SOCIAL FACTORS, WEARABLE ACTIVITY TRACKER USE AND PHYSICAL ACTIVITY PATTERNS IN OLDER ADULTS

by
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Abstract

Physical inactivity is an independent risk factor for multiple adverse health outcomes, threatening the health of the aging population. Wearable activity trackers (WATs) may be an innovative method to help improve physical activity (PA) patterns in older adults, including both moderate-to-vigorous physical activity (MVPA) and sedentary behaviors. The purpose of this study was to understand how WAT use, the COVID-19 pandemic, and social factors are associated with PA patterns among U.S. community-dwelling older adults.

This dissertation study used a multi-method design that involves secondary qualitative and quantitative analyses. The qualitative analysis was conducted using transcripts of 23 semi-structured interviews with older adults who participated in WAT-facilitated PA interventions. The quantitative analyses were conducted using older adults' data from the National Health Information Trends Survey cross-sectional data 2019 and 2020 waves to understand the associations among older adults' social factors, WAT use, and PA patterns before and during the first wave of the COVID-19 pandemic.

The qualitative analysis showed that older adults reflected positive experiences of using WATs to promote PA patterns but also reported issues related to WAT functionalities that can be improved. The quantitative analyses showed that older adults who were non-Hispanic African Americans, 65-74 years, women, with higher education, higher income, and living in the low-minority area were more likely to be frequent WAT users after adjusting for covariates. Male participants who were younger and had higher incomes had significantly longer weekly MVPA time than their counterparts. Male participants who were Non-Hispanic White, with higher education were more likely to have longer daily sedentary time. Frequent use of WATs was significantly associated with longer weekly MVPA time and shorter daily sedentary time. WAT

use significantly mediated the associations between socioeconomic status (income and education) and weekly MVPA time.

This dissertation study suggested the need to improve U.S. older adults' PA patterns to meet guideline requirements and showed the existing disparities in older adults' WAT use and PA patterns, emphasizing the need to implement WATs for older adults who are socially disadvantaged to prevent further perpetuating health disparities among older Americans.

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Dissertation Organization

This dissertation is organized into five chapters. The first chapter provides background and conceptual grounding for the study, identifying and defining key concepts, stating the purpose and aims of the dissertation study, and providing the conceptual framework used to guide the analyses.

Chapter Two (Manuscript One) presents a study using qualitative data analysis of semi-structured interviews to understand older adults' perceptions, acceptance, and experiences of using wearable activity trackers (WATs) to self-monitor and promote physical activity (PA). This qualitative study corresponds to aim 1 of this dissertation study.

Chapter Three (Manuscript Two) used a cohort dataset to describe the pattern of WAT use in older adults and examined U.S. older adults' social factors associated with their use of WATs. The findings from this manuscript correspond to aim 2 part 1 and aim 5 part 1 of this dissertation study.

Chapter Four (Manuscript Three) uses the same cohort dataset to describe sociodemographic and clinical characteristics of older adults with various PA patterns (i.e., MVPA time, sedentary time, and activity class), examines social factors associated with older adults' PA patterns, explore the associations between the use of WATs and older adults' PA patterns, and explored if this association was moderated by COVID-19 pandemic. Lastly, the mediation effect of WAT use on the association of socioeconomic status (SES) and PA patterns was tested. The findings from this manuscript correspond to aim 2 part 2, aim 3, aim 4, and aim 5 part 2 of this dissertation study.

Chapter Five provides a summary of results and discusses the integration of results across the three manuscripts and within other existing literature. The chapter discusses the implications of these results for future research, interventions, and policies.

CHAPTER 1: INTRODUCTION

Background

Physical Activity and Sedentary Behavior in Older Adults

The older adult population is increasing worldwide. In the U.S. alone, the population aged 65 or older is projected to double from 46 million in 2019 to over 98 million by 2060 (Mather, Jacobsen, & Pollard, 2015). In this demographic, improving functional ability can enable a broad range of physical and social activities that support overall well-being and will be critical in promoting healthy aging (World Health Organization [WHO], 2010).

Physical Activity (PA), defined as any bodily movement produced by skeletal muscles that require energy expenditure (WHO, 2010), encompasses exercise, sports, and physical activities performed as part of daily living, occupation, leisure, or active transportation (Garber et al., 2011; Langhammer, Bergland, & Rydwik, 2018). The World Health Organization (WHO) recommends at least 150 minutes of moderate to vigorous-intensity PA (MVPA) for older adults every week (WHO, 2010). Regular PA that meets the WHO recommendation plays an important role in the prevention and management of chronic diseases (Kruk, 2007). Consistent exercise at this moderate intensity has been found to reduce all-cause mortality and reduce risks of developing conditions such as cardiovascular disease, type 2 diabetes, and colon cancer (Oguma & Shinoda-Tagawa, 2004; Paterson, Jones, & Rice, 2007; Pinto et al., 2012; Ueshima et al., 2010).

However, most older adults living in the U.S. do not meet the PA guidelines outlined by the WHO. According to the Centers for Disease Prevention and Control (2019), 60% of this population did not achieve recommended PA patterns, with many of them experiencing significant physical function declines that compromise independence and quality of life (Gonyea, 2005; King & King, 2010). The lack of PA among older adults is concerning as both morbidity and mortality are significantly associated with inadequate PA among older adults (Carlson, Adams, Yang, & Fulton, 2018). Consequently, the lack of adequate PA among older adults may result in tremendously higher annual healthcare costs in the U.S. (Centers for Disease Prevention and Control [CDC], 2021).

In addition to lack of PA, sedentary behavior (SB) poses another health risk to older adults. SB is defined as sitting or reclining during waking hours with low energy expenditure (de Rezende, Rey-López, Matsudo, & do Carmo Luiz, 2014; Koltyn et al., 2019). According to Harvey et al.'s (2013) systematic review, approximately 60% of older adults remain sedentary for more than 4 hours per day (measured using self-report surveys), and 67% of the older population were sedentary for more than 8.5 hours daily (measured objectively using accelerometers). Prolonged sedentary time can lead to increased risk for functional decline, chronic disease, and premature mortality (Koltyn et al., 2019). On the other hand, breaks in sedentary time are linked to better health and function in older adults (Sardinha, Santos, Silva, Baptista, & Owen, 2015).

It is important to note that PA and SB are not opposing concepts, but rather independent concepts that synergistically influence an individual's health. An individual can achieve guideline-recommended activity levels and still have a sedentary lifestyle at the same time (Thivel et al., 2018). In this dissertation study, we introduce the concept "*Activity Class*" to better understand PA patterns, considering both PA and SB simultaneously. The four group are 1) high MVPA time, low sedentary time; 2) high MVPA time, high sedentary time, 3) low MVPA time, low sedentary time, and 4) low MVPA time, low sedentary time. The cut-off point for MVPA time was 150 minutes per week based on the WHO guideline, and the cut-off point for sedentary time was 6 hours per week based on previously published literature (Heron, O'Neill, McAneney, Kee, & Tully, 2019; Owen et al., 2010).

Older Adults' Barriers to Active Lifestyles

Older adults face several barriers that make it challenging to increase their PA and decrease SB (Johannsen et al., 2008; Langhammer et al., 2018). The most common barriers reported by older adults include (1) lack of interest and motivation, (2) pain, discomfort, and physical limitations, (3) fears and concerns for falling, (4) having no companion, (5) social pressure (having less time to spend with friends and family), (6) lack of professional guidance of PA, (7) time limits and competing priorities, (8) lack of access to facilities, and (9) other environmental factors (neighborhood safety and weather) (Franco et al., 2015; Nicholson et al., 2013; van Alphen, Hortobágyi, & van Heuvelen, 2016; Yarmohammadi, Mozafar Saadati, Ghaffari, & Ramezankhani, 2019).

WAT Use Help Overcome PA Barriers

Utilizing modern mobile technology can help overcome barriers to engaging older adults in a more active lifestyle. Wearable Activity Trackers (WATs), one such technology, are electronic devices that users can wear on their bodies to monitor various parameters (Tedesco, Barton, & O'Flynn, 2017). We refer to WATs as consumer wearable activity trackers (typically worn on wrists) such as Fitbit, Apple Watches, Garmin, etc. WATs offer many functionalities that may help with the PA barriers that older adults often experience. For example, WATs allow users to self-monitor various data such as step count, caloric expenditure, heart rates, sleep duration, and quality, etc. Users can also set daily/weekly exercise goals on their devices that will track their progress toward the goals. As a whole, WATs' built-in self-monitoring and goal-setting functions can promote older adults' interest and motivation toward PA and encourage better self-discipline (Beckham, 2012; Tedesco et al., 2017). WAT users can also connect with others to make plans to exercise with or compete against their friends or family. When this function is used, older adults may have a stronger sense of engagement with family and friends, including working towards the same goals (Tedesco et al., 2017). In addition, WATs often have built-in motivational prompts and exercise reminders which are pushed to users to break prolonged SB detected by the devices. These functionalities of WATs may help overcome PA barriers experienced by older adults (Beckham, 2012; Tedesco et al., 2017).

Older Adults' Experience, Capability, and Acceptance of WATs

Older adults may have different user experiences, capabilities (the degree to which they are confident and capable of using WATs), and acceptance (the degree to which they are open to the use of WATs) of WATs than younger adults. Older adults' capability and acceptance of using WATs may be influenced by difficulties in learning (Bong, Bergland, & Chen, 2019), perceived usefulness (Bong et al., 2019; Keogh, Dorn, Walsh, Calvo, & Caulfield, 2020; Preusse, Mitzner, Fausset, & Rogers, 2017), level of comfort of wearing the device(Keogh et al., 2020), familiarity with WATs (Chun & Patterson, 2012; Fischer, David, Crotty, Dierks, & Safran, 2014), issues with hearing and vision (Fischer et al., 2014), and issues with trust and privacy (Fischer et al., 2014; Gao, Li, & Luo, 2015). However, there is a current gap in understanding older adults' experience, capability, and acceptance of using WATs. This includes (1) a lack of understanding of older adults' capabilities of using WATs after given detailed instructions and digital device orientation or training (Fausset et al., 2013; Fritz, Huang, Murphy, & Zimmermann, 2014; Jarrahi, Gafinowitz, & Shin, 2018; Mercer et al., 2016; Naslund, Aschbrenner, Barre, & Bartels, 2015; Preusse et al., 2017), and (2) a lack of studies comparing older adults' experiences of using different WATs for a prolonged period (4-24 weeks).

Therefore, there is a need to understand older adults' experiences, capabilities and acceptance of using WATs considering these perspectives.

Social Factors, WAT Use, and PA

Social factors are demographic and economic characteristics of a population, including sex, race and ethnicity, income, education, and area environments. These factors influence individuals' health behaviors, including physical activity, and ultimately impact health outcomes. Several social factors have been found to be associated with the use of WATs in older adults. Studies suggest that older adults who are female, White, younger than 75 years, higher education levels, more income, and healthier have higher rates of WAT use (Kakulla & Kakulla, 2020; Li, Peng, Kononova, Bowen, & Cotten, 2020; Macridis, Johnston, Johnson, & Vallance, 2018). However, most of these findings were reported through studies with small samples (5-49 participants) who participated in an intervention (Brickwood, Watson, O'Brien, & Williams, 2019; Cadmus-Bertram, Marcus, Patterson, Parker, & Morey, 2015; Fausset et al., 2013; Preusse et al., 2017; Puri et al., 2017; Rosales, Fernández-Ardèvol, & Ferran-Ferrer, 2018). Of the three studies investigating older adults' WAT use, two of them (Kakulla & Kakulla, 2020; Vogels, 2020) only examined basic social factors (age, race, gender, education level and income). The other study (Schuster, Kadylak, & Cotten, 2023) used data that was collected solely online which may result in a sampling bias. Furthermore, there is a lack of research examining the role use of WATs play on the associations of social factors with PA patterns in older adults. Therefore, there is a need to investigate social factors associated with U.S. older adults' WAT-use and PA patterns using large scale data reflecting the Census makeup of the U.S. older adult population.

COVID-19 Pandemic, WAT Use and PA

The COVID-19 pandemic has had a significant impact on the lives of Americans, particularly those aged 65 years and above who have been the most impacted group (Elflein, n.d.). This pandemic has changed every aspect of older adults' lives in the U.S. On March 11th of 2020, the World Health Organization declared COVID-19 as a global pandemic. The U.S. government took action and implemented a series of social distancing policies to protect U.S. residents, including shelter-in-place orders, restrictions on dine-in at restaurants, closure of nonessential businesses such as gyms, and closure of public schools, libraries, senior centers, etc. Additionally, individuals entering in-door public areas are required to wear masks or face covers. While these policies were crucial in helping to "bend the curve", they could also result in a negative psychosocial impact on older adults. Compared to before the COVID-19 pandemic, older adults in the U.S. experienced more loneliness, depression, anxiety, hopelessness, and fewer social interactions during COVID-19 (Füzéki, Groneberg, & Banzer, 2020). All these factors may have affected older adults and led to reduced PA (Bu, Bone, Mitchell, Steptoe, & Fancourt, 2021; Hoffman et al., 2021; Markotegi, Irazusta, Sanz, & Rodriguez-Larrad, 2021). Current evidence indicates that an increasing number of older adults will not be meeting guidelines for PA due to the impacts of COVID-19 and it remains uncertain how to support older adults to remain physically active during and after the COVID-19 crisis (Cunningham & O' Sullivan, 2020). WATs, with the functionalities such as self-monitoring, goal setting, and providing social connections, may be effective in improving PA or buffering the effect of PA reduction among U.S. older adults during the COVID-19 pandemic. It is unknown how WATs influence U.S. older adults' PA before and during the COVID-19 pandemic.

Purpose and Study Aims

This study aims to understand how WAT use, COVID-19 pandemic, and social factors are associated with PA patterns among U.S. community-dwelling older adults.

The specific aims are:

Aim 1: Understand older adults' acceptance, capability, and experiences of using WATs for promoting PA.

Aim 2: Describe and compare characteristics among U.S. older adults with different WAT use patterns (part 1), and PA patterns (part 2).

Aim 3: Examine the association between WAT use patterns and PA patterns among U.S. older adults. *H3a:* Frequent WAT use is positively associated with PA, adjusting for covariates. *H3b*: Frequent WAT use is negatively associated with SB, adjusting for covariates. *H3c*: Frequent WAT use is positively associated with *activity classes* with high PA and low SB.

Aim 4: Explore the role of COVID-19 on the association between WAT use and PA. *H4a:* WAT use is positively associated with PA and negatively associated with SB, adjusting for covariates in both the before-COVID-19 Cohort and during-COVID-19 cohort (sub-group analyses). *H4b:* WAT use is more strongly associated with PA and SB during COVID-19 first wave than before COVID-19.

Aim 5: Evaluate the associations between social factors and older adults' WAT use patterns (part 1) and PA patterns (part 2). *H5a:* Older adults in socially and economically disadvantaged groups (low household income, low education level, live in disadvantaged area, racial and ethnic minority) are less likely to adopt WATs. *H5b:* Older adults in socially and economically disadvantaged groups are more likely to have lower PA and higher SB.

In this dissertation, chapter 2 (manuscript 1) will address the specific aim 1, chapter 3 (manuscript 2) will address specific aim 2 part 1, and specific aim 5 part 1, chapter 4 (manuscript 3) will address specific aim 2 part 2, aim 3, aim 4, and aim 5 part 2.

Additionally, shown in table 1.1, we present the definitions and terminology used in this dissertation study.

Table 1. 1 Definition of PA Patterns

PA Patterns	Moderate to Vigorous Physical Activity (MVPA) Time (Cutoff: 150 minutes/week)
	Sedentary Behavior (SB) Time (Cutoff: 6 hours/day)
	Activity Class: (1) high MVPA time, low sedentary time (2) high MVPA time, high sedentary time (3) low MVPA time, low sedentary time (4) low MVPA time, high sedentary time

Conceptual/Theoretical Framework

The conceptual framework of this dissertation study (Figure 1.2) was developed based on current literature and adapted from two existing frameworks: the Unified Theory of Acceptance and Use of Technology 2 (UTAUT2) framework (Venkatesh, Thong, & Xu, 2012) (Figured 1.1) and the Fundamental Cause Theory (Link & Phelan, 1995).

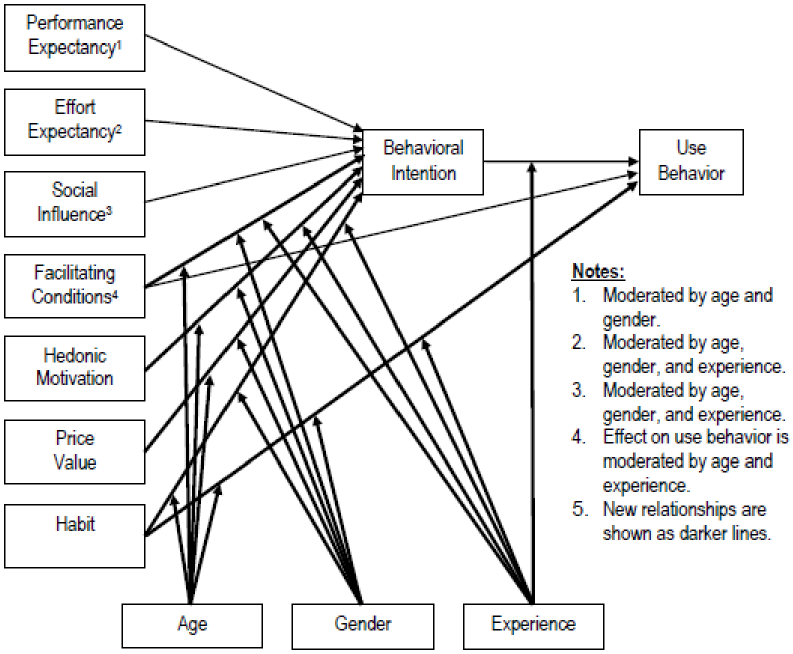

Figure 1.1 Unified Theory of Acceptance and Use of Technology

The Unified Theory of Acceptance and Use of Technology 2 (UTAUT2) Framework

The Unified Theory of Acceptance and Use of Technology 2 (UTAUT2) (Venkatesh et al., 2012) is an extension of the original theory, the Unified Theory of Acceptance and Use of Technology (Venkatesh, Morris, Davis, & Davis, 2003). It integrates existing theories and frameworks relevant to consumer acceptance of information technology, such as the Theory of Reasoned Action, the Technology Acceptance Model, the Motivational Model, and the Theory of Planned Behavior.

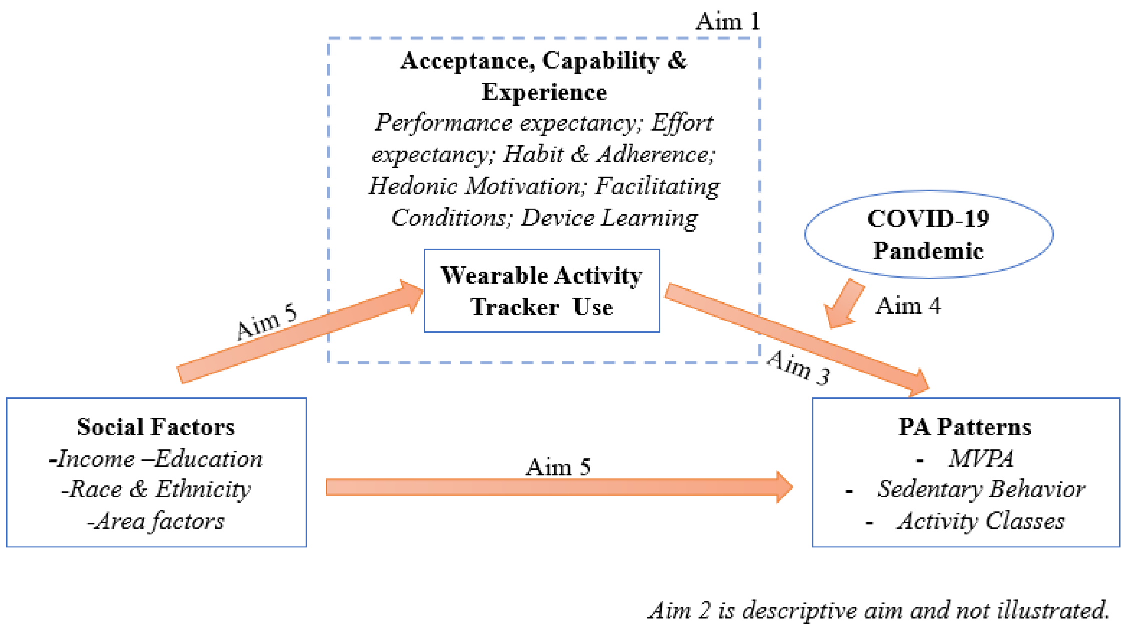

Figure 1.2 Adapted Conceptual Framework

The UTAUT posits that four constructs are key to predicting user intention to adopt technology: (1) Performance Expectancy: perceived usefulness; (2) Effort Expectancy: perceived ease of use; (3) Social Influence: extent to which the individual's family or friends believe they should use the technology; (4) Facilitating Conditions: facilitation and supports an individual may receive while using technology (Venkatesh et al., 2003). The UTAUT2 framework (Venkatesh et al., 2012) enhances the original UTAUT by adding three additional constructs: (5) Hedonic Motivation: the extent to which an individual enjoys the technology; (6) Price Value: the degree to which an individual believes the technology matches the value; and (7) Habit: if an individual form a routine of continued regular use of the technology (Venkatesh et al., 2012). The UTAUT and UTAUT2 constructs have been used to guide studies to better understand users' acceptance of adoption technologies including WATs. Literature suggests that performance expectancy (Dai, Larnyo, Tetteh, Aboagye, & Musah, 2020; Mishra, Baker-Eveleth, Gala, & Stachofsky, 2021; Wang, Tao, Yu, & Qu, 2020), effort expectancy (Dai et al., 2020; Mishra et al., 2021; Wang et al., 2020) , facilitating conditions (Dai et al., 2020; Wang et al., 2020), and social influence (Dai et al., 2020; Wang et al., 2020) positively affect users' behavioral intention to use WATs.

Fundamental Cause Theory

The Fundamental Cause Theory, developed by Link and Phelan in 1995 (Link & Phelan, 1995) posits that socio-economic status (SES) is a "fundamental cause" of various health outcomes. This theory suggests that variations in SES may cause health inequity by different levels of resources that individuals may utilize to promote health and avoid disease. Building on this theory, the conceptual framework of this dissertation study proposes that social factors are associated with the use of WAT (an important technological resource), and that WAT use is further associated with increased PA patterns in older adults. The Adapted Conceptual Framework figure (Figure 1.1) includes the corresponding aims, with aim 2 excluded as it is a descriptive aim.

Innovation

Although WAT technology is rapidly evolving and becoming a useful tool for PA motivation, most research has focused on younger adults. As a result, WATs are often designed to meet the needs of younger adults. More research is needed to understand the use of WATs in the aging population. This study provides innovative insights by identifying barriers to WAT use among older adults, promoting PA and highlighting the needs of older adults' in WAT design and functionality. This study also focuses on social factors that contribute to WATs/PA disparities among older adults. By doing so, it can inform strategies aimed at bridging the digital divide and improving mHealth interventions in older adults. Lastly , this study investigates the impact of WAT use on PA patterns among U.S. older adults during the COVID-19 pandemic.

These findings can inform the development of nursing interventions for older adults in the event of another public health emergency.

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CHAPTER 2: MANUSCRIPT ONE

Wearable Activity Tracker Use for Physical Activity in Older Adults: A Qualitative Study

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Abstract

Innovative solutions to help older adults increase physical activity are critically important. In this qualitative study, we explored older adults' acceptance, capability, and experiences of using three different types of Wearable Activity Trackers over a period of 4–24 weeks for self-monitoring and promoting physical activity. We conducted 23 semi-structured interviews with older adults who participated in three physical activity intervention studies. Two researchers analyzed the data using NVivo version 12, applying a directed content analysis that was partially guided by the Unified Theory of Acceptance and Use of Technology 2 (UTAUT2). Six themes emerged: (1) device learning, (2) hedonic motivation, (3) habit and adherence, (4) facilitating conditions, (5) effort expectancy, and (6) performance expectancy. Although most older adults (95.8%) from this study were first-time users, they reflected positive experiences and generally enjoyed using Wearable Activity Trackers. Participants reported issues related to Wearable Activity Tracker functionalities that can be improved to better enhance user experience and motivate increased physical activity. Future research should explore the role of Wearable Activity Trackers in older adults' physical activity with an emphasis on behavioral change over time.

Introduction

Regular physical activity (PA) helps older adults improve their stamina, muscle, and bone strength, lower the risk of falling and bone fractures, and reduce the risk of developing chronic conditions (Centers for Disease Prevention and Control [CDC], 2021). Conversely, long-term physical inactivity contributes to functional impairment and chronic health problems (Booth et al., 2017). It is recommended that older adults engage in moderate-intensity aerobic activity for over 150 min weekly with muscle-strengthening activities, when not contraindicated for health reasons (CDC, 2021). However, sedentary behaviors or physical inactivity remain prevalent among older adults in the United States: 26.9% of those 65–74 years of age and 36.3% of those 75 years and older are inactive (CDC, 2021). Therefore, innovative solutions to help older adults increase PA patterns need to be explored.

Many barriers make it challenging for older adults to reach optimal PA patterns including lack of interest and motivation; pain, discomfort, and physical limitations; fear of falling; having no companion; social pressure (having less time to spend with friends and family); lack of clear goals of PA, lack of professional guidance of PA; time limits and competing priorities; lack of access to facilities; and other environmental factors such as neighborhood safety and weather (Franco et al., 2015; Nicholson et al., 2013; van Alphen et al., 2016; Yarmohammadi et al., 2019). Although certain objective factors (i.e., physical limitations, neighborhood safety, weather) are difficult to overcome, other barriers, including lack of interest and motivation, having no companion, and lack of clear goals are modifiable.

Wearable Activity Trackers (WATs) are devices worn on various body parts to capture biometric data. Common wearing positions of WATs include the wrist, upper arm, and neck, with the wrist reported by older adults as the most favorable location to wear a WAT (Fang &

Chang, 2016). In this study, we specifically focused on the use of consumer-level wrist-worn devices, such as Fitbit, Apple Watch, and Garmin. WATs have been increasingly used by individuals to track their health, including daily steps, caloric expenditure, heart rate, sleep duration and quality, and other metrics (Tedesco et al., 2017). WATs can promote increased PA by providing continuous self-monitoring of activity levels and vital sign data, sending encouraging notifications and motivational messages based on users' daily and weekly progress, allowing connections between users of the same brand to provide better social support, helping users set daily, weekly, or monthly PA goals, and other behavioral changing techniques that may result in PA promotion (Cadmus-Bertram et al., 2015; Franssen et al., 2020; Lyons et al., 2017; Mercer et al., 2016; O'Brien et al., 2015). Additionally, monitoring step counts act as a motivating factor for older adults to increase daily step counts, which can further promote time spent in moderate-to-vigorous PA, light-intensity PA, and less time spent sitting (Amagasa et al., 2021). With these functionalities, using WATs may address the aforementioned modifiable barriers to PA (lack of interest and motivation, lack of companionship, and lack of clear goals of PA) and improve long-term physical function. The effectiveness of WATs in enhancing PA, including daily steps, PA time, and energy expenditures, has been tested in general adult populations (Brickwood et al., 2019; Coughlin & Stewart, 2016; Valle et al., 2017).

There is a disconnect between the benefits of WATs and current U.S. older adults' adoption of this technology. Although some behavioral change interventions incorporating WATs have been developed to effectively improve PA among older adults (Liu et al., 2020; Li et al., 2020; Li et al., 2021), WAT use by U.S. older adults remains low: 13% of U.S. older adults used a WAT in 2019 (Xie et al., 2020), 17% in 2020 (M. Li et al., 2022).

While previous research on WATs mainly focused on younger adults, an increasing number of studies have been conducted to understand older adults' use of WATs (Janevic et al., 2020; Mercer et al., 2016; Preusse et al., 2017; Puri et al., 2017; Zhang et al., 2022). Compared with younger adults, older adults have a lower adoption rate of WATs with different levels of acceptance (the degree to which they are open to the use of WATs), capability (the degree to which they are confident and capable of using WATs), and experiences of using WAT. Older adults' acceptance of using WATs can be influenced by difficulties learning and using WATs (Bong et al., 2019), beliefs that WATs are not necessary for their daily life (perceived usefulness; Bong et al., 2019; Keogh et al., 2020; Preusse et al., 2017), level of comfort of wearing the device (Keogh et al., 2020), issues with hearing and vision (Fischer et al., 2014; Holzinger et al., 2010), and issues with trust and privacy (Fischer et al., 2014; Gao et al., 2015). Capability can be influenced by a lack of familiarity with WATs and discomfort in requesting assistance (Chun & Patterson, 2012; Fischer et al., 2014). Preusse et al. (2017) pointed out that providing tutorials on challenging features is key to addressing the low acceptance and capability of using WATs for the older adult. Like users from other age groups, maintaining WAT use can be influenced by perceived long-term benefits of WATs, social support, and internal motivation, whereas merely increasing PA monitoring and awareness does not guarantee increased WAT use (Kononova et al., 2019; Shin et al., 2019). Older adults' long-term user experience of WATs to self-monitor their PA is important to understand in order to determine whether WATs can help them promote their PA.

Several gaps in the current literature need to be addressed. First, current studies mostly observed consumers' use of WATs after they were simply provided a WAT or given very limited instructions (Fausset et al., 2013; Fritz et al., 2014; Jarrahi et al., 2018; Mercer et al., 2016;

Naslund et al., 2015; Preusse et al., 2017). Limited research has focused on older adults who participate in personalized behavioral interventions to improve PA patterns (McMahon et al., 2016). Second, many studies examined older adults' user experience of just one WAT over an extended period (e.g., 3–24 months; Rosales et al., 2018; Thorpe et al., 2019; Zhou et al., n.d.), whereas others examined multiple devices over a shorter period (3 days to 3 weeks; Mercer et al., 2016; Nguyen et al., 2017; Puri et al., 2017). It is necessary to understand (1) how multiple WATs may provide different user experiences and (2) how WATs are used by older adults over an extended period of time (4–24 weeks). These factors are crucial because forming a habit of regular PA often requires consistent use of WAT over an extended duration (Friel & Garber, 2020; Gardner, 2015; Peng et al., 2021) and older adults' acceptance, capability, and experience of using WATs for a prolonged period may differ from short-term experiences (Friel & Garber, 2020).

Purpose

Within a sample of older adults who have participated in personalized behavioral interventions, the objective of this study was to qualitatively explore older adults' acceptance, capability, and experience of using WATs to self-monitor and promote PA over a prolonged period of time (4–24 weeks).

Methods

Conceptual framework

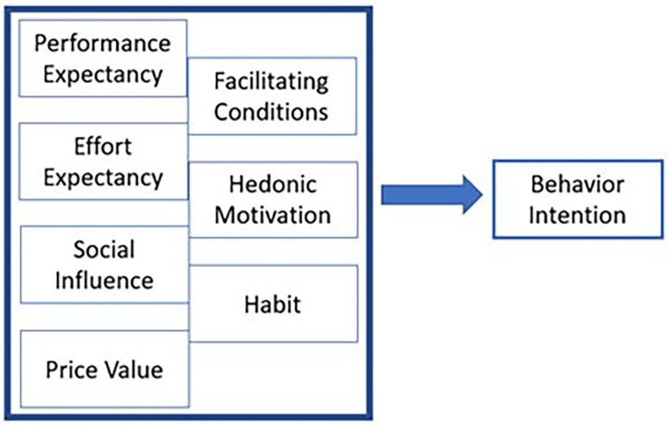


Figure 2. 1 The Unified Theory of Acceptance and Use of Technology 2 (UTAUT2; Vankatesh et al., 2012): Seven constructs that may predict intention to adopt technology.

The Unified Theory of Acceptance and Use of Technology 2 (UTAUT2) guided data analysis. The original theory, the Unified Theory of Acceptance and Use of Technology (UTAUT; Venkatesh et al., 2003), integrates the existing theories and frameworks relevant to consumer acceptance of information technology, such as the Theory of Reasoned Action, the Technology Acceptance Model, the Motivational Model, and the Theory of Planned Behavior. The UTAUT posits that four constructs are key to predicting user intention to adopt technology: (1) Performance Expectancy: perceived usefulness; (2) Effort Expectancy: perceived ease of use; (3) Social Influence: the extent to which the individual's family or friends believe they should use the technology; (4) Facilitating Conditions: facilitation and supports an individual may receive while using technology (Venkatesh et al., 2003). The UTAUT2 framework (Venkatesh et al., 2012) enhanced the original UTAUT by adding three additional constructs: (5) Hedonic Motivation: the extent to which an individual enjoys the technology; (6) Price Value: the degree to which an individual believes the technology matches the value; and (7) Habit: if an individual form a routine of continued regular use of the technology (Venkatesh et al., 2012). Figure 2.1 shows the seven constructs that may predict the intention to adopt technology based on the UTATU2. The UTAUT and UTAUT2 constructs have been used to guide studies to better understand users' acceptance of adoption technologies including WATs. Literature suggests that performance expectancy (Dai et al., 2020; Mishra et al., 2021; Wang et al., 2020), effort expectancy (Dai et al., 2020; Mishra et al., 2021; Wang et al., 2020), facilitating conditions (Dai et al., 2020; Wang et al., 2020), and social influence (Dai et al., 2020; Wang et al., 2020) positively affect users' behavioral intention to use WATs.

Study procedure

We conducted 23 interviews using semi-structured interview guides with 24 older adults who participated in one of three different studies. These three studies (J. Li et al., 2020, 2021) employed WATs in combination with personalized exercise training to promote PA. Table 1 presents a comparison of the three studies; short descriptions are below.

Parent studies

The three parent studies used mHealth-facilitated PA interventions to promote PA and sleep in community-dwelling older adults. WAT use is a part of the study interventions in these studies.

Study design

Study 1 (J. Li et al., 2020) was a within-group pretest and posttest study. Study 2 (J. Li et al., 2021) was a pilot randomized controlled trial. Study 3 (NINR, NCT03959202) is an ongoing randomized controlled trial. These studies have similar interventions with some variations.

Intervention

All three studies included similar intervention components: (1) technology learning sessions provided by research staff, (2) personalized PA training, (3) mHealth strategies including WATs to allow real-time PA self-monitoring, reception of interactive prompts, notifications, and feedback, (3) weekly financial incentives for achieving predetermined weekly PA goals, (4) phone consultations regarding participants' progress and questions they may have, and (5) additional technology support if needed. Study 1 intervention was 4 weeks; study 2 and study 3 had an intervention duration of 24 weeks. Other specific differences in each of the intervention components across the three studies can be found in related publications (J. Li et al., 2020, 2021).

Table 2. 1 Comparison of three parent studies

	Study 1	Study 2	Study 3
Title	A Personalized Behavioral Intervention Implementing MHealth Technologies for Older Adults: A Pilot Feasibility Study (J. Li et al., 2020)	An MHealth-Facilitated Personalized Intervention for Physical Activity and Sleep in Community-Dwelling Older Adults (J. Li et al., 2021)	A Personalized Behavioral Intervention to Improve Physical Activity, Sleep, and Cognition in Sedentary Older Adults (NINR, NCT03959202)
Parent Study Design	A pilot, feasibility study; single-group pretest, and posttest.	Randomized controlled pilot trial	Randomized controlled trial
Intervention Components	(A) technology learning session, (B) one personalized PA training session, (C) real-time PA self-monitoring, with interactive prompts, and feedback from a smartwatch, (D) phone consultation, and (E) weekly financial incentives for achieving the predetermined weekly PA goals.	(A) mHealth technology learning sessions, (B) one personalized PA training session, (C) real-time PA self-monitoring, with interactive prompts, and feedback from a smartwatch, (D) financial incentives for completing the prescribed PA, and (E) additional support for mHealth technology.	(A) mHealth technology learning sessions, (B) 3-4 personalized PA training sessions, (C) real-time PA self-monitoring, with interactive prompts, and feedback from a smartwatch, (D) financial incentives for completing the prescribed PA, and (E) additional support for mHealth technology.
Interview duration	4 weeks	24 weeks	24 weeks
Inclusion Criteria	Age 65 and 85; no prior diagnosis of cognitive impairment or dementia; sedentary lifestyle; poor sleep quality; no diagnosis of sleep apnea.	Age 60 and 85 years; no diagnosis of dementia; sedentary lifestyle; self-reported insomnia symptoms and no untreated sleep apnea; capability for mild to moderate PA.	Age 60 and 85 years; no diagnosis of dementia; sedentary lifestyle; self-reported insomnia symptoms and no untreated sleep apnea; capability for mild to moderate PA.
Interview number	7 interviews	8 interviews from the intervention group	8 interviews from the intervention group
Smartwatch Device	Motorola Moto 360 2nd Generation	Polar M600	Fitbit Charge 3

Wearable Activity Trackers provided.

The Moto 360 2 smartwatch was used in study 1, Polar M600 in study 2, and the Fitbit charge 3 fitness tracker in study 3. For study 1 and study 2, participants were asked to return the WATs after the intervention completion; in study 3, participants were able to keep the Fitbit 3 watch if they completed the intervention. Based on participants' performance, the WATs provided reminders or encouraging messages. If participants did not reach their goals of the day, they would receive messages that encouraged them to get moving; if they did meet their goals, then they would receive messages that congratulated them on their success. Figure 2.2 shows the design and appearance of each smartwatch, and Table 2.2 compares the functionalities.

Figure 2. 2 Three types of smartwatches used in parent studies

Technology training and support

The parent studies all provided technology training sessions, with minor variations. In study 1, participants received a Moto 360 smartwatch and a paired 7-inch Android tablet. The research team member demonstrated how to operate the devices individually with each participant, including charging the devices, opening apps (Motobody and Google Calendar) on the tablet, checking steps, reminders, and notifications on the smartwatch and tablet. The participants also received a booklet that contained and reinforced the information covered in the learning session.

In study 2 and study 3, participants who were randomly assigned to the intervention group were provided with an individual mHealth technology learning session. Each participant received a Polar M600 smartwatch (study 2) or Fitbit Charge 3 fitness tracker (study 3) and a pamphlet that described study-related technologies and common troubleshooting strategies. During the session, the research assistant demonstrated how to pair and sync the WAT with the participant's smartphone, how to charge the WAT, monitor steps, and read reminders and notifications on the WAT and smartphone. Using the Teach-Back Method (a way to confirm that the educator has explained to the participant what is important in a manner that the participant understands), the participants demonstrated their ability to use the technology by the end of the session. The participants were given 1 week to familiarize themselves with the technology before the personalized PA training. After the practice week, a research assistant provided participants with a brief booster technology session (up to 10 min) to address any difficulties with the technology before the in-person PA training at the Exercise Medicine Unit.

Sample and Sample Size

As shown in Figure 2.3, we conducted 23 interviews with 24 participants; 1 interview (from study 3) included two participants since they were from the same household. Study 1 included eight participants, of which seven participated in our postintervention individual interview, while one participant did not consent to the individual interview. In study 2, 8 of 11 participants completed postintervention individual interviews, while the other 3 participants did not consent to the interviews. Study 3 is ongoing; currently, 26 participants were assigned to the intervention group who have completed the study and consented to interview. A total of eight interviews from 26 postintervention interviews were included in the analysis until data saturation was reached. Interviews were first selected and included in the current study because they had a longer interview time and produced richer discussions regarding the topic of smartwatch use. One team member also listened to audio files from the additional 18 interviews from study 3 to confirm that no additional information was gained from the 18 interviews, confirming data saturation was reached.

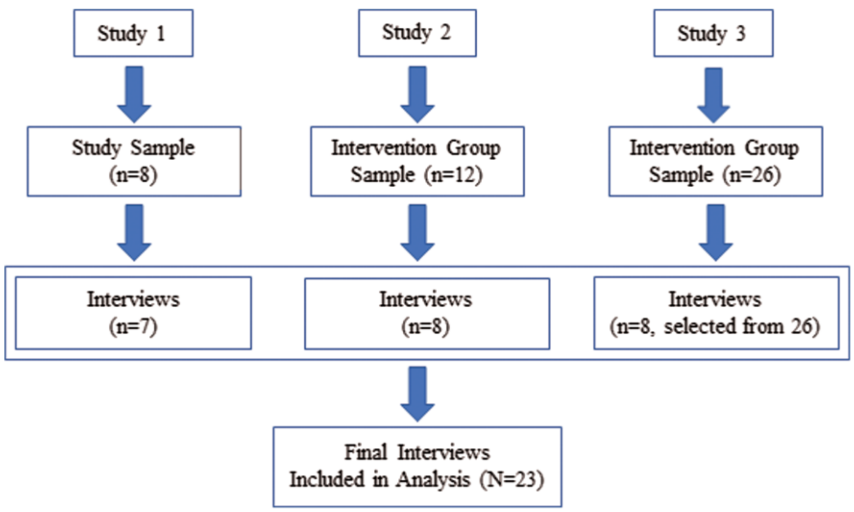


Figure 2. 3 Sample size and selection

Interview guide

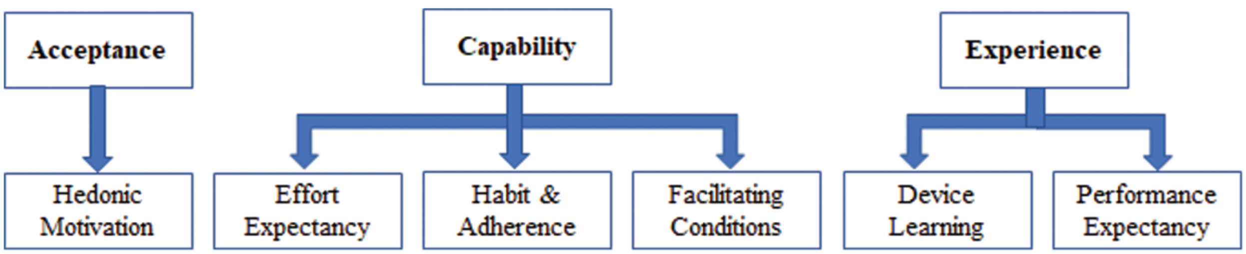
Interviews from the three studies used semi-structured interview guides that included questions about participants' prior experience with WATs, how comfortable they were when operating WATs, how they used WATs to self-monitor their PA, their acceptance of motivational notifications and messages, likes and dislikes about WATs, habits, and changes of using WATs over time throughout the study. Although three interview guides were developed separately for the three parent studies, the content was similar across the three interview guides. Table 2.3 shows an example of a semi-structured interview guide used in study 3.

Table 2. 2 Comparison of smartwatch functions

	MOTO 360 2nd Generation	Polar M600	Fitbit Charge 3
Approximate Market Prize	$ 75.00	$330.00	$75.00
What they measure：	Steps; Active time (moderate or vigorous intensity)	Steps; Active time (moderate or vigorous intensity)	Steps; Active time (moderate or vigorous intensity)
Battery life (Varies with use and other factors)	Around 1 day	Around 1 day	Up to 7 days
Charge time	2 hours	2 hours	2 hours
Functionalities	Change watch face display, received notifications (call, messages, and more), hands-free scrolling, manage to watch notifications, voice commands, navigation, connect with a phone app to monitor steps, calories burned, hear activity, etc. (Moto Body).	Track user data receive notifications from the phone, reply to an email, control music playing on the phone, heart rate monitor, integrated GPS, unique Polar smart coaching features, connect to Wi-Fi, and download apps.	Track user data, personalized step goals, sleep stages, insights, & reminders, silent alarms, sedentary reminders, calendar notifications, and guided breathing sessions.
Compatible systems	Android 4.3 or higher	Android 4.4+ or iOS 10.0+.	Apple iOS 11 or higher, Android OS 7.0 or higher, and Windows 10 v1607 or higher
Waterproof & Swim-proof	Water Resistant to 3.3-Ft	Fully waterproof for swimming	Swim proof and water resistant to 50 meters.

Data Analysis

All interviews were transcribed verbatim, checked for accuracy, and uploaded to NVivo V.12. The software was used for data storage and management. Interviews lasted 12 min on average. Two researchers (M.L. and S.H.) initially immersed themselves in the transcripts to become familiar with the data. Next, the researchers independently applied directed content analysis, given that the analysis was guided by UTAUT2 (Hsieh & Shannon, 2005). In this study, the a priori codebook was developed based on the constructs from the Unified Theory of Acceptance and Use of Technology (UTAUT2) and included inductive codes that arose from the data. Coders began with line-by-line coding and the codes were independently sorted based on UTAUT2 and the patterns were identified. There was >95% agreement between the coders. The two researchers met weekly to discuss the data, codes, categories, and themes and to reconcile any disagreements. The full team agreed to the final codes and subsequent themes that emerged. Methodological rigor was established by ensuring trustworthiness (Bowen 2008; Lincoln 2007) through the following: (1) enhancing credibility and dependability through triangulation of data sources and having two people code the interviews; (2) confirmability wherein we kept audit trails and had regular team meetings to discuss the data and determine the validity of inferences, and (3) transferability by providing thick descriptions of the findings. Furthermore, we ensured adequacy (Corbin & Strauss, 2014) given that the concepts used in our research are grounded in



the data and guided by UTAUT2.

Figure 2. 4 Aims and Corresponding Themes

Results

Participants were on average, 73.75 years old, were mostly female (79%), and were 58% Black or African American (n = 14). Most of the interviewees completed high school or higher education (91.6%). Detailed demographic descriptions for each study are included in Table 2.4.

Overall, older adults enjoyed using WATs with high acceptance, capability, and had positive experiences of using WATs to self-monitor and promote PA. Older adults also discussed the challenges they experienced and provided suggestions for future improvements. Detailed quotes from the participants are presented in the Appendix. A total of six themes emerged from our data and were organized by the aims of this study and the UTAUT2 conceptual framework as shown in the thematic map in Figure 2.4.

Older adults' acceptance of using three different types of WATs for self-monitoring and promoting PA over a period of 4–24 weeks.

Theme: Hedonic Motivation

Participants reported overall enjoyment of using WATs and described it as "a pleasant experience" (Study 2 Participant #5). Their acceptance of WATs was also related to the ap - pealing design of the WATs: "It was attractive" (Study 2 Participant #2). Some participants reported having fun with checking step counts and receiving prompts on the WATs: "I am amazed how steps accumulate on the smartwatch…I've been hooked" (Study 1 Participant #7); "It is very interesting to see how the step counts go up while you walk" (Study 2 Participant #2) and stated tracking their steps enhanced their motivation to complete daily step and activity goals: "When I look at my-- I have done 3,649. I have 351 more steps to do before I get to my goal, and I'm going to do it" (Study 3 Participant #8); "It's just very nice. You know where you are. It's nice because you feel like you are making progress, and you have little steps. You know how much effort it needs to get there" (Study 3 Participant #1). Only one participant reported a dislike of the smartwatch overall: "I don't fancy the smartwatch." (Study 2 Participant #2).

Table 2. 3 Demographic descriptions of interviewees

	Number of Interviewees	Age (Mean)	Sex	Race	Education
Study 1	7	74.71	71% Female	57% White (n=4) 43% Black or African American (n=3)	Completed high school or higher education (100%)
Study 2	8	74.50	75% Female	25% White (n=2) 75% Black or African American (n=6)	Completed high school or higher education (80%)
Study 3	9	72.33	89% Female	33% White (n=3) 67% Black or African American (n=6)	Completed high school or higher education (100%)
Total	24	73.75	79% Female	42% White (n-10) 58% Black or African American (n=14)	Completed high school or higher education (91.6%)

Older adults' capability of using three different types of WATs for self-monitoring and promoting PA over a period of 4 to 24 weeks.

Theme: Facilitating Conditions

Concerns raised by participants included difficulties in troubleshooting syncing and pairing problems between WATs and smartphones. One participant said, "When I used the smartwatch, I somehow lost step counts on display, but it was resolved after I got help from the study team" (Study 2 Participant #1). This participant also desired more in-depth training sessions and technical support while using the WATs: "I think the instructions could have been more detailed for the individual in terms of explaining the coordination between other devices and the smartwatch". Another participant reported trouble accumulating step counts when using the WAT: "Only at the very end—the last two days—I had discovered that the plastic film was still on the back of the watch, so it didn't have contact with my skin" (Study 1 Participant #2).

Table 2. 4 Example of semi-structured interview guide used in the parent studies

	Experience with smartwatch/smartphone	
General	1. Tell me about your experiences working with the smartwatch/ smartphone. 2. Describe the role of the smartwatch/technology in your physical activity or reaching the activity goals.	- How often did you check the device for things other than the time? - Imagine your smartwatch is a person that you are interviewing, what qualities does it have that you like and what qualities does it lack that you wish it had?
Comfort level	1. Describe how comfortable you were operating the smartwatch in general. 2. Tell me your favorite thing about using Fitbit if there is any. 3. Tell me what was a bit challenging for you using the Fitbit if there is any. 4. Describe how comfortable you were using Fitbit to self-monitor physical activity. 5. Describe any difficulties you had with the Fitbit /smartphone.	- Describe monitoring steps. - Describe how you dealt with <difficulty mentioned>.

Self-monitoring	1. How did you use the smartwatch to track your steps/exercise? 2. How did the celebration when you reached your step goal affect you?	- How checking steps affected you in terms of reaching your personal step goals? - How that affected your daily activity How often?
Notifications/messages	1. How did the notifications and messages affect you? 2. What was your reaction to these notifications/messages? 3. What would you suggest to the research team to improve the notifications and messages? 4. How often do you like to receive these reminders and notifications?	- Describe how they affected your daily activity - Describe <reaction>.
Pros and Cons	1. Describe what you liked about the Fitbit 2. Describe what you disliked about the Fitbit	- Describe any other problems you had with the smartwatch/smartphone.
Change over time	1. How did you change the use of Fitbit throughout the study?	

Theme: Habit and Adherence

Older adults discussed the topic of habit formation and adherence. Many older adults reported forming a habit of continued and long-term use of WATs. For example, one participant said, “I desire to continue using the watch after the study.” Most of the participants reported a change of habit in PA and adapted to a more active lifestyle motivated by monitoring their activity data on the WATs: “When I wanted to get up from a very low number of steps, I would take a walk after dinner or in the late afternoon. So I would make a conscious effort to try to reach the goal” (Study 1 Participant #6). Several participants mentioned memory issues interfering with their habits of using WATs, such as: “I did find that I had some memory issues towards the end of the test and a few days I would just forget to put it on” (Study 2 Participant 4).

Theme: Effort Expectancy (Functionalities and Usability)

Participants’ capability to use the WATs was related to smartwatch effort expectancy (ease-of-use). They reported that the WATs were easy to charge, checking the step count was convenient, and there were no difficulties in reading the smartwatch screen. The convenience of checking step counts and heart rates allowed them to increase their activity awareness. Overall, almost all participants reported that they felt comfortable with operating the WATs. In regard to the Moto 360, participants said, “The face was very easy to read for a person who’s just been diagnosed with age-related macular degeneration” (Study 1 Participant #3) and “The functions on the smartwatch were very clear… Charging was no problem. And then just swiping it and finding the information was very easy” (Study 1 Participant #7). Related to Polar M600, study 2 participant 6 said, “I did not really have any problems using it, like checking steps or notifications…I checked it every so often because it would do a weekly summary.” Related to Fitbit Charge 3, participants said, “I think the Fitbit is wonderful. It’s pretty easy to use” (Study 3 participant #5) and “It knows how many steps I take and…it checks some other things that I found out about… So it's given me good information where I probably would not have had that information before" (Study 3 Participant #3). While participants expressed enjoyment of using smartwatch technology, minor concerns were raised during the interviews. For both Moto 360 and Polar M600, participants expressed concern about the short battery life, such as "Towards the end of the day and I would need to go back on the charger" (Study 2 Participant #4); "I charged it every night…when I went to the 12-hour shifts, sometimes the watch would die, because my day started at 6 a.m" (Study 2 Participant #3). Participants mentioned that all three WATs gave inconsistent step count recordings. For example, one Polar M600 user stated, "When I was using my walker or a shopping cart in a grocery store, those steps tended not to be measured or counted at all" (Study 1 Participant #2). Another Moto 360 participant complained of inaccuracy in heart rate and said, "We were doing a lot of yard exercise in the back and I said gee, I wonder if my heart rate is higher. It wasn't any higher" (Study 1 Participant #6). Some Fitbit complaints included: "I discovered that I was folding laundry and I was reaching my goals because it's reading your arm rather than your leg. So it's not accurately doing steps" (Study 3 Participant #7); "Well one thing I noticed with the Fitbit, if you didn't charge up the steps, it didn't register as a climb" (Study 3 Participant #4). Although participants were told that the devices they received were waterproof, three participants still raised concerns related to showering: "I couldn't get it in the shower. That's the only part I didn't like" (Study 1 Participant #1); "But I had to be very careful when I was gonna take my shower, to remove it" (Study 1 Participant #5); "I needed to remember that I shouldn't get it wet" (Study 2 Participant 4). One participant talked about operating and funding information: "Sometimes they're displayed on the dial and then sometimes when I wanted to know the time, everything was blank… It was not a constant and I knew how to get the display that I wanted but

I had to think about it. It wasn't automatic" (Study 1 Participant #6). Overall, fewer technology issues were reported from using Fitbit which had fewer functionalities, simple displays, and fewer operations.

Older adults' experience of using three different types of WATs for self-monitoring and promoting PA over a period of 4–24 weeks.

Theme: Device Learning

Older adults discussed their attitudes towards and experiences of learning the smartwatch technology. A total of 23 older adults expressed that the study-provided WATs were their first experience using a WAT: "That was my first experience with the smartwatch" (Study 1 Participant #7); "When I got the smartwatch, I had to learn from scratch" (Study 2 Participant #1). Participants reflected on social influence on their willingness to learn how to use a smartwatch: "Everybody around me does this, so I'm happy to learn" (Study 1 Participant #3). One participant expressed that if a certain technology is practical and needed to be used in daily life then they would be willing to learn: "I'm resistant to some technology, but stuff that I really have to use all the time, I will learn" (Study 2 Participant #1). Participants expressed different experiences of learning how to use the WAT. A total of eight participants reported challenges related to device learning at the beginning: "I was frustrated with the equipment early on" (Study 2 Participant #2); "It was not easy to figure out and remember how you did it last time" (Study 2 Participant #1); "Swipe. Swipe, yes. I had to learn and it was – it's still a challenge to get not too heavy or not too light, not too quickly or not too slowly" (Study 1 Participant #3). Others said that WATs were easy to learn: "It came like a second nature" (Study 1 Participant #7); "I am more tech-savvy than average older adults" (Study 2 Participant #2); "I didn't see it being an overwhelming piece of technology" (Study 3 Participant #3).

Theme: Performance Expectancy

Older adults' reflections on how the smartwatch promoted their PA were categorized into three categories: (1) an increase in motivation, (2) an increase in PA awareness, and (3) an increase in PA. Most participants reported that using WATs helped increase motivation for PA, as evidenced by participants stating, "When it would remind me, I would say oh, let's get up and—so I would get up and do something" (Study 2 Participant #3); "There has been increased motivation to move and walk" (Study 1 Participant #6); "I would walk back and forth, back and forth. And so here I'm adding between 1,500 to 2,500 steps, where before I would just drive to the area to get the fluids and put it in the bus and drive back and I wouldn't walk… I would park farther away from the entrance to the garage to punch in and I would walk, so I was definitely doing more—positively" (Study 1 Participant #7). Only two participants felt that the motivational notifications and encouragement messages did not increase their motivation and did not affect whether they would reach step goals. Participant #9 from study 3 said, "I'm not going to say it motivated me because if I'm in a mode to paint, I'm going to do that. But it made me more conscious of it… So it would be in the back of my mind." Another participant mentioned, "I didn't really try extra hard to do it. So I would say it didn't have much effect at all" (Study 3 Participant #6).

Discussion

Overall, study participants enjoyed using WATs and expressed acceptance, capability to use, and positive experiences. Participants felt more accountable for exercise when using WATs and reported increased activity levels after using the WATs. Challenges, negative user experiences of functionality and usability, and suggestions for improvement were also reported.

Our findings suggest that detailed and sufficient technology training and support are essential to optimizing older adults' experience of using WATs. Consistent with previous findings, older adults in the current study reflected that they were willing to learn if technology was essential and brought value to their lives (Heinz et al., 2013). Twenty-three of the 24 older adult participants had not used a WAT before joining the research study. Although technology training and support were provided in all three studies, older adults still expressed frustrations regarding device operations. Compared to younger populations, it takes longer for older adults to learn new technology (Czaja et al., 2006), and older adults may experience a lack of clarity in instructions and support (Vaportzis et al., 2017). Therefore, when implementing and testing interventions that provide smartwatch devices, researchers should provide basic knowledge and instructions on smartwatch use. Many of the participants needed some time to learn how to operate WATs before they got used to the devices. Of note, the majority of these older adults had high school or higher education and were without cognitive impairment. Older adults with lower educational levels or cognitive deficits may need additional technology and support to use WATs appropriately and independently (Czaja et al., 2006; Malinowsky et al., 2010; Smith, 2014). We also suggest that researchers employing smartwatch technology account for and allow some time for participants to get familiarized with the devices. For example, even though some smartwatch types can be worn for showers, many older adults complained of the hassle of having to take off WATs before showering. Researchers, therefore, need to clarify the WATs' waterproof functionalities.

The extended duration of using WATs in our study allowed us to gain a better understanding of older adults' habit formation of using WATs and engaging in PA. With longer monitoring of older adults' use of WATs, it was possible to observe participants' learning process and gain a deeper understanding of the typical time for them to get used to technology and embed it in their daily lives. Most of our participants reported that they enjoyed using the WATs during the intervention and would plan on using WATs during their daily lives after the intervention ended. Six participants reported that the adoption of WATs declined overtime during the intervention and that sometimes memory issues interfered with consistency in wearing the WATs. This is consistent with the current literature that suggests most people discontinue their use of WATs within 6 months of starting (Cordeiro et al., 2015; Endeavour Partners, 2017).

Most of the participants reported habits formed toward a more active lifestyle. Peng and colleagues studied WAT long-term users and concluded that successful habit formation includes meaningful initiation of wearable activity trackers, starting with a small behavioral change goal and gradually increasing it, consistent time and locational cues, contextual cues, and reminders to facilitate action planning, and a positive mindset to manage unfulfillment (Peng et al., 2021).

Older adult participants provided important feedback regarding WAT functionalities and usability (effort expectancy). Overall, fewer technology issues were reported from using Fitbit which had fewer functionalities, simple displays, and fewer operations. Most of the feedback was related to charging/battery life, synchronizing, screen display, measurement accuracy, appearance, and design. Several functions of WATs can be enhanced, including prolonged battery life, improved accuracy in step, stair, and sleep recordings, and better display functions. Regarding battery life, although participants using Moto 360 2nd generation and Polar 600 reported the short battery life of the WATs (roughly 24 hr), Fitbit users did not complain of short battery life (battery life approximately 5–7 days). Improving battery life is imperative to reduce the hassle related to daily charging and would be more user-friendly for those with memory impairments. Since WATs are wrist-worn devices, it can be hard to capture/register exercises that did not require wrist movement. One solution to this issue is to provide a variety of exercise/PA options that users can select from, and step counts can be calculated based on a comprehensive analysis of data provided by wrist-worn sensors along with other data such as heart rate and caloric expenditures.

In the parent studies, most older adult participants expressed that using WATs motivated them to engage in more PA and therefore might lead to a more active lifestyle. This was achieved by several mechanisms. First, the self-monitoring functionality allows older adults to have a better sense and awareness of how much they were moving. Some participants reported that simply by looking at their step counts/calories burned, they felt motivated to exercise and engage in PA. Second, along with the progressively increased personalized goals set for older adults in the parent study interventions, participants were more aware of their progress toward their daily activity goals and that motivated them to be more active. In addition, encouraging and motivational messages sent to older adults' WATs played an important role. Older adults shared the feeling of accomplishment after they received congratulatory messages when they achieved their daily goals. However, several participants also reflected on the issue of getting used to notification messages that resulted in no responses/reactions to messages received. This "Push Notification Fatigue" is commonly observed in users of mobile and digital technology devices (Ting, 2013).

This study has several limitations. First, although the interview questions were specifically related to WAT uses, other intervention components might have influenced older adults' experiences using WAT to promote PA. Second, although the key intervention components remained the same across the three studies, the intervention durations were different. This might have limited our understanding of the smartwatch device used in the shorter (4-week) intervention (Moto 360 2nd generation) and may have interfered with the comparison of participants' experience among the three WATs. Third, this study used qualitative data collected from three different interventions, and therefore these participants did not have the opportunity to use all three types of smartwatch devices and provide a direct comparison. However, previous studies compared older adults' use of multiple WATs but often had short intervention periods (Mercer et al., 2016; Nguyen et al., 2017; Puri et al., 2017). In the current study, we were able to interview participants who used three types of WATs for longer periods (4–24 weeks). Therefore, the current study could better capture participants' habit formation compared to previous studies. Last, although UTAUT2 partially guided the data analysis in this study, it was retrospectively used. Without initial consideration of UTAUT2, our interview guides did not include certain questions that closely relate to UTAUT2 constructs.

The study also had several strengths. Our findings provide direction for future studies. First, although WAT use is helpful in promoting PA, difficulties still exist when implementing technology solutions for older adults. Future studies should focus on training and support for older adults and carefully review WATs to limit the implementation of those with complex designs and technology requirements. Second, there are other smartwatch functionalities not available in the parent studies that could potentially promote PA in older adults; for example, functions that facilitate connection with family and friends. Future studies could be designed to include these functionalities. Finally, future studies can incorporate popular WATs, such as the Apple Watch, in a more diverse aging population and be designed to enroll older adults with mild cognitive impairment.

Conclusion

This study provided an important understanding of older adults' acceptability, capability, and experiences of using WATs and how the smartwatch helped promote their PA. We also compared the three types of WATs used in parent studies from older adults' perspectives. Although older adults have positive experiences in using WATs, there are still improvements in smartwatch functionalities that can be made to enhance their user experience and better motivate

PA. Future research should explore the role of WATs for older adults' PA with an emphasis on behavioral changes over time.

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CHAPTER 3: MANUSCRIPT TWO

Social Factors and Older Adults' Use of Wearable Activity Trackers:

Before and During the First Wave of the COVID-19 Pandemic

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Abstract

Background:

A wearable activity tracker (WAT) is one potential strategy for self-monitoring of health. In the present study, we aimed to (1) examine the prevalence of WAT use among U.S. older adults before and during the first wave of the COVID-19 pandemic, and (2) identify social associated with the use of WATs among U.S. older adults. We also explored social factors associated with the use of WATs among U.S. older adults before and during the first wave of the COVID-19 pandemic.

Methods:

We described characteristics of U.S. older adults with different WAT use patterns before and during first wave of the COVID-19 pandemic, using cross-sectional data of 3,302 older adults from the Health Information National Trends Survey. Logistic and Multinomial Logistic Regression Models were used to identify social factors (sex, education, income, race/ethnicity, and area factors) associated with WAT use.

Results:

Only 9.7% of the sample (9.4% pre-covid vs. 10.6% 1st wave) were frequent WAT users (almost everyday/everyday use). In the total sample and pre-COVID-19 subsample, older adults who were non-Hispanic African Americans, 65-74 years, women, with a college degree or above were more likely to be frequent WAT users after adjusting for covariates. Lower-income and high-minority area living were associated with lower odds of frequent WAT use. In the 1st wave sub-sample, only aged 65-74 years were associated with frequent WAT use. Our findings suggest disparities in WAT use among older Americans.

Keywords: Socioeconomic Status, Technology, COVID-19

Introduction

A wearable activity tracker (WAT) is one potential strategy for self-monitoring of health. WATs refer to smart electronic devices—often wrist-worn—that detect, analyze, and transmit information on body signals such as vital signs, physical activity, or ambient data to provide real-time biofeedback to the wearer (Düking, Hotho, Holmberg, Fuss, & Sperlich, 2016; O'Donoghue & Herbert, 2012). Commercial WATs, such as Fitbit, Apple Watch, Gamin, etc., are commercially accessible and may promote health outcomes through self-monitoring of health parameters (e.g., physical activity, heart rate, and sleep), safety alerts (e.g., fall risk detection), stress reduction (e.g., breathing techniques), and symptom tracking and management (e.g., reporting COVID-19 symptoms) (Tedesco et al., 2017; Zhang, Giordani, Margulis, & Chen, 2022).

Several qualitative studies have found that older adults reported positive feedback regarding the ease of use, usefulness, and acceptability, and showed a willingness to learn how to operate WATs (M. Li, Mcphillips, Wenzel, Szanton, & Li, 2022; Zhang et al., 2022), but also noted issues including low familiarity or limited access to the technology, lack of available training and assistance, privacy issues (Fischer, David, Crotty, Dierks, & Safran, 2014; M. Li et al., 2022), and design challenges (Fang & Chang, 2016; Puri et al., 2017) among older adults. Quantitative studies have focused mainly on the effectiveness of WAT-facilitated interventions that often incorporate the use of WATs with behavioral change techniques including goal setting, providing positive feedback, providing social support, and improving self-efficacy towards activity goals (Olander et al., 2013; Western et al., 2021). WATs and WAT-based interventions have demonstrated effectiveness in improving health outcomes such as improving physical activity levels (Liu, Kor, Chan, Kwan, & Sze-Ki, 2020; Ringeval, Wagner, Denford, Paré, &

Kitsiou, 2020; Stockwell et al., 2019) and decreasing weight among older adults (Ringeval et al., 2020).

Despite older adults' acceptance and potential health benefits of WATs, the use of WATs among U.S. older adults 65 years and older remains unknown. First, although it has been reported that about 25% of adults between 18 and 49 years of age and 17% of adults over 50 years of age used a WAT in 2019 (Vogels, 2020), there is a lack of evidence showing the prevalence of WAT use among older adults aged 65 years and above. There are many social differences between older adults aged 50-64 years old and those 65 years and older, including income, insurance and lifestyle differences due to retirement status. Older adults aged 65 years and above may have different needs of using WATs than those who are younger. Therefore, it is necessary to separately investigate WAT use prevalence of those 65 years and above. Second, based on previous evidence, only persistent and frequent use of WAT use may improve users' physical activity levels and health benefits, yet there is limited evidence focusing on frequency of U.S. older adults' use of WATs (Chandrasekaran, Katthula, & Moustakas, 2020). Third, the public's use of digital technology has significantly increased during the COVID-19 pandemic (De', Pandey, & Pal, 2020), yet there is lack of evidence of the use of WATs since the COVID-19 pandemic among older adults aged 65 and over.

WAT use in older adults is closely relevant to the issue of digital divide. Digital divide is defined as the gulf between those who have ready access to access to computers and the Internet and those who do not (Lai & Widmar, 2021). Older adults are considered to be on the disadvantaged side of the digital divide (van Deursen & van Dijk, 2011) and this disadvantage could be resulted from different reasons. For older adults with lack of previous experience of using technology, it could be difficult to adopt new technology due to lack of digital literacy and difficulty in finding technological support when needed (Harris, Blocker, & Rogers, 2022). On the other hand, digital divide can also exist between older adult with less resources to access and afford digital products and those who can easily access technological products (Winslow, 2019). Since COVID-19 was announced as a global pandemic by the World Health Organization in March 2020, in-person activities significantly decreased and reliance on digital technology drastically increased (De' et al., 2020). This have further deepened the digital divide that already existed (Lai & Widmar, 2021).

A better understanding of social factors that are associated with older adults' use of WATs is needed as social factors are closely related to the digital divide (Mubarak, Suomi, & Kantola, 2020). Social factors are social, demographic and economic characteristics of a population, including sex, race and ethnicity, income, education, and area environments. Different social factors have been found to be associated with the use of WATs in older adults. Older adults who are female, White, younger than 75 years, have higher education levels, more income, and are healthier have higher rates of WAT use (Kakulla & Kakulla, 2020; L. Li, Peng, Kononova, Bowen, & Cotten, 2020; Macridis, Johnston, Johnson, & Vallance, 2018). However, most of these findings were reported through studies with small samples (5-49 participants) who participated in an intervention (Brickwood, Watson, O'Brien, & Williams, 2019; Cadmus-Bertram, Marcus, Patterson, Parker, & Morey, 2015; Fausset et al., 2013; Puri et al., 2017; Rosales, Fernández-Ardèvol, & Ferran-Ferrer, 2018). With the three studies investigating older adults' WAT use, two of them (Kakulla & Kakulla, 2020; Vogels, 2020) only examined basic social factors (age, race, sex, education level and income), the other study (Schuster, Kadylak, & Cotten, 2023) used data only collected online which may result in sampling bias. There is still a need to examine social factors including age, sex, race, education, income, and area factors associated with older adults aged 65 years and above with a secondary cohort data.

Study Aims and Hypotheses

Aim 1: Describe characteristics among U.S. older adults with different WAT use patterns.

Aim 2: Identify social factors (age, gender, race/ethnicity, education, income, and area factors) associated with the use of WATs among U.S. older adults.

Hypothesis: Older adults in socially and economically disadvantaged groups (low household income, low education level, live in disadvantaged areas, racial and ethnic minority) are less likely to adopt WATs.

Exploratory Aim: Explore social factors associated with the use of WATs among U.S. older adults before and during the first wave of the COVID-19 pandemic.

The results of this study will provide important guidance to WAT-related or technology-related clinical practice and interventions, research directions, and policy changes to benefit the older adult population.

Methods

HINTS design and recruitment

This is a cross-sectional secondary data analysis using the Health Information National Trends Survey (HINTS) dataset with data collected from January to April 2019 and February to June 2020. Launched by NIH's National Cancer Institute (NCI) in 2003, HINTS regularly collects data about the American public's knowledge of, attitudes toward, and use of cancer-related and other health-related information. To recruit participants, HINTS sent postal mail to random samples of non-vacant U.S. residential addresses for both the 2019 and 2020 cohorts.

The present study includes 3,370 participants aged 65 and above from both cycles 3 and 4. All data collected in HINTS are self-reported on paper and sent back by mail.

Measures

WAT use is based on the subject's self-reported WAT use over the prior 12 months and the frequency of use over the past month of data collection. Two questions were asked regarding WAT use: (1) "In the last 12 months, have you used a Wearable Activity Tracker to monitor or track your health or activity? For example, a Fitbit, Apple Watch, or Garmin Vivofit." (2) "In the past month, how often did you use a wearable device to track your health?" For those who answered "Yes" in the previous question, options included "Every day," "Almost every day," "1-2 times per week," "Less than once per week," or "I did not use a wearable device in the past month."

Based on these questions, we developed two outcome variables related to WAT use. Outcome one is a binary outcome: (A) Used WAT vs. (B) Did not use a WAT (in the past 12 months). We further categorized the participants into three categories (outcome two): (1) Frequent WAT use: those who reported using a WAT "Every day" or "Almost every day" in the past month; (2) Infrequent use: those who reported using a WAT "1-2 times per week," "Less than once per week," or "I did not use a wearable device in the past month (but used one in the past year)"; and (3) No use: respondents who did not use a WAT in the past month and those who did not use a WAT over the past 12 months.

COVID-19 Pandemic: A "Pandemic" variable was made available in the HINTS cycle 4 (2020) to flag households whose survey was received after the World Health Organization declared COVID-19 to be a pandemic on March 11, 2020. For this analysis, all data collected in 2019 and before March 11, 2020, were categorized as "Before COVID-19," and data collected after March

11 before June (end of data collection) were categorized as “During the first wave of COVID-19” to reflect the period during the first wave of the COVID-19 pandemic.

Sociodemographic Factors included age, sex, annual household income, education, race/ethnicity, and area factors. Participants’ sex was self-reported, including “Male” and “Female.” Based on previous literature and data distribution, the age variable was dichotomized into 65-74 years and 75 years and above (Lee, Oh, Park, Choi, & Wee, 2018). Annual household income was categorized into (1) low income (less than $35,000), (2) intermediate income ($35,000-$75,000), and (3) high income ($75,000) (Xie, Jo, & Hong, 2020). The educational variable was categorized into (1) high school or less, (2) some college, and (3) college degree or higher. Race and ethnicity were categorized into three categories: (1) White, (2) Black, and (3) Hispanic, non-Hispanic Asians, and others. Area factors included region and area minority percentage. Region population was a variable created to reflect the USDA 2013 rural-urban continuum codes in which a classification scheme was used to distinguish metropolitan counties by population size of the metro area. For the present study, the region population was dichotomized into (1) Large Metro Area: Counties in metro areas of at least 250,000 population; and (2) Small/Non-Metro Area: Counties in metro areas of fewer than 250,000 population or non-metro areas. The area minority level was formed using the census tract-level characteristics from the 2014-2018 American Community Survey data file. According to HINTS 5, addresses in census tracts with a population proportion of Hispanics or African Americans that equaled or exceeded 34 percent were assigned to the high minority level category, and the remaining addresses were assigned to the low minority level category.

Other covariates were included in the analyses. Body Mass Index (BMI) was calculated using the respondents’ self-reported heights and weights and was dichotomized into (1) non-obesity: under 30, and (2) obesity: 30 and above. Smoking status was a variable derived from two questions on past smoking experience and current smoking frequency and was categorized into current, former, and never smoker. The marital status question was included in the questionnaire and dichotomized into two categories: (1) married or living with a partner, and (2) divorced, widowed, separated, or never married. Comorbidity was measured by the sum of reported medical conditions reported by respondents and categorized into: (1) one or no comorbidity and (2) multiple comorbidities. General health status was assessed by the item: "In general, would you say your health is …" with the choices of "Excellent, Very good, Good, Fair, or Poor." Depression was assessed by the item: "Has a doctor or other health professional ever told you that you had depression or anxiety disorder?" Health insurance coverage was a variable derived from several health insurance-related items from the HINTS survey and dichotomized into "Yes" and "No."

Statistical Analysis

Since 14.6% of data were missing on the variable "annual household income," an imputation of this variable generated by HINTS was used for this data analysis. We first described and compared sample characteristics grouped by WAT use frequency (no use, infrequent use, and frequent use) using Pearson's Chi-Square. Tests with a *p*-value of less than 0.10 were considered statistically significant in bivariate analyses; corresponding variables (sex, age, education, race and ethnicity, smoking status, marital status, comorbidity, depression, and area minority level) were then included in the regression analyses. Because the outcome variables were binary (used and did not use a WAT in the past year) and categorical (no use, infrequent use, and frequent use), both logistic regression and multinomial logistic regression models were conducted to examine the social factors associated with older adults' WAT use. A test with a *p*-value of less than 0.05 was considered statistically significant for multivariable regression.

Results

Sample characteristics

Most of the 3,302 older adults were non-Hispanic white (n = 2008, 60.8%), female (n = 1,821, 55.1%), and aged 65-74 (n = 2,007, 60.8%); 36.7% with the education of a college degree or higher, 32.4% with obesity, and 34.6% with multiple comorbidities.

The pattern of WAT use

In the total sample, 85.2% (n = 2812) reported no WAT use and 9.7% (n = 321) were WAT frequent users. Among WAT users, 65.5% were frequent users. Small but non-significant differences in WAT use were observed during vs. before the COVID-19 pandemic: 14.5% of participants were WAT users (frequent users: 9.4%) before COVID-19 and 16.0 % (frequent users: 10.6%) during the first wave of COVID-19.

Associations between social factors and WAT use

In bivariate analysis, older adults with younger age, higher education, higher annual household income, smoking status of "former" or "never" smoker, marital status of "married or living with a partner," a "good" self-rated general health status, one or no comorbidity, and no depression diagnosis reported frequent use of WATs (all $p < 0.05$; see Table 3.1).

Logistic regression within the total sample shows that sex, age, race/ethnicity, educational levels, annual household income, and area minority levels are significantly associated with older adults' use of WATs. Specifically, female older adults are more likely than their male counterparts to use WATs (OR 1.82, 95% CI: 1.43, 2.32). Younger cohorts of older adults (aged 65-74 years) are more likely than those aged 75 and above to be WAT users (OR 1.96, 95% CI: 1.51, 2.54). Older adults with a college degree or higher are more likely than those with an educational level of high school or lower to use WATs (OR 1.96, 95% CI: 1.42, 2.70). Older adults with an intermediate annual household income (OR 0.61, 95% CI: 0.47, 0.80) and low income (OR 0.39, 95% CI: 0.28, 0.54) are less likely to use WATs compared to those with

Table 3. 1 Sample characteristics based on WAT use frequency

		Total	**No WAT use**	**Infrequent WAT use**	**Frequent WAT use**	***p*-value**
		n = 3302	n = 2,812	n = 169	n = 321	
Data Collection Time (COVID-19)	Before COVID-19	2,510 (76.0%)	2,147 (85.5%)	126 (5.0%)	237 (9.4%)	0.55
	During COVID-19	792 (24.0%)	665 (84.0%)	43 (5.4%)	84 (10.6%)	
Sex	Male	1,449 (43.8%)	1,253 (86.5%)	62 (4.3%)	134 (9.2%)	0.12
	Female	1,821 (55.1%)	1,533 (84.2%)	103 (5.7%)	185 (10.2%)	
Age	75&above	1,295 (39.2%)	1,170 (90.3%)	46 (3.6%)	79 (6.1%)	<0.001
	65-74	2,007 (60.8%)	1,642 (81.8%)	123 (6.1%)	242 (12.1%)	
Education	High school or lower	1,004 (30.4%)	912 (90.8%)	35 (3.5%)	57 (5.7%)	<0.001
	Some college	1,017 (30.8%)	885 (87.0%)	44 (4.3%)	88 (8.7%)	
	College degree or higher	1,213 (36.7%)	955 (78.7%)	85 (7.0%)	173 (14.3%)	
Race/Ethnicity	Non-Hispanic White	2,008 (60.8%)	1,693 (84.3%)	108 (5.4%)	207 (10.3%)	0.30
	Non-Hispanic Black	353 (10.7%)	298 (84.4%)	20 (5.7%)	35 (9.9%)	
	Hispanic, Asian, and Other	480 (14.5%)	419 (87.3%)	15 (3.1%)	46 (9.6%)	
Annual Household Income	75K or more	861 (26.1%)	650 (75.5%)	73 (8.5%)	138 (16.0%)	<0.001
	35k to less than 75k	1,089 (33.0%)	926 (85.0%)	48 (4.4%)	115 (10.6%)	
	less than 35k	1,316 (39.9%)	1,206 (91.6%)	46 (3.5%)	64 (4.9%)	
Smoking Status	Current Smoker	279 (8.4%)	254 (91.0%)	12 (4.3%)	13 (4.7%)	0.021
	Former Smoker	1,166 (35.3%)	980 (84.0%)	57 (4.9%)	129 (11.1%)	
	Never Smoker	1,803 (54.6%)	1,532 (85.0%)	97 (5.4%)	174 (9.7%)	
BMI	Non-Obesity	2,231 (67.6%)	1,884 (84.4%)	115 (5.2%)	232 (10.4%)	0.16
	Obesity	1,071 (32.4%)	928 (86.6%)	54 (5.0%)	89 (8.3%)	
Marital Status	Married or living with a partner	1,529 (46.3%)	1,253 (81.9%)	78 (5.1%)	198 (12.9%)	<0.001
	Divorced, Widowed, Separated, or Never Married	1,711 (51.8%)	1,504 (87.9%)	87 (5.1%)	120 (7.0%)	
General Health Status	Good	2,603 (78.8%)	2,183 (83.9%)	136 (5.2%)	284 (10.9%)	<0.001
	Fair or Poor	642 (19.4%)	582 (90.7%)	28 (4.4%)	32 (5.0%)	
Comorbidity	One or No Comorbidity	1,911 (57.9%)	1,603 (83.9%)	101 (5.3%)	207 (10.8%)	0.025
	Multiple Comorbidities	1,242 (34.6%)	1,084 (87.3%)	57 (4.6%)	101 (8.1%)	
Depression	No	2,682 (81.2%)	2,276 (84.9%)	128 (4.8%)	278 (10.4%)	0.018

	Yes	543 (16.4%)	472 (86.9%)	34 (6.3%)	37 (6.8%)	
Region	Large Metro Area	2,606 (78.9%)	2,205 (84.6%)	142 (5.4%)	259 (9.9%)	0.16
	Small/Non-Metro Area	696 (21.1%)	607 (87.2%)	27 (3.9%)	62 (8.9%)	
Area Minority Level	Low Minority	1,306 (39.6%)	1,082 (82.8%)	70 (5.4%)	154 (11.8%)	0.004
	High Minority	1,996 (60.4%)	1,730 (86.7%)	99 (5.0%)	167 (8.4%)	

high income. Non-Hispanic African American older adults are more likely than non-Hispanic White older adults to use WATs (OR 1.60, 95% CI: 1.13, 2.29). Older adults who live in an area with a high minority level are less likely to use WATs than those who live in areas with fewer minorities (OR 0.77, 95% CI: 0.60, 0.98).

Association between social factors and frequent WAT use

Multinomial logistic regression within the total sample shows the factors associated with frequent WAT use among older adults. Similar to results from the logistic regression model, the following are positively associated with frequent use of WATs: female sex, age between 65 and 74 years, being non-Hispanic African American, having a college or higher degree, having a high annual household income, and living in an area with a low minority level.

Associations before and during the first wave of COVID-19

Subgroup analyses were conducted as an additional exploration of the sociodemographic and area factors associated with older adults' WAT use in both models before and during the first wave of the COVID-19 pandemic, with detailed data shown in Table 3.2. Before COVID-19, sex, age, race/ethnicity, educational levels, annual household income, and area minority levels are associated with frequent use of WATs. In addition to the findings with the total sample, with the before COVID-19 subsample, older adults categorized as "Hispanic, non-Hispanic Asian, and Other" are also more likely to be frequent WAT users than non-Hispanic White older adults (OR 1.67, 95% CI: 1.08, 2.58). During the first wave of COVID-19, only younger cohorts of older adults (65-74 years) are associated with frequent use of WATs compared to their older counterparts (75 years and above) (OR 2.67, 95% CI: 1.30, 5.48).

Table 3. 2 Associations between social factors and Wearable Activity Tracker use

	Logistic Regression Model (User & Non-User)			**Multinomial Logistic Regression Model (No use, Infrequent use & Frequent use)**					
				Total Sample n = 2652		**Before COVID-19** n = 2025		**First Wave COVID-19** n = 627	
	Total Sample n = 2,658	**Before COVID-19** n = 2,030	**First Wave COVID-19** n = 628	Infrequent Use	Frequent Use	Infrequent Use	Frequent Use	Infrequent Use	Frequent Use
Social Factors	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)
Sex									
Male (ref)									
Female	1.82*** (1.43, 2.32)	2.01*** (1.52, 2.67)	1.37 (0.85, 2.22)	1.77** (1.19, 2.64)	1.86*** (1.40, 2.47)	1.77* (1.11, 2.82)	2.17*** (1.55, 3.03)	1.82 (0.81, 4.05)	1.21 (0.69, 2.11)
Age									
75&above (ref)									
65-74	1.96*** (1.51, 2.54)	1.88** (1.40, 2.53)	2.25** (1.26, 4.00)	1.88** (1.22, 2.90)	2.04*** (1.49, 2.79)	1.87* (1.14, 3.05)	1.90*** (1.33, 2.71)	1.93 (0.75, 4.92)	2.67** (1.30, 5.48)
Education									
High school or less (ref)									
Some college	1.25 (0.89, 1.76)	1.27 (0.85, 1.88)	1.19 (0.61, 2.32)	1.08 (0.61, 1.90)	1.34 (0.89, 2.02)	1.09 (0.56, 2.13)	1.36 (0.84, 2.20)	0.92 (0.32, 2.68)	1.26 (0.56, 2.87)
College Degree or higher	1.96*** (1.42, 2.70)	1.99*** (1.37, 2.89)	1.83 (0.96, 3.48)	1.87* (1.11, 3.15)	2.01 *** (1.36, 2.98)	2.11* (1.14, 3.89)	1.93** (1.22, 3.04)	1.34 (0.48, 3.77)	2.16 (0.99, 4.72)
Race/Ethnicity									
Non-Hispanic White (ref)									
Non-Hispanic African Americans	1.60** (1.13, 2.29)	1.57* (1.01, 2.42)	1.54 (0.81, 2.90)	1.48 (0.85, 2.57)	1.60* (1.04, 2.45)	1.11 (0.54, 2.26)	1.83* (1.09, 3.07)	2.53 (0.95, 6.75)	1.06 (0.48, 2.35)
Hispanic, Non-Hispanic Asian, and Others	1.09 (0.78, 1.52)	1.32 (0.91, 1.91)	0.57 (0.27, 1.22)	0.75 (0.41, 1.36)	1.28 (0.87, 1.88)	0.81 (0.41, 1.60)	1.63* (1.06, 2.51)	0.59 (0.16, 2.25)	0.55 (0.22, 1.36)
Annual Household Income									
75K or more (ref)									
35k to less than 75k	0.61*** (0.47, 0.80)	0.58*** (0.43, 0.78)	0.79 (0.45, 1.38)	0.43 *** (0.27, 0.67)	0.71* (0.52, 0.96)	0.44** (0.27, 0.74)	0.64* (0.4, 0.90)	0.38 (0.14, 1.03)	1.04 (0.55, 2.00)
less than 35k	0.39 *** (0.28, 0.54)	0.34*** (0.23, 0.50)	0.64 (0.32, 1.27)	0.34 *** (0.20, 0.58)	0.39 *** (0.26, 0.60)	0.31*** (0.17, 0.57)	0.33*** (0.20, 0.53)	0.54 (0.18, 1.61)	0.71 (0.31, 1.63)
Area Minority Level									
Low Minority (ref)									
High Minority	0.77* (0.60, 0.98)	0.73* (0.55, 0.96)	0.90 (0.54, 1.50)	0.88 (0.59,1.31)	0.72 * (0.54, 0.96)	0.86 (0.55, 1.35)	0.66* (0.48, 0.92)	0.93 (0.39, 2.21)	0.89 (0.49, 1.60)

Reference group: No WAT use.
Odds ratios presented in this table were adjusted for income, education, race & ethnicity, smoking status, BMI, marital status, health, total conditions, depression, insurance, region, and minority levels. *P*<0.001 ***,
P<0.01 **, *P*<0.05 *

Discussion

In the present study, we examined the prevalence of WAT use in older adults before and during the first wave of the COVID-19 pandemic and examined sociodemographic factors associated with older adults' use of WATs. We found that only 9.7% of the sample (9.4% pre-covid vs. 10.6% 1st wave) were frequent WAT users. Only 65.5% of WAT users frequently used WATs. In the total sample and pre-COVID-19 subsample, older adults who were non-Hispanic African Americans, 65-74 years, women, with a college degree or above were more likely to be frequent WAT users after adjusting for covariates. Lower-income and high-minority area living were associated with lower odds of frequent WAT use. In the 1st wave sub-sample, only aged 65-74 years were associated with frequent WAT use.

It is not surprising that income and educational levels are associated with the use of WATs. Research has reported that the adoption of digital tools and applications is associated with the users' educational levels and income in the adult population(Chandrasekaran et al., 2020; Sheon, 2018). Like other commercially available digital devices, most WATs require an Internet connection and other digital tools such as smartphones for data synchronization. To use a WAT, people need to afford the Internet, a smartphone, and a WAT device (Tedesco et al., 2017). The financial cost is a key factor that influences older adults' willingness to purchase a WAT device(Rosales et al., 2018). It has been reported that seniors who are older, less affluent, or with lower levels of educational attainment are expected to have less experience using digital technology, including WATs(Alley et al., 2016; Macridis et al., 2018). However, older adults with lower socioeconomic status (SES) and those who experience social inequity may be in higher need of WATs as they are more likely to experience health disparities (e.g., physical inactivity, sleep disturbances, depression). Therefore, enhancing the use of WAT technologies potentially promotes beneficial health outcomes in this population. Limited research examined the health benefits of WAT-facilitated interventions in low-SES populations. It is unclear whether current WAT-facilitated interventions among lower-SES older adults may achieve the same level of effectiveness as in the general older adult population. Therefore, future research should focus on finding effective ways to promote both WAT utilization and WAT-based intervention effectiveness among low-SES older adults to help promote beneficial health outcomes in this population.

Our data show that women are more likely than men to use WATs. This is consistent with the current literature. Li et al.(L. Li et al., 2020) found that an online panel of older adult females were more likely to be long-term WAT users. Population-based surveys from both Canada and Australia report that, among general adults, females use physical activity-tracking devices more than males(Alley et al., 2016; Macridis et al., 2018), although males are more likely to use advanced trackers(Alley et al., 2016). A similar finding in terms of e-health utilization indicated that female adults were more likely than male adults to have ever looked for health information online or owned a mobile app for health (Escoffery, 2018). Findings from a national survey in the United States also showed that females were significantly more likely to report health information technology use than males (Hung, Lyons, & Wu, 2020). This could be related to the fact that women are more likely than men to actively seek health care. Another national survey in the US found that female older adults were more likely than male older adults to use mental health services (Karlin, Duffy, & Gleaves, 2008). A study focusing on health information-seeking behaviors in older adults found that females were inclined to have more control over health information retrieval and favorable attitudes toward self-directed or informed treatment(Chaudhuri, Le, White, Thompson, & Demiris, 2013).

Consistent with previous evidence, we found that relatively younger age is associated with greater WAT use among older adults. Generally, age is negatively associated with the use of WATs. A survey in 2019 estimated that 25% of U.S. adults between 18-49 years of age reported using a WAT regularly; 17% of those 50 years of age and older reported using a WAT regularly (Vogels, 2020). In addition, current WATs studies often compare young adults with older adults (Xie et al., 2020) but no study has investigated WAT use within different subgroups of older adults. The present study focuses on WAT use among U.S. older adults, specifically comparing older adults between 65 and 74 years of age and older adults aged 75 and above(Lee et al., 2018; Little & Little, 2014). We compared these subgroups in that it is necessary to acknowledge the differences among each age group considering the development of technology in the past few decades. For example, the "Baby Boomers", born between 1946 and 1964(Hogan, Perez, & Bell, 2008), are currently between the ages of 60 and 74 years. Reports have shown that this population embraces digital life and is more likely to adopt technology such as smartphones, social media, and use tablet computers than older adults 75 years and above (Vogels, 2019).

Black/African American older adults did not differ from White older adults in WAT use before adjusting for covariates but were significantly more likely to use WATs than White older adults, after adjusting for covariates. Meanwhile, older adults living in areas with higher minority levels were less likely to use WATs. These findings could potentially indicate that other SES play a more important role in older adults' WAT use rather than race and ethnicity. Consistent with our study findings, Pew Research Center also reported higher WAT use among African Americans: approximately 23% of Black U.S. adults and 20% of White U.S. adults reported regular use of a WAT in 2019 (Vogels, 2020). Evidence suggests that the differences between race and ethnicity in WATs could be explained by their acceptance of data sharing. White adults are more likely than Black and Hispanic adults to find it unacceptable to share WAT data for research (Vogels, 2020). Other underlying explanations of racial and ethnic differences in WAT use among U.S. older adults should be explored in future studies.

The present study is one of the first studies to additionally observe the frequent use of WATs in a large cohort dataset. Studies have investigated older adults' *adherence* to using WATs as part of a study in which participants were provided devices and asked to wear them (J. Li et al., 2021; M. Li et al., 2022; Paolillo et al., 2022). Few studies that focused on older adults' WAT use considered user frequency (Junde Li, Ma, Chan, & Man, 2019). A survey in Japan estimated that about 58% of female and 68% of male users used a WAT every day, and 14% of female users in Japan used WATs only once a week (Statista, 2022). No studies have been found to present U.S. older adults' frequency of WAT use based on national data. In the present study, we found that, among older adults who do use WATs, only 65.5% used WATs frequently, and about one-third of WAT users used the technology only occasionally, which could lead to decreased health benefits from using WATs. The reasons for low adherence to WAT use could include forgetting to wear the device, forgetting to charge the device, and having difficulties with synchronizing the device or operating the device (M. Li et al., 2022). Therefore, training demonstrating the health benefits of using WATs, with detailed instructions on WAT operation, charging, and synchronization designed for the aging populations should be included in future research.

Several limitations exist in the present study. First, in the HINTS survey, cycle 5 data were collected between February and June 2020. The COVID-19 pandemic started in March in the U.S.; therefore, the data reflecting the COVID-19 pandemic were available only from March to June. This means that the data represent the start and first wave of COVID-19 and do not provide changes in WAT use patterns throughout the pandemic. Additional studies are needed to explore the WAT use changes considering the entire COVID-19 progression. Second, because of the short period of data collection during COVID-19, limited subgroup data (627 participants since the start of COVID-19) made it difficult to conduct statistical analyses. Therefore, we did not aim to compare changes in WAT use before and during COVID-19 but instead presented the available data to show the within-sample prevalence of WAT use. Additionally, other factors may impact the frequency of WAT use, such as cognitive function, perceived ease of use, interest/acceptance of technology, etc.(Adapa, Nah, Hall, Siau, & Smith, 2018; Dai, Larnyo, Tetteh, Aboagye, & Musah, 2020; Wang, Tao, Yu, & Qu, 2020), were not assessed in the HINTS data.

The findings of the present study provide important implications for future WAT-related research and manufacturers. The inequality of WAT use among older Americans needs to be addressed to foster equal access to WATs among older Americans. As Sieck et al. stated(Sieck et al., 2021), improved access to digital devices in diverse communities with different SES levels is needed to avoid the risk of digital technologies becoming another social determinant of health. Future WAT-based interventions should focus on the inclusion of low-SES older adults and tackle health disparities among older Americans.

Conclusions

In this study, we described the characteristics of older adults with various levels of WAT use frequency, and the use of WATs before and during the start of the COVID-19 pandemic, and explored sociodemographic factors associated with older adults' use of WATs. Our findings suggest that WATs are an under-utilized tool that could be used to address health disparities among older Americans. Additionally, further understanding of the impact of the COVID-19 pandemic on WAT use among older adults and potential opportunities should be investigated.

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Conflicts of Interest: All authors declare that they have no conflicts of interest.

IRB Approval: This study was exempted from the Protection of Human Subjects because we only used public-available and de-identified data.

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CHAPTER 4: MANUSCRIPT THREE

Social Factors, Wearable Activity Tracker Use, and Physical Activity Levels Among U.S. Older Adults

Target Journal: TBD

Date of Submission: Plan to submit in April.

Abstract

Background: In research focused on social factors, wearable activity tracker (WAT), and physical activity (PA), few have investigated WAT use frequency and PA patterns in relation to both MVPA time and sedentary behavior. In addition, there is a lack of evidence showing the role WAT use plays in the association of social factors and older adults' PA patterns. The present study aims to describe PA patterns including both MVPA and sedentary behavior among U.S. older adults, and to examine the association of social factors and WAT use with PA patterns among U.S. community dwelling older adults.

Methods: We used cross-sectional data from 3,370 older adults from the Health Information National Trends Survey. Older adults' sociodemographic and clinical characteristic were described based on PA patterns. Linear regression models and multinomial logistic regression models were used to identify associations among social factors, WAT use, and PA patterns. Baron and Kenney's approach was used to examine the mediation effect of wearable activity tracker use in the associations of SES with activity and sedentary time.

Results: Participants were 55.6% female and aged 73.9 years (SD=1.7) on average. Over half of the participants reported less than 150 minutes of weekly MVPA time (66.2%) and over 6 hours of daily sedentary time (55.5%). Older adults who are younger (aged 65 to 74 years) (b=45.9, 95% Confidence Interval [CI]: 28.2, 63.6) and have higher annual household income (middle income: b=27.8, 95% CI: 6.8, 48.8; high income: b=37.4, 95% CI: 12.9, 61.9) had significantly longer weekly MVPA time compared to their counter parts. Older women had significantly shorter weekly MVPA time (b=-45.7, 95% CI: -63.5, -28.0) and shorter daily sedentary time (b=-0.46, 95% CI: -0.74, -0.17) compared to men. Non-Hispanic Black older adults (b=-0.89, 95% CI: -1.36, -0.44) and Hispanic, Asian, and other older adults (b=-0.78, 95% CI: -1.18, -0.39) had a shorter daily sedentary time than Non-Hispanic White older adults. Older adults with some college education (b=-0.46, 95% CI: 0.21, 1.34) and college or higher degree (b=0.41, 95% CI: 0.15, 1.30) have significantly longer daily sedentary time. Frequent use of WATs was significantly associated with longer weekly MVPA time and shorter daily sedentary time. WAT use mediated the associations between income and weekly MVPA time (IE: 3.75, 95% CI: 1.69, 5.80) and education and weekly MVPA time (IE: 1.59, 95% CI: 0.45, 2.74). WAT use, however, did not mediation the associations between SES and daily sedentary time.

Conclusion: U.S. older adults reported low PA and frequent WAT use was significantly associated with improved PA patterns. Social disparities existed in PA patterns, but WAT use was found to partially mediate the associations between socioeconomic status and PA patterns. There is still an urgent need to promote PA patterns in U.S. older adults especially in socially and economically disadvantaged older adults. WATs could be an effective way to improve PA patterns in older adults and frequent WAT use should be encouraged. In addition, increasing adoption of WATs among socially and economically disadvantaged older adults may help better promote PA patterns in this population.

Introduction

Physical inactivity is strongly linked to mortality and morbidity such as diabetes, cardiovascular disease, cancer, obesity and mental illness, threatening the health of the aging population (Booth, Roberts, Thyfault, Ruegsegger, & Toedebusch, 2017; Mokdad, Marks, Stroup, & Gerberding, 2004). The prevalence of inactivity significantly increases with age: an estimation of 26.9% of adults aged 65-74 years and 35.3% of adults aged 75 years and above were inactive (Watson et al., 2016). Physical inactivity in the U.S. population results in approximately $117 billion in annual health care costs and about 10 percent of premature mortality (CDC, 2022b). There is an urgent need to improve PA levels among older adults to promote health, prevent chronic illnesses, and reduce health care costs in this population.

Physical activity and sedentary behavior are two important indicators of PA levels that can impact older adults' health. Physical activity is defined as "any bodily movement produced by skeletal muscles that requires energy expenditure" (World Health Organization [WHO], 2010) and engaging in both moderate- and vigorous-intensity physical activity (MVPA) improves health. Sedentary behavior is defined as "any sitting behavior with low energy expenditure", according to the American Physical Activity Guideline (HHS, 2018). To achieve and maintain an active lifestyle, older adults should engage in MVPA for at least 150 minute per week and reduce sedentary behavior (CDC, 2022a; WHO, 2010). Although there is a lack of a standard cut-off point for sedentary behavior, 6 hours or more of sitting time has been considered as high sedentary behavior (Heron, O'Neill, McAneney, Kee, & Tully, 2019). It is important to note that although MVPA and sedentary behavior are different concepts, they are not opposite to each other: one can reach guideline recommended activity levels and have a sedentary lifestyle at the same time (Thivel et al., 2018). Therefore, MVPA and sedentary behavior may synergistically impact health. One way to better understand older adults' PA patterns considering both MVPA and sedentary behavior simultaneously is by grouping older adults into four *activity classes*: 1) high MVPA time, low sedentary time; 2) high MVPA time, high sedentary time, 3) low MVPA time, low sedentary time, and 4) low MVPA time, low sedentary time.

Older adults PA patterns are prone to be influenced by social disparities. Studies show older adults who are female, older, have less education, and living in urban area have lower physical activity levels on average (Gidlow, Johnston, Crone, Ellis, & James, 2006; Lim & Taylor, 2005). Evidence on social factors associated with sedentary behavior in older adults have been mixed. Although some studies found that those who are males, older, with lower education (less than college) are more likely to engage in sedentary behavior in adults and older adults (Aithal, Visaria, & Malhotra, 2022; da Silva et al., 2020; Patterson et al., 2018), other evidence suggested no associations with sex, age, education, income and sedentary behavior in older adults (Heseltine et al., 2015). Therefore, it is necessary to confirm social risk factors for sedentary behavior with a larger sample of older adults. In addition, to the authors' best knowledge, no study has investigated social factors associated with older adults' activity class, simultaneously considering both MVPA and sedentary time.

As modern technology advances, WATs have been increasingly adopted to motivate and improve physical activity globally. They are consumer devices that provide feedback to the wearer such as fitness trackers, activity-tracking smartwatches, and pedometers (Tedesco, Barton, & O'Flynn, 2017). Although most U.S. older adults have never used a WAT (Xie, Jo, & Hong, 2020), they showed general interest and acceptance of using a WAT device to monitor their physical activity levels (Kononova et al., 2019; M. Li, Mcphillips, Wenzel, Szanton, & Li, 2022). In addition, WATs have demonstrated promising potential for PA enhancement through behavior change techniques (i.e. self-monitoring of real-time data, PA goal setting, motivational messages, etc.) in both observational and experimental studies with the aging population (Coughlin & Stewart, 2016; Zhang, Giordani, Margulis, & Chen, 2022). However, limited research focused on older adults' WAT use patterns (how frequently they used a WAT) and whether if various WAT use frequencies associate with different PA patterns (Chandrasekaran, Katthula, & Moustakas, 2020). In addition, it is unclear if wearable technology can improve PA levels by increasing MVPA time, decreasing sedentary behavior, or both. Understanding the mechanism through which WAT use is associated with older adults' PA patterns can help health care providers and researchers better develop methods to promote PA in older adults.

In addition, it is important to include social factors when investigating the associations between WAT use and PA patterns. As shown in the literature, SES are strongly linked to WAT use in older adults (Vogels, 2020) because purchasing a WAT device often requires access to wireless internet and a smartphone for data synchronization purposes and software system requirements (Tedesco et al., 2017). Based on the current literature, WATs could potentially mediate the associations between SES and PA patterns in older adults. However, to the authors' best knowledge, no studies have investigated the role WATs play in this association.

In addition, older adults' use of WATs and PA patterns may be impacted by the COVID-19 pandemic started in March 2020, especially during the first wave lockdown (Bu, Bone, Mitchell, Steptoe, & Fancourt, 2021; Füzéki, Groneberg, & Banzer, 2020). Evidence shows increased used of WATs and decreased PA in older adults since the pandemic (Panicker & Chandrasekaran, 2022), but no study has examined if the association of WAT use with PA was moderated by the COVID-19 pandemic. Whether the strength of the association between WAT use and PA increased or decreased during the first wave of COVID-19 due to the lockdown has not been investigated.

Considering the COVID-19 pandemic, an exploration of the associations among older adult social factors, WAT use, and PA patterns is imperative to fill in current gaps in literature. There is an urgent need to examine social factors associated with older adults' PA patterns, understand how older adults' WAT use is associated with their PA patterns, evaluate the role WAT plays in the association between social factors and older adults' PA patterns, and explore how COVID-19 may moderate the association between older adults' WAT use and PA patterns. In this study, PA patterns include (1) PA time, (2) sedentary time, and (3) activity classes (considering both PA and sedentary time).

Purpose

The purpose of this research study is to understand the associations among social factors, WAT use, and PA patterns among U.S. older adults and to explore how COVID-19 moderate the associations between older adults' WAT use and PA patterns.

Aim 1: Examine social factors (e.g., sex, age, education, income, and area factors) associated with older adults' PA patterns (MVPA time- minutes per week, sedentary time -hours per day, and activity class).

Aim 2: Examine the association between WAT use and older adults' physical activity and explore the moderating role of COVID-19 on the association of WAT use with PA. *Hypothesis 2a:* Older adults who frequently used WATs have higher MVPA time and lower sedentary time; *Hypothesis 2b:* COVID-19 moderates the association between WAT use and PA: after the COVID-19 pandemic, the positive association between WAT use and PA may be stronger.

Aim 3: Examine whether the use of WATs mediates the associations between socioeconomic status (income and education) and older adults' PA levels.

Hypothesis 3: WAT use positively mediates the association between socioeconomic status (income and education) and older adults' PA: Higher income and education are associated with higher odds of WAT use, which is further associated with longer MVPA time and shorter sedentary time.

Methods

Conceptual Framework

The conceptual framework for the current study, shown in Figure 4.1, has been developed based on available evidence and adapted from the Fundamental Cause Theory (Link & Phelan, 1995). The Fundamental Cause Theory posits that SES can influence an individuals' access to certain important recourses that may impact their health outcomes. In this study, we hypothesized that social factors are associated with WAT use and PA patterns. Corresponding to the Fundamental Cause Theory, in this study, WAT use was considered as an important technological resource that can influence health, and PA patterns are the health outcomes. Based on previous literature, social factors, including sex, age, income, education, and area factors are associated with WAT use (Li, et al., 2023) and WAT use is associated with physical activity (Tang, Moore, McGavigan, Clark, & Ganesan, 2020). In addition, social factors are also associated with older adults' PA (Gidlow et al., 2006). Adapting from the Fundamental Cause Theory and the literature, this conceptual framework provides guidance to the study hypotheses.

The HINTS Study Design and Recruitment

This is a cross-sectional secondary data analysis using the Health Information National Trends Survey (HINTS) dataset with data collected from January to April 2019 and February to

June 2020. Launched by NIH's National Cancer Institute (NCI) in 2003, HINTS regularly collects data about the American public's knowledge of, attitudes toward, and use of cancer-related and other health-related information. To recruit participants, HINTS sent postal mail to random samples of non-vacant U.S. residential addresses for both the 2019 and 2020 cohorts. More details about the HINTS study are available through HINTS briefs and reports (National Institutes of Health [NIH], 2021; NIH, n.d.). The present study includes 3,370 participants aged 65 and above from both cycles 3 and 4. All data collected in HINTS are self-reported on paper and sent back by mail.

Measures

Social Factors include age, sex, annual household income, education, race/ethnicity, and area factors. Participants' sex includes "Male" and "Female." Based on previous literature and data distribution, the age variable was dichotomized into 65-74 years and 75 years and above (Lee, Oh, Park, Choi, & Wee, 2018). Annual household income was categorized into (1) low income (less than $35,000), (2) intermediate income ($35,000-$75,000), and (3) high income ($75,000) (Xie, Jo, & Hong, 2020). The educational variable was categorized into (1) high school or less, (2) some college, and (3) college degree or higher. Race and ethnicity were categorized into three categories: (1) White, (2) Black, and (3) Hispanic, non-Hispanic Asians, and others. Area factors included region and area minority percentage. Region population was a variable created to reflect the USDA 2013 rural-urban continuum codes in which a classification scheme was used to distinguish metropolitan counties by population size of the metro area. For the present study, the region population was dichotomized into (1) Large Metro Area: Counties in metro areas of at least 250,000 population; and (2) Small/Non-Metro Area: Counties in metro areas of fewer than 250,000 population or non-metro areas. The area minority level was formed using the census tract-level characteristics from the 2014-2018 American Community Survey data file. According to HINTS 5, addresses in census tracts with a population proportion of Hispanics or African Americans that equaled or exceeded 34 percent were assigned to the high minority level category, and the remaining addresses were assigned to the low minority level category.

WAT Use The participants' WAT use over the prior 12 months and the frequency of use over the past month of data collection were assessed with two items: (1) "In the last 12 months, have you used a Wearable Activity Tracker to monitor or track your health or activity? For example, a Fitbit, Apple Watch, or Garmin Vivofit." (2) "In the past month, how often did you use a wearable device to track your health?" For those who answered "Yes" in the previous question, options included "Every day," "Almost every day," "1-2 times per week," "Less than once per week," or "I did not use a wearable device in the past month." Based on these questions, we developed *WAT Use* into a categorial variable: (1) Frequent WAT use: those who reported using a WAT "Every day" or "Almost every day" in the past month; (2) Infrequent use: those who reported using a WAT "1-2 times per week," "Less than once per week," or "I did not use a wearable device in the past month (but used one in the past year)"; and (3) No use: respondents who did not use a WAT in the past month and those who did not use a WAT over the past 12 months.

Physical Activity Patterns (PA Patterns)

PA patterns consists of (1) weekly MVPA time, (2) daily sedentary time, and (3) Activity classes, which is 4-category variable considering both MVPA and sedentary time.

Weekly MVPA time was assessed using two items: (1) MVPA: "In a typical week, how many days do you do any physical activity or exercise of at least moderate intensity?" Choices include: “None”, “One day per week”, “Two days per week” … “Seven days per week”. (2) MVPA duration: “On the days that you do any physical activity or exercise of at least moderate intensity, how long do you typically do these activities?” The respondents are asked to answer the number of minutes per day. Based on these 2 items, the HINTS dataset provides a variable named “Minutes per week of at least moderate-intensity exercise” that is derived from the answers to these two questions that measure PA. Consistent with previous literature (Xie, Jo, and Hong 2020), this study also uses this variable (Minutes per week of at least moderate-intensity exercise) as a measure of PA. The PA outcome variable is continuous.

Daily sedentary time is assessed using one item: Daily sedentary time: “During the past 7 days, how much time did you spend sitting on a typical day at home or at work?” The respondents were asked to answer with the number of hours per day.

Activity Classes: Based on current PA guidelines and literature, a weekly MVPA time under 150 minutes and a daily sedentary time more than 6 hours were used as cutoffs for low MVPA time and high sedentary time (DHS, 2018). Four physical activity classes were categorized: (1) high MVPA low sedentary, (2) high MVPA high sedentary, (3) low MVPA low sedentary, and (4) low MVPA high sedentary groups.

Covariates: *Body Mass Index (BMI)* was calculated using the respondents’ self-reported heights and weights and was dichotomized into (1) non-obesity: under 30, and (2) obesity: 30 and above. *Smoking status* was a variable derived from two questions on past smoking experience and current smoking frequency and was categorized into current, former, and never smoker. The *marital status* question was included in the questionnaire and dichotomized into two categories: (1) married or living with a partner, and (2) divorced, widowed, separated, or never married. *Comorbidity* was measured by the sum of reported medical conditions reported by respondents and categorized into: (1) one or no comorbidity and (2) multiple comorbidities. *General health status* was assessed by the item: "In general, would you say your health is …" with the choices of "Excellent, Very good, Good, Fair, or Poor." *Depression* was assessed by the item: "Has a doctor or other health professional ever told you that you had depression or anxiety disorder?"

Statistical Analysis:

Description of sample sociodemographic factors and clinical factors based on MVPA time, sedentary time, and activity class.

Descriptive analyses were conducted including frequency and percentages for categorical variables and mean and standard deviation for continuous variables. We described and compared sample characteristics grouped by PA patterns (weekly MVPA time, daily sedentary time, and activity class) using Pearson's Chi-Square.

Associations of social factors with MVPA time, sedentary time, and activity class

Multivariate linear regression models were conducted to examine the social factors associated with older adults' PA patterns. A test with a p-value of less than 0.05 was considered statistically significant. Multinomial logistic regression models were built to examine social factors associated with the physical activity classes, with the low MVPA high sedentary group being the reference group.

Associations of WAT use frequency with PA Patterns.

WAT use frequency associated with weekly MVPA time and daily sedentary time were examined using simple linear regression models adjusting for covariates. WAT use frequency associated with activity classes was assessed with a multinomial logistic regression model adjusting for covariates.

Exploration of COVID-19 on the association between WAT Use and PA Patterns.

To explore the role COVID-19 played in the association of WATs and older adults' PA patterns, we added an interaction term (WAT use * COVID-19) to the multivariate linear regression models of WAT use and weekly MVPA time, and WAT use and daily sedentary time. Subgroup analyses were then conducted in the pre-COVID-19 sub-sample and the beginning of the COVID-19 sub-sample to explore the associations between WAT use and PA during the two separate periods.

Assessing the role of Using WATs on the association between SES and PA Patterns

Mediation analyses were performed to illustrate the association of SES (income and education) with physical activity levels (weekly MVPA minutes and daily sedentary hours) mediated by the use of WATs (Figure 4.1). Baron and Kenny's approach to test mediation (MEDSEM procedure in Stata version 17) was used to estimate the total effects, indirect effects (IE), and direct effects (DE) of SES on physical activity levels. Two models were estimated: a multivariate logistic regression model for WATs use (mediator) conditional on social factors (exposure), and all study confounders and a multivariate linear regression model for physical activity levels (outcome) conditional on social factors. The DE represented the effect of social factors on physical activity levels that were independent of WAT use. An IE represented the proportion of social factors that could be explained by its association with WATs use. Sobel Test was used to test the significance of IE. To quantify the magnitude of mediation, the study estimated the proportion of the association mediated by the use of WATs (IE/[DE+IE]).

Results

Sample characteristics by MVPA time, sedentary time, and activity classes.

Sample characteristics were described in total and by MVPA time, sedentary time, and activity classes (Table 4.1). The current study included a total of 3370 participants, with 55.6% female, average age 73.9 years (SD=1.7), 37.5 % had a college degree or higher, and most were Non-Hispanic White (70.8%). Over half of the participants exercised less than 150 minutes per week (66.2%) and sat for more than 6 hours per day (55.5%). The percentage of participants classified as the "Low MVPA and High Sedentary" class was 40%.

Social factors associated with MVPA time, sedentary time, and activity classes.

Social factors associated with MVPA time.

Table 4.2 shows factors associated with MVPA time and sedentary time using multivariate linear regression. Older adults who are younger (aged 65 to 74 years) (b=45.9, 95% Confidence Interval [CI]: 28.2, 63.6), have higher annual household income (middle income: b=27.8, 95% CI: 6.8, 48.8; high income: b=37.4, 95% CI: 12.9, 61.9), and higher education (Some college: b=26.2, 95% CI: 4.5, 48.0; College or higher: b=25.2, 95% CI: 3.0, 47.4) had significantly longer weekly MVPA time compared to their counterparts. Female older adults had significantly shorter weekly MVPA time (b=-45.7, 95% CI: -63.5, -28.0) compared to male older adults.

Social factors associated with sedentary time.

Older women had significantly shorter daily sedentary time (b=-0.46, 95% CI: -0.74, -0.17) compared to men. Compared to Non-Hispanic White older adults, Non-Hispanic Black older adults (b=-0.89, 95% CI: -1.36, -0.44), and Hispanic, Asian, and other older adults (b=-0.78, 95% CI: -1.18, -0.39) had a shorter daily sedentary time. Older adults with some college education (b=0.46, 95% CI: 0.21, 1.34) and college or higher degree (b=0.41, 95% CI: 0.15, 1.30) have significantly longer daily sedentary time.

Social factors associated with activity class.

Table 4.3 and Figure 4.2 show social factors associated with the four physical activity classes with "High MVPA time low sedentary time" as the reference group. Older adults who are younger (65-74 years) (AOR: 0.56, 95% CI: 0.43, 0.72), Hispanic, Asian, or others (AOR: 0.63, 95% CI: 0.44, 0.89), and those with the highest annual household income ($75,000 and above) (AOR: 0.65, 95% CI: 0.46, 0.93) were less likely to be in the "Low MVPA time and high sedentary time class", and older adults living the high minority areas (AOR: 1.30, 95% CI: 1.00, 1.68), were more likely to be in the "Low MVPA time and high sedentary time class". Female (AOR: 1.55, 95% CI: 1.18, 2.04), minority older adults (Non-Hispanic Black (AOR: 1.61, 95% CI: 1.03, 2.50), Hispanic, Asian, & Others (AOR: 1.51, 95% CI: 1.06, 2.15)), had higher odds, and younger older adults (AOR: 0.62, 95% CI: 0.47, 0.82) with some college completion (AOR: 0.70, 95% CI: 0.49, 0.99) had lower odds to be in the "Low MVPA time low sedentary time" group. Female older adults (AOR: 0.75, 95% CI: 0.56, 1.00) have lower odds, and older adults who have a college or higher degree (AOR: 1.57, 95% CI: 1.05, 2.34) have higher odds to be in the "High MVPA time High sedentary time group".

Frequent WAT Use was associated with PA Patterns

Table 4.4 shows the associations between WAT use frequency and older adults' physical activity adjusting for covariates. We found that older adults who frequently used WATs had significantly longer weekly MVPA times (b=61.15, 95%CI: 33.55, 88.75), shorter daily sedentary times (b=-0.56, 95%CI: -1.0, -0.11), and were less likely to be in the activity classes with low MVPA time (Low MVPA time, High sedentary time: AOR=0.40, 95%CI: 0.26, 0.53; Low MVPA time, Low sedentary time: AOR=0.41, 95%CI: 0.27, 0.60).

COVID-19 Did Not Moderate the Association between WAT and PA

As shown in Table 4.5, no significant moderating effects of the COVID-19 pandemic were found in the association between WAT use and weekly MVPA time (interaction term: b=-14.8 95% CI: -68.6, 38.9), nor in the association between WAT use and a daily sedentary time (b=-0.5, 95% CI: -1.3, 0.4), after adjusting for covariates.

After adjusting for covariates, the results of the sub-group analyses showed that the use of WAT was significantly associated with weekly MVPA time in the pre-COVID-19 subsample (b=46.6, 95% CI: 18.6, 74.6), but this association was not significant in the first wave of COVID-19 subsample (b=21.0, 95% CI: -22.66, 64.6). While the association of WAT uses with daily sedentary time was not significant in the pre-COVID-19 subsample (b=-0.2, 95% CI: -0.6, 0.3), it was significant in the first wave of the COVID-19 subsample (-0.8, 95% CI: -1.7, -0.1).

WAT use significantly mediates the associations between SES and MVPA time.

Table 4.6 demonstrates the mediating effects of WAT use in the associations between SES and older adults' physical activity levels. *SES and weekly MVPA time:* WAT use explained 13% of the association (IE: 3.75, 95% CI 1.69, 5.80) between income and weekly MVPA time and 10% of the association (IE: 1.59, 95% CI 0.45, 2.74) between education and weekly MVPA time. *SES and daily sedentary time*: No mediation effect of WAT use was detected in the associations between SES and daily sedentary time in the study sample.

Discussion

The present study described U.S. older adults' PA patterns and illustrated the associations among social factors, WAT use, PA patterns, and the COVID-19 pandemic. We found that over half of the study sample reported less weekly MVPA time than the WHO recommendation (at least 150 minutes of moderate-intensity physical activity), and daily sedentary time more than 6 hours. Older adults who were male, younger, had high income and education were more likely to have higher MVPA time; older adults who were male, Non-Hispanic White, had higher education, and were urban residents were more likely to have longer sedentary time. Older adults who frequently used WATs were more likely to have longer MVPA time and shorter sedentary time. The COVID-19 pandemic did not significantly moderate the association between WAT use and PA patterns. In addition, WAT use partially mediated the association between SES and MVPA time in older adults.

Social factors associated with older adults' physical MVPA time is consistent with the previous literature. Firstly, previous research consistently showed gender differences in PA and concluded that males generally engaged more PA than females across different age groups (Azevedo et al., 2007; Hamrani et al., 2015; McCarthy & Warne, 2022). Secondly, higher income has been linked to higher leisure time physical activity or exercises (Kari et al., 2020; Zapata-Lamana, Poblete-Valderrama, Cigarroa, & Parra-Rizo, 2021). Furthermore, younger age is also linked to increased PA since PA generally decrease as adult adults age (Suryadinata, Wirjatmadi, Adriani, & Lorensia, 2020).

In this study, we examined social factors associated with older adults' sedentary behavior. According to the American Physical Activity Guideline 2nd edition, there is a lack of recommendations regarding optimal/limitation of hours of sedentary/sitting time during each day

(Department of Health and Human Services, 2018) and contradictory findings on social factors associated with older adults' sedentary behavior (Aithal et al., 2022; da Silva et al., 2020; Heseltine et al., 2015; Patterson et al., 2018). In this large sample, we found that older adults who were male and urban residents were more likely to engaged in sedentary behavior, which is consistent with current evidence (Aithal et al., 2022; da Silva et al., 2020; Lim & Taylor, 2005; Patterson et al., 2018). However, we also found that older adults who are Non-Hispanic White and had a higher education level were more likely to have longer sedentary time, this is inconsistent with previous literature in which higher education level was considered as predictor of less sedentary time (Heseltine et al., 2015; Prince, Roberts, Melvin, Butler, & Thompson, 2020). One possible explanation is that older adults with higher education may have established a lifestyle from their mid-age work routine that involved prolonged sitting time. Factors associated with older adults' sedentary behavior remains to be a research topic the require further investigation.

In addition to investigating social factors associated with MVPA and sedentary behavior in older adults, this study also created four activity classes to reflect older adults' activity and sedentary time synergistically. Notably, female older adults are more likely to be grouped into the "Low MVPA time, Low sedentary time" group, meaning although female older adults do not engage in as much PA as male older adults, but generally have less sedentary time. In addition, older adults with college or higher degree had higher odds of being in the high MVPA time and high sedentary time group than the high MVPA time and low sedentary time group. High sedentary time could be an extension of habits formed from mid-age period or before retirement. Further, older adults who are racial minorities including Non-Hispanic Black, Hispanic and Non-Hispanic Asian and others, were more likely to have low MVPA time and low sedentary time, compared to high MVPA time and low sedentary time. These findings may inform the design of future interventions that aim to target population with high sedentary behavior or have inadequate physical exercise.

The present study was one of the first studies to additionally illustrate important associations between the frequency of WAT use and older adults' self-reported PA patterns. Although previous literature focused on determinants of long-term use and adherence to WATs in older adults (Hermsen, Moons, Kerkhof, Wiekens, & De Groot, 2017; L. Li, Peng, Kononova, Bowen, & Cotten, 2020; Paolillo et al., 2022), limited research focused on patterns/frequency of WAT use in the general adult population (Brickwood, Watson, O'Brien, & Williams, 2019) and in the aging population (M. Li et al., n.d.). To the authors' best knowledge, no study had specifically investigated the associations of frequent WAT use with both MVPA and sedentary time among older adults. Yet, given that only 65.5% of older adults WAT users used WATs frequently in 2019 and 2020 (M. Li et al., n.d.), it was especially important to illustrate the link between WAT use frequency and physical activity patterns in the aging population. The finding of this research suggested the importance of not only long-term WAT use but also the frequent WAT use (daily or almost daily use) in promoting PA.

Furthermore, this study was one of the first studies that explored the role the COVID-19 pandemic plays in the association between WAT use and PA among older adults. The COVID-19 pandemic had a substantial influence on global health and has influenced older adults' habits and lifestyles. Studies investigated the changes in PA in older adults due to the pandemic and concluded that COVID-19 was linked to decreased mobility and increased sedentary behavior (Park, Zhong, Yang, Jeong, & Lee, 2022). In addition, analyses had been conducted to demonstrate the fast increasing purchases of WATs since the start of the COVID-19 pandemic

(Ammar et al., 2021; Buoite Stella et al., 2021). However, to the author's best knowledge, although some studies emerged to explore WAT and PA during the COVID-19 pandemic (Panicker & Chandrasekaran, 2022), this was the first study that explore the moderating role the COVID-19 pandemic plays on the association of WAT use and PA. The insignificant results could be due to limited data collection time after COVID-19 pandemic started as data were collected from February to June, only capturing the first wave of COVID-19. In addition, a COVID-19 could have resulted in different habit changes in older adults: some may find it difficult to access facilities that allow them to exercise but others may have more flexible time during this period. However, in the before COVID-19 sub-sample, we found that WAT use was significantly associated with weekly MVPA time, but this association was not significant during the first wave of COVID-19 sub-sample. One of the possible explanations for this difference could be due to the lockdowns during the first wave of the pandemic: even though the WATs could promote users' motivation for exercise, users may not do the exercises due to restricted sports amenities and public gatherings, home confinement, and fear of COVID-19 infection in outdoor spaces (Stockwell et al., 2021). On the other hand, we found that WAT use was not significantly associated with sedentary time in the before COVID-19 sub-sample but was significantly associated with decreased daily sedentary time in the first wave of COVID-19 sub-sample. It could be possible that before the lockdown, WAT users focused more on getting in the exercises, and after the first wave of COVID-19, with the lockdown and difficulties accessing gym and other facilities, although many WAT users stayed at home, but WATs could prompt the users to stand up/take steps instead of remaining sedentary positions.

Importantly, the present study found that the use of WATs partially mediates the association between SES status (income and education) and PA levels. This finding showed the potential of using WATs to increase PA levels in older adults with lower SES status. There is currently a lack of understanding of the underlying mechanisms between SES and physical activities in older adults. To the best of the author's knowledge, no study has been conducted to understand the role WATs play in the association between SES and PA in older adults, therefore, the findings of this study can point a direction to future studies to better understand the relationships among income, education, technological device use, and health outcomes. This study explained that one of the potential mechanisms could be better access to consumer WATs that can help motivate and promote PA. This finding connected the current understanding of the SES and WAT use, WAT use and PA, and SES and PA in the aging population (Gidlow et al., 2006).

Several limitations existed in the present study. In the HINTS survey, all items were self-reported by the participants, therefore the data were prone to have recall bias and social-desirability bias. Second, the cross-sectional study design limited the power of the mediation analysis and does not present a causal relationship between the exposure, mediator, and outcome. Additionally, the frequency of WAT use was developed based on two questionnaire items which assess participants' WAT user frequency in the past months while not evaluating prolonged behavior of WAT use.

Despite the limitations, the findings of the present study filled in scientific gaps and provided important implications for future research, policy, and clinical practice focused on WATs and physical activity levels in older adults. First, inequities exist among older adults with different levels of social backgrounds and result in various PA patterns. Efforts should be focused on eliminating health inequities through future research and policy revision. Second, this research shed light on the potential of using WATs to promote older adults’ physical activity levels and the importance of emphasizing adherence to both length and frequency of WAT use. Meanwhile, it is a priority to ensure equal access to WATs for older adults with lower social-economic positions to avoid the risk of digital technologies becoming another social determinant of health (Sieck et al., 2021). Future WAT-based interventions should focus on the inclusion of low-SES older adults and tackle health disparities among older Americans.

Conclusion

This present study found that U.S. older adults reported overall low PA and frequent WAT use was significantly associated with improved PA patterns. Social disparities existed in PA patterns, and WAT use was found to partially mediate the associations between SES and PA patterns. There is still an urgent need to promote PA patterns in U.S. older adults especially in socially and economically disadvantaged older adults. WATs could be an effective way to improve PA patterns in older adults and frequent WAT use should be encouraged. In addition, increasing adoption of WATs among socially and economically disadvantaged older adults may help better promote PA in this population.

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Table 4. 1 Sociodemographic and Clinical Characteristics by PA Patterns

	Total	Weekly MVPA Time			Daily Sedentary Time			Activity Classes				
		<150min/wk	≥150 min/wk	p-value	<6 hrs/day	≥6 hrs/day	p-value	Low MVPA High Sedentary	Low MVPA Low Sedentary	High MVPA High Sedentary	High MVPA Low Sedentary	p-value
	N=3370	n=2,142 (66.2%)	n=1,093 (33.8%)		n=1,330 (44.5%)	n=1,662 (55.5%)		n=1,170 (40.0%)	n=746 (25.5%)	n=469 (16.0%)	n=539 (18.4%)	
Sex												
Male	1,481 (44.4%)	861 (60.4%)	565 (39.6%)	**<0.001**	563 (41.2%)	804 (58.8%)	**0.002**	526 (39.3%)	276 (20.6%)	268 (20.0%)	269 (20.1%)	**<0.001**
Female	1,857 (55.6%)	1,261 (70.7%)	523 (29.3%)		750 (46.8%)	853 (53.2%)		639 (40.8%)	460 (29.4%)	201 (12.8%)	266 (17.0%)	
Age (years) 73.9 +- 1.7												
75&above	1,330 (39.5%)	912 (72.6%)	345 (27.4%)	**<0.001**	491 (42.7%)	658 (57.3%)	0.14	499 (44.8%)	302 (27.1%)	147 (13.2%)	165 (14.8%)	**<0.001**
65-74	2,040 (60.5%)	1,230 (62.2%)	748 (37.8%)		839 (45.5%)	1,004 (54.5%)		671 (37.1%)	444 (24.5%)	322 (17.8%)	374 (20.7%)	
Education												
High school degree and lower	1,024 (31.1%)	735 (75.9%)	233 (24.1%)	**<0.001**	414 (47.9%)	451 (52.1%)	**0.028**	350 (42.0%)	277 (33.3%)	90 (10.8%)	116 (13.9%)	**<0.001**
Some college	1,036 (31.4%)	682 (68.4%)	315 (31.6%)		387 (41.7%)	542 (58.3%)		409 (45.0%)	209 (23.0%)	126 (13.9%)	164 (18.1%)	
College degree or higher	1,237 (37.5%)	683 (56.5%)	525 (43.5%)		503 (43.8%)	645 (56.2%)		394 (34.7%)	245 (21.6%)	246 (21.7%)	250 (22.0%)	
Race and Ethnicity												
Non-Hispanic White	2,044 (70.8%)	1,280 (64.5%)	705 (35.5%)	**0.003**	760(40.6%)	1,114(59.4%)	**<0.001**	784 (42.6%)	391 (21.2%)	316 (17.2%)	350 (19.0%)	**<0.001**
Non-Hispanic Black	358 (12.4%)	255 (73.9%)	90 (26.1%)		149 (49.3%)	153 (50.7%)		114 (38.6%)	104 (35.3%)	37 (12.5%)	40 (13.6%)	
Hispanics, Asians, and others	486 (16.8%)	307 (65.7%)	160 (34.3%)		236 (53.6%)	204 (46.4%)		137 (31.6%)	147 (33.9%)	67 (15.5%)	82 (18.9%)	
Annual Household Income												
less than 35k	1,345 (40.4%)	965 (75.8%)	308 (24.2%)	**<0.001**	489 (43.0%)	647 (57.0%)	0.51	498 (45.1%)	325 (29.5%)	139 (12.6%)	141 (12.8%)	**<0.001**
35k to less than 75k	1,113 (33.4%)	696 (64.7%)	380 (35.3%)		454 (44.7%)	562 (55.3%)		391 (39.3%)	254 (25.6%)	162 (16.3%)	187 (18.8%)	
75K or more	875 (26.3%)	459 (53.8%)	394 (46.2%)		370 (45.6%)	441 (54.4%)		271 (33.9%)	160 (20.0%)	166 (20.8%)	202 (25.3%)	
Smoking Status												
Current Smoker	285 (8.6%)	203 (74.6%)	69 (25.4%)	**0.001**	110 (44.2%)	139 (55.8%)	**<0.001**	100 (41.2%)	77 (31.7%)	36 (14.8%)	30 (12.3%)	**<0.001**
Former Smoker	1,189 (35.9%)	775 (67.3%)	376 (32.7%)		420 (39.1%)	654 (60.9%)		474 (45.1%)	225 (21.4%)	170 (16.2%)	182 (17.3%)	
Never Smoker	1,835 (55.5%)	1,133 (63.9%)	640 (36.1%)		792 (48.3%)	849 (51.7%)		581 (36.2%)	439 (27.4%)	258 (16.1%)	326 (20.3%)	
Body Mass Index (BMI)												
BMI under 30	2,277 (67.6%)	1,339 (61.4%)	842 (38.6%)	**<0.001**	957 (47.0%)	1,080 (53.0%)	**<0.001**	717 (36.1%)	482 (24.3%)	345 (17.4%)	441 (22.2%)	**<0.001**
BMI 30 or higher	1,093 (32.4%)	803 (76.2%)	251 (23.8%)		373 (39.1%)	582 (60.9%)		453 (48.2%)	264 (28.1%)	124 (13.2%)	98 (10.4%)	
Marital Status												
Married or living with a partner	1,559 (47.2%)	916 (60.7%)	592 (39.3%)	**<0.001**	655 (45.8%)	776 (54.2%)	0.13	520 (37.1%)	330 (23.5%)	245 (17.5%)	307 (21.9%)	**<0.001**

Divorced, Widowed, Separated, or never married	1,744 (52.8%)	1,191 (71.3%)	480 (28.7%)		649 (43.0%)	861 (57.0%)		635 (43.1%)	402 (27.3%)	215 (14.6%)	223 (15.1%)	
Overall Health												
Good	2,656 (80.2%)	1,569 (61.2%)	993 (38.8%)	**<0.001**	1,121 (47.0%)	1,266 (53.0%)	**<0.001**	829 (35.5%)	588 (25.2%)	420 (18.0%)	497 (21.3%)	**<0.001**
Fair or Poor	656 (19.8%)	535 (85.6%)	90 (14.4%)		189 (33.5%)	375 (66.5%)		324 (58.8%)	144 (26.1%)	45 (8.2%)	38 (6.9%)	
Comorbidity												
One or No Comorbidity	1,950 (60.6%)	1,161 (61.8%)	719 (38.2%)	**<0.001**	849 (48.0%)	920 (52.0%)	**<0.001**	610 (35.3%)	446 (25.8%)	300 (17.4%)	370 (21.4%)	**<0.001**
Multiple Comorbidity	1,267 (39.4%)	881 (72.3%)	338 (27.7%)		420 (38.0%)	685 (62.0%)		517 (47.6%)	262 (24.1%)	157 (14.4%)	151 (13.9%)	
Living Area												
Large Metro Area	2,658 (78.9%)	1,666 (65.4%)	883 (34.6%)	**0.048**	1,042 (44.2%)	1,317 (55.8%)	0.55	911 (39.5%)	582 (25.2%)	387 (16.8%)	426 (18.5%)	0.19
Small/Non-Metro Area	712 (21.1%)	476 (69.4%)	210 (30.6%)		288 (45.5%)	345 (54.5%)		259 (41.9%)	164 (26.5%)	82 (13.3%)	113 (18.3%)	
Area Minority Level												
Low Minority	1,339 (39.7%)	819 (63.4%)	472 (36.6%)	**0.007**	535 (44.3%)	674 (55.7%)	0.86	459 (38.8%)	274 (23.2%)	205 (17.3%)	244 (20.6%)	**0.006**
High Minority	2,031 (60.3%)	1,323 (68.1%)	621 (31.9%)		795 (44.6%)	988 (55.4%)		711 (40.8%)	472 (27.1%)	264 (15.2%)	295 (16.9%)	

Weekly MVPA minutes mean 142.7; sd: 219. Daily sedentary hours mean:6.5; sd: 3.6

Table 4. 2 Adjusted Associations between Social Factors and Physical Activity using Multivariate Linear Regression

Social Factors	Weekly MVPA Minutes n=2627			Daily Sedentary Hours n=2462		
	Coefficient	95% CI	P Value	Coefficient	95% CI	P Value
Sex						
Male (ref)						
Female	-45.7***	-63.5, -28.0	<0.001	-0.46**	-0.74, -0.17	0.002
Age Group						
75 and older (ref)						
65-74	45.9***	28.2, 63.6	<0.001	-0.004	-0.29, 0.29	0.979
Race/Ethnicity						
Non-Hispanic White (ref)						
Non-Hispanic Black	-17.0	-44.0, 10.0	0.22	-0.89***	-1.36, -0.44	<0.001
Hispanic, Asian, and Others	-5.2	-38.9, 18.4	0.67	-0.78***	-1.18, 0.39	<0.001
Annual Household Income (US Dollars)						
Low: <35,000 (ref)						
Middle: 35,000 to 75,000	27.8**	6.8, 48.8	0.009	-0.21	-0.56, 0.14	0.194
High: >75,000	37.4**	12.9, 61.9	0.003	-0.18	-0.59, 0.22	0.344
Education						
High school or less (ref)						
Some college	26.2*	4.5, 48.0	0.018	0.46*	0.21, 1.34	0.011
College or higher	25.2*	3.00, 47.4	0.026	0.41*	0.15, 1.30	0.028
Region						
Large Metro Area (ref)						
Small/Non-Metro Area	3.8	-16.5, 24.1	0.713	-0.34*	-0.67, -0.01	0.046
Area Minority Level						
Low Minority Area (ref)						
High Minority Area	7.8	-10.2, 25.97	0.393	0.10	-0.20, 0.40	0.519

P<0.001 ***, P<0.01 **, P<0.05 * Adjusted for smoking status, marital status, health status, total conditions, depression, and BMI.

Table 4. 3 Adjusted Associations between Social Factors and Activity Class using Multinomial Logistic Regression

Social Factors	Low MVPA time High sedentary time			Low MVPA time Low sedentary time			High MVPA time High sedentary time		
	AOR	95% CI	P Value	AOR	95% CI	P Value	AOR	95% CI	P Value
Sex									
Male (ref)									
Female	1.10	.85, 1.41	0.466	1.55	1.18, 2.04	0.002	.75	.56 1.00	0.051
Age Group									
75 and older (ref)									
65-74	.56	.43, .72	<0.001	.62	.47, .82	0.001	.89	.65 1.21	0.456
Race/Ethnicity									
Non-Hispanic White (ref)									
Non-Hispanic Black	.87	.57, 1.34	0.522	1.61	1.03, 2.50	0.035	.83	.50 1.38	0.463
Hispanic, Asian, &Others	.63	.44, .89	0.009	1.51	1.06, 2.15	0.021	.83	.56 1.23	0.354
Annual Household Income									
<35,000 (ref)									
35,000 to 75,000	.76	.55, 1.04	0.090	.84	.60, 1.18	0.320	.87	.60 1.28	0.487
>75,000	.65	.46, .93	0.018	.66	.45, .97	0.033	.84	.55 1.27	0.404
Education									
High school or less (ref)									
Some college	.94	.68, 1.31	0.731	.70	.49, 0.99	0.048	1.11	.73 1.68	0.622
College or higher	.83	.59, 1.15	0.256	.71	.50, 1.01	0.055	1.57	1.05 2.34	0.027
Region									
Large Metro Area (ref)									
Small/Non-Metro Area	.97	.72, 1.29	0.813	.97	.71, 1.3	0.874	.80	.57 1.13	0.203
Area Minority Level									
Low Minority Area (ref)									
High Minority Area	1.30	1.00, 1.68	0.044	1.13	.8557817 1.50348	0.381	1.19	.89 1.60	0.245

AOR: Adjusted Odds Ratio. Reference group: High MVPA time & Low sedentary time.
Adjusted for smoking status, marital status, health status, total conditions, depression, and BMI.

Table 4. 4 Adjusted Associations between WAT Use Pattern and Physical Activity Patterns

WAT Use	Weekly MVPA Time (Minutes)		Daily Sedentary Time (Hours)		Activity Classes					
					Low MVPA time High sedentary time		Low MVPA time Low sedentary time		High MVPA time High sedentary time	
	Coefficient (95% CI)	P Value	Coefficient (95% CI)	P Value	AOR (95% CI)	P Value	AOR (95% CI)	P Value	AOR (95% CI)	P Value
No Use (ref)										
Infrequent Use	-17.89 (-56.06, 20.29)	0.358	-0.11 (-0.73, 0.51)	0.724	0.93 (0.54, 1.60)	0.808	1.01 (0.56, 1.80)	0.979	1.18 (0.65, 2.14)	0.590
Frequent Use	61.15*** (33.55, 88.75)	<0.001	-0.56* (-1.0, -0.11)	0.014	0.40*** (0.26, 0.53)	<0.001	0.41*** (0.27, 0.60)	<0.001	0.72 (0.50, 1.05)	0.092

Table 4. 5 COVID-19's Role in the Association Between WAT Use and Physical Activity (MVPA Time, Sedentary Time)

	Overall		Before COVID-19		First Wave of COVID-19	
	Weekly MVPA Minutes (n=2564)	Daily Sedentary Hours (n=2403)	Weekly MVPA Minutes (n=1956)	Daily Sedentary Hours (n=1840)	Weekly MVPA Minutes (n=608)	Daily Sedentary Hours (n=563)
No WAT Use (ref)	-	-				
Yes WAT Use	-	-	46.6*** (18.6, 74.6)	-0.16 (-0.60, 0.27)	21.0 (-22.6, 64.6)	-0.85* (-1.66, -0.05)
WAT Use ## COVID-19	-14.8 (-68.6, 38.9)	-0.48 (-1.35, 0.40)				

***:P<0.001 **:0.001<p<0.1 *: 0.1<p<0.5; Results were presented after adjusting covariates (sex, education, race and ethnicity, income, insurance, marital status, health condition, total chronic conditions, BMI, region, and area minority level)

Table 4. 6 Mediation Analysis: Adjusted Direct and Indirect Association for Physical Activity

Weekly MVPA Time				Daily Sedentary Time			
Variables	Coefficients	95% CI	*p*	Variables	Coefficients	95% CI	*p*
With Income via WAT use				*With Income via WAT use*			
Total Effect	29.39	18.87, 39.90	<0.001	Total Effect	-.257	-0.43, -0.08	0.004
Indirect Effect	3.75	1.69, 5.80	<0.001	Indirect Effect	-.03025	-0.06, 0.00	0.074
Direct Effect	25.64	14.98, 36.30	<0.001	Direct Effect	-.227081	-.40, -.050	0.012
Mediated Proportion		13%		No Mediation			
With Education via WAT use				*With Education via WAT use*			
Total Effect	15.80	19.67, 65.78	<0.001	Total Effect	0.18	0.00, 0.36	0.055
Indirect Effect	1.59	0.45, 2.74	0.006	Indirect Effect	-.014	-0.03, 0.00	0.079
Direct Effect	14.21	3.33, 25.09	0.010	Direct Effect	.1922	0.01, 0.37	0.038
Mediated Proportion		10%		No Mediation			

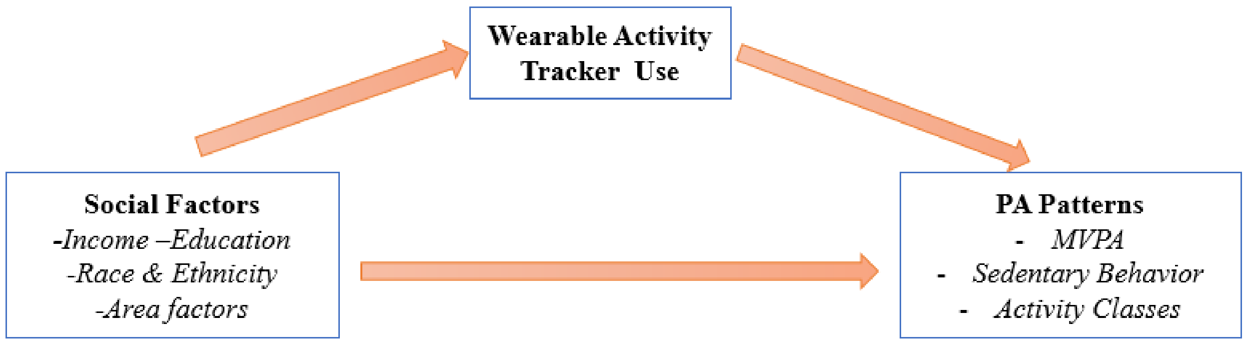
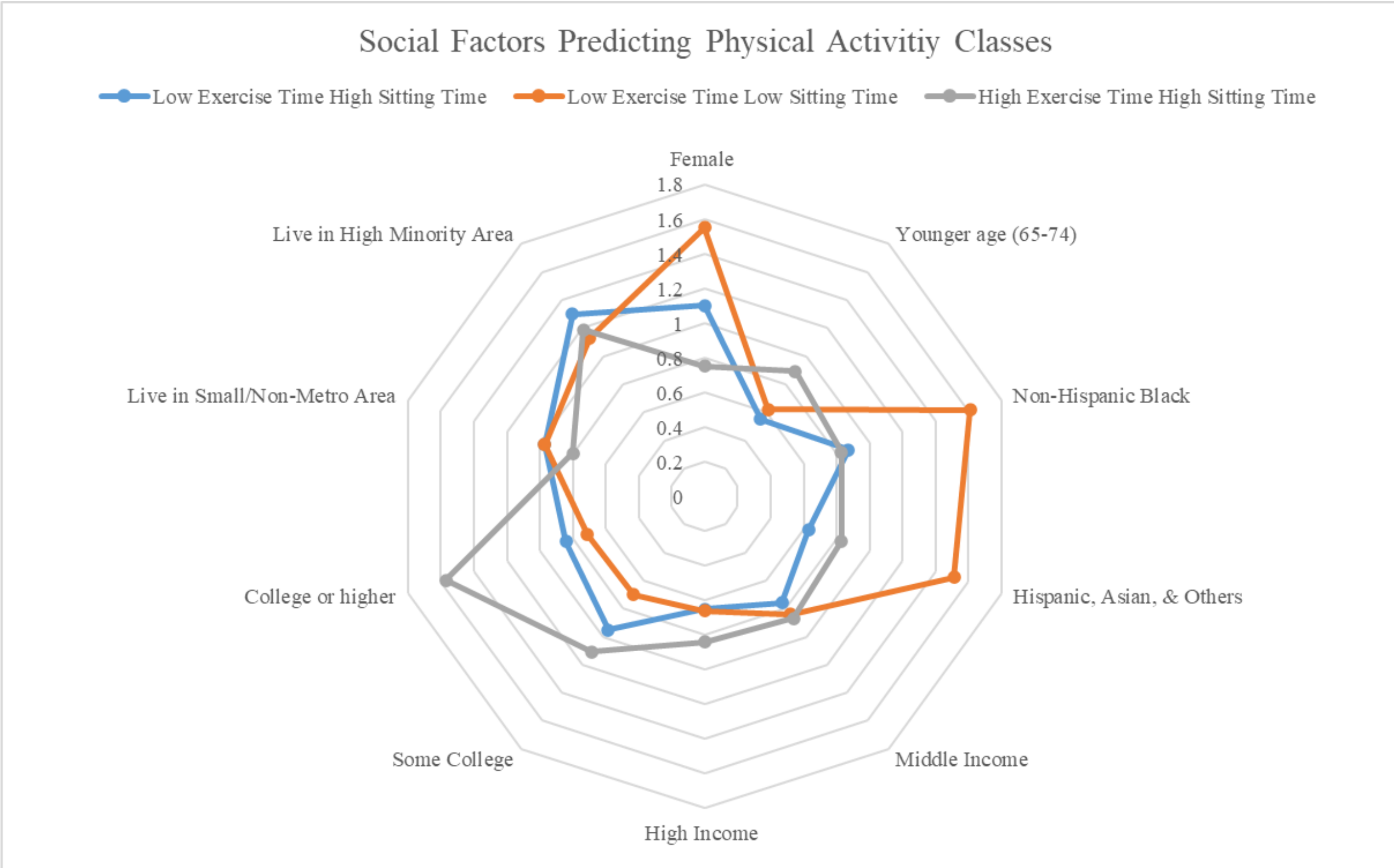


Figure 4. 1 Conceptual Framework

Figure 4. 2 Social Factors Predicting Physical Activity Classes in Older Adults using Rader Chart



Footnote: Middle Income: $35,000-$75,000; High Income: >$75,000. Annual Household Income Reference Group: Low Income (<$35,000); Reference Group: High MVPA low sedentary time group. Numbers: Adjusted odds ratio of being in the group in comparison with the reference

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CHAPTER 5: SYNTHESIS/DISCUSSION

Summary of Findings

This dissertation aimed to provide a deeper understanding of older adults' experiences, capabilities, and acceptance of using WATs. It described the characteristics of older adults with different WAT use frequencies and physical activity patterns, while examining associations among social factors, wearable activity tracker use, and physical activity patterns in this population. As a whole, WAT use mediated the associations between SES and physical activity levels.

Chapter 2

This study utilized semi-structured individual interviews and analyzed transcripts to understand older adults' experiences, capability, and acceptance of using WATs in the context of the UTAUT2 framework. Six themes emerged: (1) device learning, (2) hedonic motivation, (3) habit and adherence, (4) facilitating conditions, (5) effort expectancy, and (6) performance expectancy. Although most older adults (95.8%) from this study were first-time users, they reflected positive experiences and generally enjoyed using Wearable Activity Trackers. However, participants did identify issues related to Wearable Activity Tracker functionalities that could be improved to enhance user experience and motivate increased physical activity. These include charging/battery life, synchronizing, screen display, measurement accuracy, appearance, and design. This completed the dissertation study aim 1.

Chapter 3

This study described characteristics of U.S. older adults with different patterns of WAT usage (Aim 2 part 1). The study found that a very low percentage of the sample used WATs frequently. Additionally , this study examined social factors associated with U.S. older adults WAT use patterns (Aim 5 part 2). Generally, older adults who were non-Hispanic African Americans, 65-74 years, women, with a college degree or above were more likely to be frequent WAT users after adjusting for covariates. Conversely, lower-income and high-minority area living were associated with lower odds of frequent WAT use. These findings suggest disparities in WAT use among older Americans.

Chapter 4

This study aimed to describe characteristics among older adults in the U.S. with different PA patterns (Aim 2, part 1) and found that the study sample had an overall low MVPA time and high sedentary time The study also examined the association between WAT use and PA patterns among U.S. older adults (Aim 3), and found that frequent use of WATs was significantly associated with longer MVPA time and shorter sedentary time.

After exploring the role of COVID-19 on the association between WAT use and PA (Aim 4), the study concluded that during the first wave of the COVID019, the pandemic did not significantly moderate the association between WAT use and PA. Additionally, social factors associated with older adults' PA patterns (Aim 5) were evaluated. Male sex, younger age and high income were significantly associated with longer MVPA time, while male sex, non-Hispanic White ethnicity, and higher education were significantly associated with longer sedentary time. Furthermore, the study examined the role of older adults' WAT use in the association between SES and PA patterns among older adults and found that WAT use significantly mediated the associations between income and weekly MVPA time; and education and weekly MVPA time. WAT use did not mediate the associations between SES and daily sedentary time.

Limitations

This dissertation study has some limitations. For the qualitative study, the intervention durations were different. This might have limited our understanding of the smartwatch device used in the shorter (4-week) intervention (Moto 360 2nd generation) and may have interfered with the comparison of participants' experience among the three WATs. Secondly, participants did not have the opportunity to use all three WATs for a prolonged period of time and therefore no direct comparison could be made from each individual's perspective. For the quantitative study, as a result of the cross-sectional design, causal inferences could not be made and future studies with longitudinal designs should be conducted to further understand the mediating relationships between SES, WAT use and PA in older adults. Because this study used publicly available HINTS data, limited variables were available, and no objective data were collected. This could lead to potential recall and social desirability bias from self-reported data and a lack of other factors that may impact the frequency of WAT use, such as cognitive function, perceived ease of use, interest/acceptance of technology, etc. (Adapa, Nah, Hall, Siau, & Smith, 2018; Dai, Larnyo, Tetteh, Aboagye, & Musah, 2020; Wang, Tao, Yu, & Qu, 2020). Recall bias could also result from ownership of WATs: WAT frequent users may have better estimation of their physical activity than those who don't use WATs. Further, data collected after the onset of the COVID-19 pandemic were collected from February to June of 2020 and therefore only captured the first wave of the pandemic, impacting the results of the analyses.

Strengths

The qualitative component of this dissertation facilitated the comparison of older adults' experiences of using different types of consumer WATs across prolonged periods of time, providing insights on WAT preferences that can inform the selection of WAT use for future research. Moreover, in the quantitative part of this study, samples were collected using random selections of mail addresses across the U.S., resulting in findings that can reflect the Census makeup of the U.S. older adult population. This fills the existing research gap of the lack of large-scale data examining the associations among social factors, WATs use, and PA patterns among. U.S. older adults. Additionally, this analysis provides important and updated data on WAT use in this demographic, while facilitating a timely understanding of changes in older adults' lifestyles during the COVID-19 pandemic. These findings can help better prepare for future public health emergencies happens.

Research, Practice, and Policy Implications

Research Implications: This dissertation study provided a comparison of older adults' perspectives on the advantages and disadvantages of three types of WATs. This information may help inform WAT selection for future research. Secondly, the study suggested that social factors may impact older adults' PA patterns through WAT use. Future studies with longitudinal designs are needed to verify this finding. Third, WATs algorithms are often times developed and tested on younger adults, and WAT data for older adults may not be accurate. Future studies should aim to develop WAT algorithms and thresholds specific to the aging population. In addition, future studies should include some key factors related to physical activity that were not available in HINTS data and these factors may include neighborhood safety, older adults' physical and cognitive function, transportation methods and other potential environmental factors. Further, this study showed social disparities in WAT use. Therefore, future studies should investigate the use of WATs among socially and economically disadvantaged older adults to understand how to utilize technology to improve physical activity and health outcomes in this population.

Practice Implications: The findings of this dissertation study provided valuable information and directions for nursing and clinical practice. Firstly, it emphasized the need for improvements in WAT functions and features to better suit the aging population, including prolonged battery life, improvement in accuracy of steps, stairs, and sleep recordings, and displays with better clarity. Secondly, WAT-based interventions designed for older adults should allow the users some time to first familiarize themselves with the device and provide detailed and sufficient instructions to the users before the intervention, with easily accessible assistance during the intervention period. While this study is mainly focused on WATs and PA patterns, other ways WATs can be utilized to aid and promote clinical practice should be explored. This includes vital sign detection and monitoring, fall detection and prevention, symptom management, etc. Furthermore, based on the low WAT use rates in older adults and WATs' potential to promote PA patterns, nurses and community health providers should advocate for WAT use and help promote access in communities. Digital technology education and support are critical to ensure these initiatives are well accommodated.

Policy Implications: This dissertation demonstrated that WATs may alleviate the negative associations between SES and PA patterns in older adults. Therefore, this study highlights the significance of mitigating social disparities and promoting equal access to WATs among older adults, particularly among those who are socially and economically disadvantaged. Since WAT use often times requires smartphones and Internet access, it is imperative to advocate for government investment in public digital infrastructure in low-income populations.

Conclusion

This dissertation study provides a deeper understanding of associations among social factors, WAT use, and PA patterns among U.S. community-dwelling older adults. It describes their experience, capacity, and acceptance of WAT use to promote PA among older adults, usages of WATs and PA patterns before and during the first wave of the COVID-19 pandemic, and examines the social factors associated with WAT use and PA levels. This study highlights the need to improve PA among older adults living in the U.S. to meet WHO guideline requirements and emphasizes the benefits of WATs in PA promotion. As a whole, the implementation of WATs for older adults who are socially disadvantaged to prevent further perpetuating health disparities among older Americans will be crucial.

Appendices

Appendix A: Detailed Quotes

Theme	Sub-Categories	Quotes
Hedonic Motivation	Positive	"It was attractive." "It is very interesting to see how the step counts go up." "I like that the technology helped with checking steps and heart rate." "I am amazed how steps accumulate on the smartwatch." "I've been hooked, I've been hooked." "It is very interesting to see how the step counts go up while you walk" "I like the watch. It fits on small wrists." "I am addicted to checking my steps." "It was a pleasant experience." "It was a pretty good experience. I didn't quite understand all of the menu but overall it was a good experience." "When I look at my-- I have done 3,649. I have 351 more steps to do before I get to my goal, and I'm going to do it." "It's just very nice. You know where you are. It's nice because you feel like you are making progress, and you have little steps. You know how much effort it needs to get there."
	Negative	"I don't fancy the smartwatch."
Habit & Adherence	Habit formation	"I desire to continue using the watch after the study." "I got very used to the smartwatch." "I don't want to stop using the smartwatch." "When I wanted to get up from a very low number of steps, I would take a walk after dinner or in the late afternoon. So I would make a conscious effort to try to reach the goal."
	Adherence issues	"I wore the smartwatch every day at the beginning of the study, but sometimes I forget now." "I didn't wear it every day because I did not charge it." "I did find that I had some memory issues towards the end of the test and a few days I would just forget to put it on." "At one time, I forgot to put it back on after it was charged. Maybe once or twice. It wouldn't be on and then I was-- oh God, where is it at? And then I'd find it so, but it would be only like a day or two."
Facilitating Conditions	Training/help was useful	"I was able to synchronize after help." "Initial training was useful." "Need to call and asked for help for synchronize." "Had smartwatch issue resolved with help from study team." "Got technology help from study team." "When I used the smartwatch, I somehow lost step counts on display, but it was resolved after I got help from the study team."
	Suggestions	Need to pay attention to details: "I think the technology instruction should be more detailed." "Only at the very end – the last two days – I had discovered that the plastic film was still on the back of the watch, so it didn't have contact with my skin."
Effort Expectancy	Positive	**Moto 360 2nd :** **Comfort & Appearance:** "I am very comfortable with using this watch." "The design of the watch was very nice." "I am comfortable using the watch to monitor my physical activity." **Display:** "The face was very easy to read for a person who's just been diagnosed with age-related macular degeneration." "Words are not too small." **Convenience & ease-of-use:** "It is very convenient to check the steps." "Easy to navigate the watch." **Function & Charging:** "The functions on the smartwatch were very clear… Charging was no problem. And then just swiping it and finding the information was very easy." "I checked my messages on the smartwatch." "I checked exercise goals using the smartwatch." "Check heart activity using the smartwatch" "It can record a lot of things."
		Polar M600: **Comfort:** "I am very comfortable with charging this watch." **Ease of use:** "No difficulties with using the smartwatch." **Charging:** " I had no issues with charging." **Functionality:** "I did not really have any problems using it, like checking steps or notifications…I checked it every so often, because it would do a weekly summary."
		Fitbit Charge 3: **Ease of use:** "That was just automatically very easy." "I think the Fitbit is wonderful. It's pretty easy to use." "I have no problems (using Fitbit)." **Functionality:** "It knows how many steps I take and I don't know how many steps I'm taking and it checks some other things that I found out about … So it's given me good information where I probably would not have had that information before."
	Negative	**Moto 360 2nd :** **Inaccuracy:** "There are some discrepancies between reminder and agenda. " "When I was using my walker or a shopping cart in a grocery store, that steps tended not to be measured or counted at all." "We were doing a lot of yard exercise in the back and I said gee, I wonder if my heart rate is higher. It wasn't any higher." "Step recordings can be inaccurate if wrists did not move." **Issues with Charging & Battery:** "Charging might be a hassle." "Prefer a reminder to charge smartwatch every day." **Issues with Showering: "**Taking off smartwatch was a hassle." "I couldn't get it in the shower. That's the only part I didn't like." "But I had to be very careful when I was gonna take my shower, to remove it." **Issues with Synchronizing:** "Synchronize sometimes worked sometimes did not." "Not able to synchronize." **Operation:** "Sometimes they're displayed on the dial and then sometimes when I wanted to know the time, everything was blank… It was not a constant and I knew how to get the display that I wanted but I had to think about it. It wasn't automatic."
		Polar M600: **Issues with Charging & Battery**: "Prefer a longer battery life" "when I went to the 12-hour shifts – sometimes the watch would die." "For the Polar watch you need to be careful with charger falling off." "Towards the end of the day and I would need to go back on the charger" "I charged it every night…when I went to the 12-hour shifts, sometimes the watch would die, because my day started at 6 a.m." **Inaccuracy:** "The Polar watch counted steps too fast." **Issues with Showering**: "I needed to remember that I shouldn't get it wet." **Issues with Synchronizing:** "The only challenge I had was when I went out of my area, when I went to [another city] for the teacher's convention. Then when I came back, it seemed like it lost the sync because it was used to the same home."

		Others- bulky and inconvenient: "And I would have preferred something that was easier like if you take your sweater off and on or something it catches on the watch and it bangs on things. And it's just big and bulky."
		Fitbit Charge 3: **Inaccuracy: (Inaccuracy in step counts)**: "I discovered that I was folding laundry and I was reaching my goals because it's reading your arm rather than your leg. So it's not accurately doing steps."**(Inaccuracy in stair count)"**Well one thing I noticed with the Fitbit, if you didn't charge up the steps, it didn't register as a climb." **(Inaccuracy in sleep measurement)**" It kept telling me that I wasn't getting enough sleep which I didn't feel was correct because I think it was misreading like when I'd get up to go to the bathroom and maybe I move around more. So it would think oh, she's up when I really wasn't up. I was just in bed. I was in bed asleep." **Design-Band was broken:** "I couldn't take it off fast enough. So, I was pulling and tugging, and I broke it. I broke the band." **Notification: Confusion**: "I don't know if I was receiving any messages from them or just Fitbit itself would just say, "Track your exercise" or "You can do this." They will always ask me do I want to upgrade or do this so I really don't know if I got any notifications." **Errors:** "Yes, but it [Fitbit notifications] stopped; it didn't do it when I hit 6000 steps." **Privacy & Security:** "I didn't like that I don't know what happened or if it was something I did or what, that people started wanting to, what they call it, follow you?"(Followed by a user that the participant didn't know).
Device Learning	First experience; attitude towards learning	"That was my first experience with the smartwatch" "When I got the smartwatch, I had to learn from scratch." "I thought I understood electronics more than I actually did." "It was not easy to figure out and remember how you did it last time." "Swipe. Swipe, yes. I had to learn, and it was – it's still a challenge to get not too heavy or not too light, not too quickly or not too slowly." "The smartwatch was hard at the beginning, but it got easier." "It was hard at the beginning. But…after I started playing with it a little bit I was able to operate it a little." "I was frustrated with equipment early on." "It came like a second nature." "I am more tech savvy than average older adults." "I didn't see it being an overwhelming piece of technology" "Everybody around me does this, so I'm happy to learn." "I'm resistant to some technology, but stuff that I really have to use all the time, I will learn."
Performance Expectancy	Increased motivation, awareness & physical activity	"When it would remind me, I would say oh, let's get up and let's do some – so I would get up and do something." "When I wanted to get up from a very low number of steps, I would take a walk after dinner or in the late afternoon. So I would make a conscious effort to try to reach the goal." "There has been increased motivation to move and walk" "I would park far away and walk more." "I would walk back and forth, back and forth. And so here I'm adding between 1,500 to 2,500 steps, where before I would just drive to the area to get the fluids and put it in the bus and drive back and I wouldn't walk."
	No increase	"I'm not going to say it motivated me because if I'm in a mode to paint, I'm going to do that. But it made me more conscious of it…So it would be in the back of my mind." "I didn't really try extra hard to do it. So I would say it didn't have much effect at all."

CURRICULUM VITAE

Education

PhD in Nursing	Johns Hopkins University School of Nursing	2019-Present
Bachelor of Science in Nursing	University of Pittsburgh School of Nursing	2014-2018

Positions

Registered Nurse	UPMC Mercy Medical-Surgical Oncology Progressive Unit	2018-2019
Research Assistant	mHealth Exercise Intervention to Promote Sleep and Cognition in Older Adults, PI: Dr. Junxin Li	2021-2022
Research Assistant	The Power of 40Hz Sound/Music for Older Adults PI: Dr. Junxin Li	2021-2022
Teaching Assistant	Johns Hopkins School of Nursing Course Development Course Name: NRSA Bootcamp	2022
Teaching Assistant	Johns Hopkins School of Nursing Course Course Name: Promoting Health in Older Adults	2021-2022
Teaching Assistant	Johns Hopkins School of Nursing Course Course Name: The Research Process and Its Application in Evidence- Based Practice in Nursing Research	2021-2022
Research Assistant	University of Pittsburgh School of Nursing ADRD PI: Jennifer Lingler	2014-2018
Student Nurse	Fanny Edel Falk Laboratory School	2016-2018

Awards

Gerontological Society of America Annual Scientific Meeting Travel Award	2021, 2022

University of Pittsburgh School of Nursing: Undergraduate Research Award 2018

UPMC Aging Center Research Day – Special Mention Award 2017

Publications (Published/Accepted)

Li, M., McPhillips, M., Wenzel, J., Szanton, S. L., Li, J. (2022). Wearable Activity Tracker Use for Physical Activity in Older Adults: A Qualitative Study. Work, Aging and Retirement, waac023, **https://doi.org/10.1093/workar/waac023**

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Kawi, J., Yeh, C.H., **Li, M.**, Caswell, K., Mazraani, M., Lukkahatai, N., Mensah, S., Taylor, J, Budhathoki, C., & Christo, P.J. (2021). Auricular point acupressure smartphone application to manage chronic musculoskeletal pain: A longitudinal, one-group, open pilot trial. *Global Advances in Health and Medicine.* doi:10.1177/2164956120987531

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Li, M., Huang, J., Liu, S., Budhathoki, C., Szanton, S., Li. J. Technology-based interventions for older adults with vision impairment: A systematic review. In preparation.

Research Funding

Johns Hopkins University School of Nursing 2021

- Center for Innovative Care in Nursing Pilot Grant $2,500 (Pre-doctoral)

Johns Hopkins University School of Nursing 2021

- Discovery and Innovation Award $2,000 (Pre-doctoral)

The Greater Pittsburgh Nursing Research Conference 2017

- Undergraduate Research Award $500 (Undergraduate)

Conference Presentations

2022 **Li, M.,** Huang, J., Budhathoki, C., Szanton, S, L., Li, J. Social factors associated with U.S. Older Adults' use of Wearable Activity Trackers: Before and during the beginning of the COVID-19 pandemic. *Gerontological Society of America* annual scientific meetings.

2022 Huang, J., **Li, M.,** McPhillips, M., Lukkahatai, N., Li, J. The association of sleep and physical activity among older adults and the moderation of chronotype. *Gerontological Society of America* annual scientific meetings.

2021 **Li, M.,** McPhillips, M., Wenzel, J., Szanton, S. L., Li, J. Wearable Activity Tracker use for physical activity in older adults: A qualitative study. *Gerontological Society of America* annual scientific meetings.

2021 Xu, J., **Li, M.,** Byiringiro, S., Wenzel. J., & Dennison-Himmelfarb. C. Life after left ventricular assist device implant: A qualitative perspective through online focus groups of LVAD caregivers. *American Heart*

Association scientific sessions.

2021 Xu, J., **Li, M.,** Byiringiro, S., Wenzel. J., & Dennison-Himmelfarb. C. Family caregivers' experience of caring for patients implanted with left ventricular assist device: a mixed method study. *American Heart Association* scientific sessions.

2018 **Li, M.,** Erlen, J., Sun, R., Sereika, S., Tamres, L. The associations between patient's cognitive function and caregiver's perceived patient problem behaviors and caregiver's vigilance. *National Council on Undergraduate Research*.

2017 Erlen, J., Lingler, J., Sun, R., **Li, M.,** Tamres, L. Research and teaching: bridging the gap to facilitate communication skills. *National Conference on Professional Nursing Education and Development.*

2017 **Li, M.,** Knox, M., Lingler, J., Tamres, L., Erlen, J. Correlates of cognitively impaired older adults' willingness to participate in clinical research. *National Council on Undergraduate Research*.

2015 **Li, M.,** Knox, M., Erlen, J., Tamres, L., Lingler, J. Associations between quality of life and burden in informal caregiver of people with memory loss. *Sigma Theta Tau Eta Chapter* Scholars Night.

Other Presentations

University of Pittsburgh School of Nursing ADRD Center, Guest Speaker	2021
University of Houston-Downton, Natural Science Colloquium Talks	2021

Certifications

Registered Nurse Certification

BLS Certification

Montreal Cognitive Assessment (MoCA) Certification

Applying Human-Centered Design to Behavioral Interventions