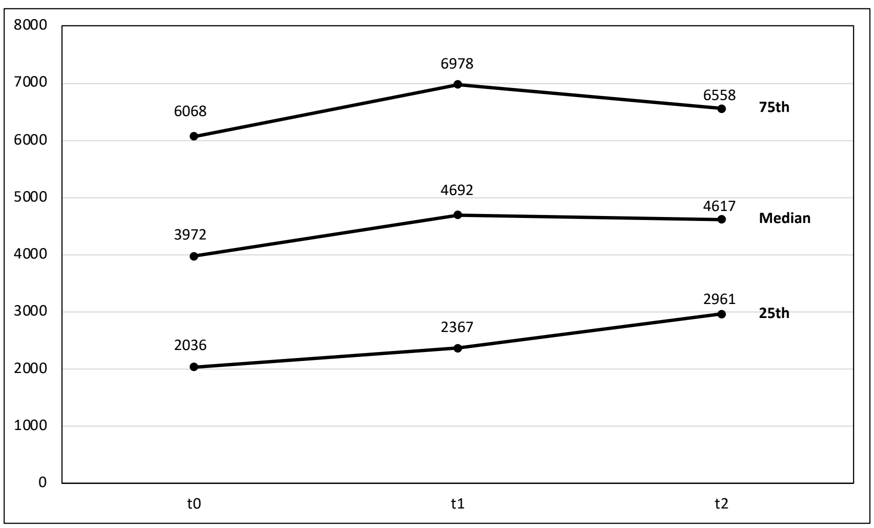



**Figure 2: Medians and 25th–75th percentiles of total PA MET-minutes per week at different time points**




## 4.2 Changes in PA categories between different time points

The changes in PA categories were investigated by examining the changes in the number of participants in PA categories low, moderate, and high (based on the IPAQ-E PA categorization) at different time points (Table 3). More precisely, it was investigated how many were increasingly active (i.e., moved from low → moderate/high or moderate → high), decreasingly active (i.e., moved from high → moderate/low or moderate → low), or equally active (i.e., stayed in the same category) between different time points (Table 4). Table 3 shows the number of participants in different PA categories at different time points, whereas Table 4 shows the changes in the number of participants in different PA categories between different time points.

**Table 3: Number of participants in different PA categories at different time points (N = 229)**

| | **t0** | | **t1** | | **t2** | |
|---|---|---|---|---|---|---|
| **PA category** | **n** | **%** | **n** | **%** | **n** | **%** |
| Low | 22 | 9.6 | 4 | 1.7 | 10 | 4.4 |
| Moderate | 63 | 27.5 | 56 | 24.5 | 44 | 19.2 |
| High | 144 | 62.9 | 169 | 73.8 | 175 | 76.4 |

**Table 4: Changes in the number of participants in different PA categories between different time points (N = 229)**

| **PA category** | **t1:** Low | **t1:** Moderate | **t1**: High |
|---|---|---|---|
| **t0**: Low | 0 | 8 | 14 |
| **t0**: Moderate | 3 | 22 | 38 |
| **t0**: High | 1 | 26 | 117 |

| **PA category** | **t2:** Low | **t2:** Moderate | **t2**: High |
|---|---|---|---|
| **t0**: Low | 4 | 6 | 12 |
| **t0**: Moderate | 3 | 20 | 40 |
| **t0**: High | 3 | 18 | 123 |

| **PA category** | **t2:** Low | **t2:** Moderate | **t2**: High |
|---|---|---|---|
| **t1**: Low | 0 | 1 | 3 |
| **t1**: Moderate | 8 | 18 | 30 |
| **t1**: High | 2 | 25 | 142 |

The McNemar-Bowker test suggested that the overall changes in PA categories were statistically significant between t0 and t1 ($\chi^2(3) = 15.789$, $p = 0.001$) as well as between t0 and t2 ($\chi^2(3) = 14.745$, $p = 0.002$), but not between t1 and t2 ($\chi^2(3) = 6.099$, $p = 0.107$). Of the participants, between t0 and t1, 26.2% were increasingly active, 13.1% were decreasingly active, and 60.7% were equally active. Between t0 and t2, 25.3% were increasingly active, 10.5% were decreasingly active, and 64.2% were equally active (Table 4). The equally active participants could belong to any of the three PA categories. Here it should be noted that obviously participants in the high category could only shift to a lower category or stay in the same category, whereas participants in the low category could only shift to a higher category or stay in the same category. In addition, we investigated whether belonging to the increasingly active, decreasingly active, or equally active groups had a statistically significant dependency with gender, age group, marital status, or educational attainment by using contingency tables (crosstabs) and the Pearson's $\chi^2$ tests of independence. The results of the Pearson's $\chi^2$ tests of independence were advanced by using the Monte Carlo exact tests (Mehta & Patel, 2012), which were based on 10,000 sampled tables and 99% confidence level. This procedure is considered reliable and independent of the dimension, distribution, allocation, and the balance of the analyzed data (Mehta & Patel, 2012). The results show that there were no statistically significant differences between the increasingly active, decreasingly active, and equally active groups based on gender, age group, marital status, or educational attainment neither between t0 and t1 nor between t0 and t2.

## 5 Discussion and Conclusions

The main purpose of the present study was to investigate the following research question: Whether and how PA tracker application use is related to PA behavior among older adults during the first 24 months of use? To answer this question, we examined the changes in PA levels and PA categories between three different time points: the baseline before taking the application into use (t0), after 12 months of use (t1), and after 24 months of use (t2). The study was part of a research program in which older adult participants used a mobile PA tracker application to track their everyday PA.

Overall, in line with recent reviews (e.g., Changizi & Kaveh, 2017; Larsen et al., 2019; McGarrigle & Todd, 2020), the results indicate that PA tracker application use can promote PA behavior among older adults. There was a statistically significant increase in walking, moderate PA, and total PA levels. More specifically, with walking and total PA, there was a statistically significant increase between t0 and t1 as well as between t0 and t2. With moderate PA, the post-hoc test could not identify which time points differed from each other. There were no significant changes between t1 and t2 in any of the measured types of PA, indicating that the increase in PA levels takes place during the first 12 months of use and is sustained for at least 24 months of use, but no further increase takes place between 12 and 24 months. Based on this, it seems that most of the increase in total PA came from the increase in walking, which is typically a low intensity PA. Recent evidence suggests that health benefits of PA for older adults can be realized at lower intensity than the often-used guidelines of moderate to vigorous intensity PA (cf. Bangsbo et al., 2019).

In terms of walking, the median minutes per week increased from 540 to 840 between t0 and t1, and from 540 to 720 between t0 and t2, with increases also in the 25$^{th}$ and 75$^{th}$ percentiles (cf. Table 2 and Figure 1). In terms of total PA, the median MET-minutes per week increased from 3,972 at t0, to 4,692 at t1 and to 4,617 at t2, with increases also in the 25$^{th}$ and 75$^{th}$ percentiles (cf. Table 2 and Figure 2). Especially the increases in the 25$^{th}$ percentile should be noted, as the greatest relative health benefits are observed in physically inactive individuals who become more physically active (Moxley & Habtzghi, 2019; Warburton & Bredin, 2016). Moreover, an increase of this magnitude in walking (e.g., Kelly et al., 2014) and total PA (e.g., Warburton & Bredin, 2016) has the potential to protect against cardiovascular and all-cause mortality as well as against chronic diseases (e.g., Arem et al., 2015; Kelly et al., 2014; Warburton & Bredin, 2016). For example, Kelly et al. (2014) showed that for a standardized dose of 675 MET-minutes per week of walking, the reduction in risk for all-cause mortality was 11%, and the dose-response relationship was favoring more walking.

For sedentary behavior (i.e., sitting), there was no statistically significant changes. In other words, while the PA tracker application use was related to PA behavior, it was not related to sedentary behavior. Some previous reviews (e.g., Yerrakalva et al., 2019), on the other hand, have found evidence that mHealth application-based interventions could reduce the time in sedentary behavior. This suggests that applications that are aimed to support PA but do not include features for pausing or reducing sedentary behavior may not be efficient in decreasing sedentary behavior.

In addition to examining PA levels, we also investigated the change in PA behavior through PA categories of low, moderate, and high based on the classification by Hurtig-Wennlöf et al. (2010). This investigation revealed that there were more *increasingly active* than *decreasingly active* participants, while most remained in the same category. Similar to the statistically significant changes in PA levels, the overall changes in categories were statistically significant between t0 and t1 as well as between t0 and t2, but not between t1 and t2. More specifically, between t0 and t1, 26.2% were increasingly active and 13.1% were decreasingly active, whereas between t0 and t2, 25.3% were increasingly active and 10.5% were decreasingly active. We especially observed a shift from the low and moderate categories to the high category. Of the decreasingly active participants, the majority belonged to the high category at t0 – meaning that these participants could only shift down or remain in the same category. Reasons for shifting to a lower PA category were not explored, but based on casual messages received from the participants, this shift could potentially result from injury, sickness, or other health-related incidents which obviously hindered an individual's possibility to maintain PA levels. Indeed, several studies conducted among older adults (e.g., Moschny et al., 2011) have found that the most frequently cited barriers for PA are health related.

In general, our results are mostly in line with recent reviews on the potential of PA tracker applications to promote PA behavior among older adults (e.g., Changizi & Kaveh, 2017; Larsen et al., 2019; McGarrigle & Todd, 2020). What warrants further mention is that for all the participants in the present study, the follow-up measurements t1 and t2 took place during the COVID-19 pandemic, which in Finland caused restrictions on the use of exercise facilities and group activities. Hence, another positive remark is that the older adult participants were able to keep up and even increase their PA despite such restrictions. Further, our results suggest that PA tracker application use can be an efficient way to promote PA behavior among older adults under free-living PA conditions, that is, without supplementary PA programs or PA counseling. This is promising, as for most older adults, implementing a digital wellness technology for own use is a more viable option compared to finding and joining a PA program, be it a digital or non-digital one.

To summarize, a PA tracker application appears to have potential in promoting PA behavior among older adults and in sustaining the higher PA levels also for the longer-term, as indicated by the sustained change after 24 months of use. From a practical perspective, different stakeholders that work with PA promotion could utilize digital wellness technologies in supporting PA promotion. Digital wellness technologies also seem promising during exceptional times, such as the COVID-19 pandemic, when there are restrictions that prevent general gatherings in force. Individual users could also benefit by adopting digital wellness technologies for their own use to promote and sustain personal PA behavior. Hence, we can recommend their use for PA promotion both at societal and individual level.

## 6 Limitations and Future Research

There are two main limitations in the present study that should be acknowledged. First, all participants voluntarily joined the program and thus likely had some motivation to increase their PA levels. Also, considering that the proportion of participants in the high PA category at t0 was 62.9%, it seems that the participants represented a rather physically active subset of older adults. This limits the generalization of the results. Future research should aim to acquire more participants with lower PA levels to achieve more generalizable results. It might also be that that the actual benefits of application use could be higher (or lower) among the less active older adults and, hence, future research could focus on investigating its efficiency for older adults with different PA levels. Second, there was no control group in the study. Thus, while unlikely, it is possible that the changes in PA levels resulted from some other reason than using the application. However, as no exercise counseling was provided to the participants and they conducted PA and exercise in free-living conditions, we have a strong reason to believe that the PA tracker application use had a significant role in promoting PA. Moreover, our longitudinal study covered over 24 months. The pensioners' associations found it hard and were reluctant to invite members to potential control groups as they should take part in the study but not receive the potential benefits from the provided technology. Also, the possible influence of some external factors such as the COVID-19 restrictions, which have potentially influenced some participants' PA levels, cannot be ruled out. For future research, it would also be interesting to compare the effectiveness of different digital wellness technologies and focus on other outcomes besides PA behavior.

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**Declaration of conflicting interests**

The Authors declare that there is no conflict of interest.

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