Full-Length Research Report

Technology, Physical Activity, Loneliness, and Cognitive Functioning in Old Age

Editor's Choice

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Abstract: Information and communication technology (ICT) has the potential to benefit aging processes. This study examined portable ICT usage and associated changes in physical activity, loneliness, and cognitive functioning. Ninety-two mostly-novice tablet-users aged 51–85 years participated in technology workshops and then reported on their portable ICT use biweekly for 6+ months. Physical activity, loneliness, and executive functioning were assessed before and after this period. More frequent use of exercise functions was associated with more moderate-intensity physical activity and less sitting, controlling for pretracking levels. More frequent use of social functions was associated with more social loneliness and a tendency toward less emotional loneliness, controlling for pretracking levels of loneliness. The use of exercise and social functions showed no associations with executive functioning. Portable ICT thus may bring both risks and benefits for physical and social functioning in older adulthood.

Keywords: information and communication technology, physical activity, loneliness, cognitive functioning, successful aging

Introduction

Information and communication technology (ICT), including tablet computers, has the potential to facilitate the everyday activities that shape aging trajectories (Cotten, 2017). The present study drew on an ethnically and socioeconomically diverse sample of 92 adults aged 51–85 years, many of whom had little or no previous tablet experience. Over a period of 6+ months, we examined everyday self-directed tablet use and associations with changes in physical activity, loneliness, and executive functioning.

Technology and Aging

The percentage of older adults who use ICT is rapidly growing. According to Eurostat (2018), 52% of adults aged 65–74 years use the internet at least once a week (28% via a smartphone), with popular activities being reading and writing emails (45%), finding information about goods/services (43%) or health (30%), watching videos (21%), and social networking (19%). Contrary to common stereotypes, older adults generally have positive attitudes toward new technology and are capable of learning to use it (Mitzner et al., 2010). Of the various ICT options, tablets have proved particularly popular with older adults because of their intuitive design, durability, large screen, and portability (Dasgupta, Chaudhry, Koh, & Chawla, 2016; Ramprasad, Tamariz, Garcia-Barcena, Nemeth, & Palacio, 2017).

What are the implications of older adults' ICT use? While much theoretical work has been done on technology adoption (e.g., Venkatesh, Thong, & Xu, 2012), conceptual models addressing the role of technology for aging are sparse. Schulz et al. (2015) linked technology with prominent lifespan theories, emphasizing that technology may (1) help older adults to prioritize relationships and contexts that facilitate positive socioemotional experiences (Carstensen, Fung, & Charles, 2003), (2) help to optimize the use of resources and to maintain functioning when faced with age-normative losses (Baltes & Baltes, 1990), and (3) provide means for maintaining primary control (Heckhausen, Wrosch, & Schulz, 2010). The COntext Dynamics in Aging framework (CODA, Wahl & Gerstorf, 2018) advances these ideas and explicitly includes technology as a major context influencing aging trajectories, alongside socioeconomic, social, physical, and care/service environments.

The CODA model proposes three pathways through which technology may impact health and well-being. First, technology can help to preserve individual agency; this is illustrated by ordering medications online when unable to walk to the pharmacy. Second, technology can foster belonging and social connections, for example, when viewing digital family pictures. Third, however, when older adults are incapable of meeting technological demands, technology can elicit stress, contributing to negative health and well-being, for example, when they feel overwhelmed at having to set up a doctor's appointment online rather than by phone.

Everyday portable ICT (e.g., tablets, smartphones), in particular, has the potential to facilitate positive aging processes (Ramprasad et al., 2017). Portable ICT provides several means of daily living support so important for healthy aging. For example, it provides access to online resources relevant to social and physical functioning (e.g., finding a local book club or fitness program designed for older adults; Levy & Simonovsky, 2016). Furthermore, applications for physical activity tracking, social networking, and text/video chat can facilitate everyday activities that contribute to health, social engagement, and cognitive functioning in old age (Ammann, Vandelanotte, de Vries, & Mummery, 2013; Ramprasad et al., 2017; Schulz et al., 2015). Beyond facilitating everyday activities that older adults already recognize as important, technology may also encourage exploration of new interests and opportunities that are not (yet) part of their daily routines (e.g., taking up a new hobby after consulting online resources). Lastly, accessing new information is cognitively stimulating and may help maintain or even build cognitive resources in old age (Lindenberger, Lövdén, Schellenbach, Li, & Krüger, 2008). Yet, little research has investigated associations between older adults' portable ICT use and adaptive aging outcomes in an everyday life context.

To fill this gap, the present study examined everyday portable ICT use and its associations with three aging outcomes. In line with Rowe and Kahn's (1997) seminal model of successful aging, we focused on physical activity as an indicator of physical health, loneliness as an indicator of (insufficient) social engagement, and executive functioning as an indicator of cognitive function. The present study maximized ecological validity (Peek et al., 2016) by examining self-selected portable ICT use instead of instructing older adults which functions to use on their devices. We recognize that technology itself is value-neutral and may be used both in ways that promote adaptive aging (e.g., physical activity tracking) and in ways that hinder adaptive aging (e.g., sedentary screen time). Therefore, we focused on older adults' use of specific ICT functions or applications previously shown to have beneficial effects: exercise functions and social functions (e.g., Cotten, 2017). We defined portable ICT functions/applications broadly to include those built for specific purposes (e.g., video-chatting applications) and those with multiple uses (e.g., internet-browsing functions). Below we describe our three core aging outcomes (physical activity, loneliness, and executive functioning) and how everyday ICT use may shape each of these indicators.

Portable ICT Use and Physical Activity

Physical activity is a core pathway to physical and mental health, yet the majority of older adults fail to meet even minimum guidelines for physical activity (Jefferis et al., 2014). Tablet technology may offer opportunities to promote physical activity in old age. Tablets cater to individual needs by offering a spectrum of applications, such as step trackers and daily exercise prompts, that encourage different types and levels of physical activity (Dasgupta et al., 2016). They allow older adults to choose exercise functions based on their own physical abilities and preferences. Previous technology-based interventions increased walking and moderate-to-vigorous-intensity physical activity among older adults (Bickmore et al., 2013; King et al., 2016; Lee, Jung, Byun, & Lee, 2016). We therefore expected that more frequent use of self-selected exercise functions would lead to increased physical activity (vigorous-intensity activity, moderate-intensity activity, and walking). However, the use of any kind of portable ICT application may also increase overall screen time and encourage sedentary behavior (King et al., 2016). Hence, we explored whether more frequent use of exercise functions is also linked with increased sitting time.

Portable ICT Use and Loneliness

In old age, social networks shrink, increasing the risk of loneliness among older adults, which in turn has been associated with depressive symptoms, functional limitations, and mortality (Cacioppo & Cacioppo, 2014). Technology, however, enables older adults with age-normative health limitations to maintain everyday social interactions through the use of tools like text messaging, email, video chat, and social media (Czaja, Boot, Charness, Rogers, & Sharit, 2018; Gatto & Tak, 2008; Sims, Reed, & Carr, 2017). ICT use has also been linked to volunteering, religious participation, community event attendance, and other forms of social engagement (Kim, Lee, Christensen, & Merighi, 2017). Such social benefits may be especially important for older adults who are immigrants and hence may have reduced opportunities for social interaction (Czaja et al., 2018). Overall, we expected more frequent use of social functions to be associated with decreased loneliness. Because previous research on loneliness has distinguished between social loneliness (negative appraisals of one's social relationships) and emotional loneliness (negative emotions stemming from these appraisals; Russell, Peplau, & Cutrona, 1980), we examined social and emotional loneliness separately to explore whether frequency of social function use might be linked with decreases in both types of loneliness.

Portable ICT Use and Executive Functioning

Social and physical activities may bring benefits not only for social and physical outcomes, but also for executive functioning (e.g., Chan, Haber, Drew, & Park, 2016). Greater social engagement and higher levels of physical activity have been linked with better cognitive abilities in older adults (Benedict et al., 2013; Krueger et al., 2009). Furthermore, engaging in cognitively demanding activities, like learning to use a new device, may counteract cognitive decline or even enhance cognitive functioning in old age (Park & Reuter-Lorenz, 2009). However, the evidence linking tablet use with cognitive functioning in old age is mixed (e.g., Chan et al., 2016; Lee et al., 2016; Vaportzis, Martin, & Gow, 2017), preventing clear inferences regarding which cognitive abilities may be affected. This study focused on executive functioning, assessed via a trail-making task (Reitan & Wolfson, 1985) and an animal-naming task (Drachman & Leavitt, 1972). Performance on these tasks has been linked with older adults' ability to carry out instrumental activities of daily living such as transportation, housework, and managing finances (Pereira, Yassuda, Oliveira, & Forlenza, 2008; Tomaszewski Farias et al., 2009). We explored whether more frequent use of exercise and social functions is associated with increased executive functioning.

Current Study

This study examined associations between portable ICT use and changes in the physical activity, loneliness, and executive functioning of older adults over a period of 6+ months. Our first hypothesis was that using portable ICT more frequently for exercise functions would be associated with increases in self-reported physical activity. We also explored whether more frequent exercise function use would be linked with changes in sitting time. Our second hypothesis was that using portable ICT more frequently for social functions would be associated with reductions in social and emotional loneliness. Finally, we explored whether using portable ICT for exercise and social functions would be associated with improvements in executive functioning. Given previous research linking tablet use with specific demographic characteristics and with positive attitudes toward ICT (Kim et al., 2017; Vroman, Arthanat, & Lysack, 2015), we also considered the following variables: age, sex, relationship status, ethnicity, education, previous tablet experience, tablet ease of use, tablet usefulness for oneself and for others, and tablet enjoyment.

Methods

Participants

The sample consisted of 92 community-dwelling adults aged 51 to 85 years ($M = 67.7$, $SD = 8.7$) from the Vancouver Metropolitan Area who participated in a study on social engagement and well-being in old age (for further study details, see the Electronic Supplementary Material, ESM 1 and Lay et al., 2018).[1] Participants were eligible if they could read newspaper-sized print, had not been diagnosed with a neurodegenerative disease or brain dysfunction, and were physically able to handle a tablet-sized device. A total of 108 participants were recruited; of these, 8 participants did not complete the 6-month tablet use tracking period (e.g., because of time constraints or personal concerns), and 8 were excluded because of missing data or technological issues resulting in data loss. Excluded participants did not differ from retained participants on sociodemographic or focal study variables included in the analyses. Of the final 92-participant sample, 64% were women, 60% were in a relationship, and 77% were retired. Reflecting the diversity of the Metro Vancouver older adult population, 60% were East Asian, 36% were European/White, and 4% were of other/mixed heritage; 67% of participants were first-generation immigrants; and 36% did not have any college/university education. Full demographical details are provided in ESM 2 (Table 1).

Procedure

Participants attended two in-lab sessions (Pretracking Sessions 1 and 2), separated by a 10-day daily-life assessment module (not part of the present analyses). The Pretracking sessions included training on basic tablet functions and measures of self-reported physical activity, self-reported loneliness, and executive functioning. After Pretracking Session 2, participants used their tablets (iPad mini 2, 2012/2013) for 6+ months and reported on their

[1] Although older adults were our main focus, we recruited participants aged 50+ years, with the aim of reaching individuals of diverse socioeconomic status and immigration history reflective of the Vancouver metropolitan population.

tablet use every 2 weeks via an app (iDialogPad; G. Mutz, Cologne, Germany). During this period, all but four participants attended a personalized 3-h technology workshop to learn to use tablet functions of their choice (*M* time from Pretracking Session 2 to workshop = 3.6 weeks, *SD* = 3.8, range: 0.0–22.9). Detailed information is provided in the ESM 1. After a period of at least 6 months, participants returned for a Posttracking Session, during which they completed measures of physical activity, loneliness, executive functioning, and technology use (*M* time from Pretracking Session 2 to Posttracking = 30.5 weeks, *SD* = 3.7, range: 24.7–45.9).[2] Participants chose between keeping their tablet (87%) or receiving CAD $100. Participants could complete the study in English (55% of participants), Mandarin (32%), or Cantonese (13%). Materials were translated and independently back-translated for verification. Participants provided informed consent, and the study was approved by the university's behavioral research ethics board.

Measures

Pretracking and Posttracking Measures

Physical Activity

Before and after the 6-month tracking period, participants completed the International Physical Activity Questionnaire (IPAQ, Craig et al., 2003), which is widely used for assessing everyday physical activity of varying intensity and has been validated in older adult samples (Cleland, Ferguson, Ellis, & Hunter, 2018). Participants were asked how many hours, over the past week, they had engaged in "*vigorous physical activities* like heavy lifting, digging, aerobics, or fast bicycling" (pretracking *M* = 2.6 h, *SD* = 4.5; posttracking *M* = 3.6 h, *SD* = 6.6), "*moderate physical activities* like carrying light loads, bicycling at a regular pace, or doubles tennis" (pretracking *M* = 4.6 h, *SD* = 6.5; posttracking *M* = 5.3 h, *SD* = 8.5), and "*walking*" (pretracking *M* = 8.5 h, *SD* = 9.0; posttracking *M* = 6.8 h, *SD* = 5.3), and how much time they had spent "*sitting* on a weekday" (pretracking *M* = 4.9 h, *SD* = 2.7; posttracking *M* = 4.2 h, *SD* = 3.1).

Loneliness

Loneliness was assessed using eight items adapted from the Revised UCLA Loneliness Scale (Russell et al., 1980)[3]. Intervention research has demonstrated that the UCLA is a valid tool for tracking changes in loneliness associated with the introduction of technology in old age (e.g., Contrera, Sung, Betz, Li, & Lin, 2017). This measure encompasses *social loneliness* or negative appraisals of one's social relationships and *emotional loneliness* or subjective feelings of isolation. Four items measure social loneliness (e.g., "There are people I can turn to," reverse coded; pretracking *M* = 2.1, *SD* = 0.9, Cronbach's α = .79; posttracking *M* = 2.1, *SD* = 0.8, α = .73) and four items measure emotional loneliness (e.g., "I feel left out"; pretracking *M* = 1.6, *SD* = 0.8, α = .83; posttracking *M* = 1.7, *SD* = 0.9, α = .84). Participants responded on a 5-point Likert scale with higher scores indicating greater social/emotional loneliness. Social and emotional loneliness were correlated at *r* = .31 pretracking and *r* = .29 posttracking.

Executive Functioning

To measure executive functioning, we used the time necessary to complete the Trail-Making Test – Trail B (*trail-making B*; Reitan & Wolfson, 1985; pretracking *M* = 112.6 s, *SD* = 56.5; posttracking *M* = 118.6 s, *SD* = 73.1), and number of (unique) animals written down in one minute (*animal-naming task*; Drachman & Leavitt, 1972; pretracking *M* = 12.0, *SD* = 3.8; posttracking *M* = 12.7, *SD* = 3.7). These measures have been shown to be sensitive to age-related cognitive decline and to improve with interventions, including physical activity (Gates, Fiatarone Singh, Sachdev, & Valenzuela, 2013; Salthouse, 2005).

Covariates

Sociodemographics and previous tablet experience were assessed at Pretracking Session 1. Sex was coded 0 = "male", 1 = "female". Relationship status was coded 0 = "not in a relationship", 1 = "in a relationship". Ethnicity was coded 0 = "not European/White", 1 = "European/White". Education was coded 0 = "no college/university", 1 = "at least some college/university". Previous tablet experience was rated on a 5-point Likert scale from 1 (*no experience at all*) to 5 (*a lot of experience*).

Tablet Use Experiences

At Pretracking Session 2 and at Posttracking, participants provided feedback on their tablet experiences, including ease of use, usefulness for themselves and others, enjoyment, and types of applications/functions used.

Biweekly Measures

During the tracking period of 6+ months, participants completed self-report questionnaires every 2 weeks about their tablet use over the past 2 weeks[4] (*M* = 11.4 questionnaires completed per participant, range: 3–19). We included

[2] Adjusting for time elapsed from Pretracking Session 2 to Posttracking, and time elapsed from Pretracking Session 2 to workshop date, did not change the reported findings.

[3] We used slightly modified forms of items 2, 4, 5, 10, 11, 14, 19, and 20 from Russell et al. (1980).

[4] We chose a biweekly sampling frame to maximize collection of tablet use data (given that participants may not use their tablets every day) while reducing participant burden over the tracking period.

questionnaires that surpassed the minimum 6-month period (3.4%) for analyses because their exclusion did not change the reported findings. However, 332 questionnaires were excluded because they were duplicates, that is, they were completed twice during the same 2-week period. In these cases, we retained only the first set of complete responses for each period.

Frequency of Exercise Function and Social Function Use

Participants were given a list of nine different descriptions of ICT functions and were asked which of these functions they had used in the past 2 weeks on their tablet or on another portable electronic device (see ESM 3). Participants could select one or more functions; the present study focused on three items that specifically captured exercise or social functions. Selecting the item "exercise tracking or finding fitness information" was coded as *exercise function use* for that biweekly period. Selecting either the item "chat, messaging, email, or social networking websites" or the item "finding or contacting community groups, programs, or social events" was coded as *social function use* for that period. Frequency of exercise function use (M = 25.1% of assessments, SD = 32.7) and frequency of social function use (M = 80.0% of assessments, SD = 29.0) were calculated for each participant. These indexes were used in analyses to indicate relative frequency of exercise/social function use.

Overall Hours of Portable ICT Use

Participants were also asked how many hours they had spent using their device(s) (including tablets, smartphones, and other portable ICT devices) over the past 2 weeks. Responses 3 SD above the mean (1.8%) were excluded as outliers. *Overall hours of portable ICT use* per 2-week period was computed for each participant by averaging their responses across all of their biweekly questionnaires (M = 22.4 h of tablet use, SD = 19.4).

Statistical Analysis

We used lagged confirmatory regression (path) models to test our hypotheses. Specifically, models predicted post-tracking scores for each of the physical activity, loneliness, and cognitive measures from frequency of exercise function use and frequency of social function use over the tracking period of 6+ months, controlling for overall hours of portable ICT use, age, sex, relationship status, ethnicity, education, previous tablet experience, and pretracking score on the respective measure. Three path models were tested using the *lavaan* package in *R* (Rosseel, 2012): (1) a physical activity model predicting vigorous-intensity activity, moderate-intensity activity, walking, and sitting, (2) a loneliness model predicting social and emotional loneliness, and (3) a cognitive functioning model predicting trail-making B and animal-naming scores. Cohen's f^2 was calculated to estimate effect sizes ($f^2 \geq 0.02$, $f^2 \geq 0.15$, and $f^2 \geq 0.35$ represent small, medium, and large effect sizes, respectively; Cohen, 1988). We used the *simsem* package in *R* (Pornprasertmanit, Miller, & Schoemann, 2015) to conduct power analyses using standardized regression coefficients as effect size estimates for our predicted associations. Our sample size of 92 was sufficient to detect medium-sized effects (r = .30) for frequency of exercise and social function use with power > .80 under a range of conditions.

Results

Descriptives

Table 1 presents descriptive statistics and intercorrelations of central study variables and covariates. Overall hours of portable ICT use, frequency of exercise function use, and frequency of social function use were positively correlated. Most participants (67%) indicated having "no experience at all" or "very little experience" with portable electronic devices before entering the study. Yet, at the end of the study, they reported (on a 5-point Likert scale) that the tablets were easy to use (M = 4.13, SD = 0.90), useful in daily life (M = 4.11, SD = 0.95), and enjoyable (M = 4.20, SD = 0.85), and that they would recommend this technology to others of their age (M = 4.14, SD = 0.98). The average participant reported using 11 different ICT functions (SD = 5.66), of a list of 22 functions in the technology use follow-up questionnaire. The 5 most-used functions were email, news or weather forecasts, messaging, location finding, and transit information. About 41% of the sample shared their new technological skills by teaching others (primarily friends, spouses/partners, acquaintances).

Technology Use and Changes in Physical Activity, Loneliness, and Executive Functioning

Physical activity levels did not change, on average, over the period of 6+ months, whereas time spent sitting decreased (see ESM 2, Table 2). As shown in Table 2, more frequent use of exercise functions was associated with more moderate-intensity physical activity (β = 0.28, $p < .01$, $f^2 = .08$, ΔR^2 = .05),[5] but also with more time spent sitting (β = 0.30,

[5] ΔR^2 values compare path models with and without the predictor in question (exercise/social function use).

Table 1. Means, standard deviations, and intercorrelations of central study variables and control variables (*N* = 73–92)

Variable	*M* (*SD*) or proportion	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1. Age	67.69 (*8.73*)	–.15	.00	.09	.09	–.09	–.17	–.20	–.25*	–.09	.03	–.14	–.09	–.05	–.14	.23*	–.01
2. Sex (women)	0.64		–.24*	.05	.05	.10	.12	.04	–.02	.20	.16	.04	.07	–.24*	.11	–.02	.08
3. Relationship status (in a relationship)	0.60			–.25*	.04	.20	.27**	.21*	.34**	–.13	.24*	.03	–.18	.10	–.35**	–.07	–.18
4. Ethnicity (European/White)	0.34				.15	.14	–.24*	.06	–.17	.01	–.22*	–.07	.10	–.24*	–.04	–.27*	.47**
5. Education (some college/university)	0.64					.22*	–.04	–.12	.04	–.07	–.18	–.10	.05	–.05	–.12	–.38**	.36**
6. Previous tablet experience	2.01 (*1.03*)						.06	.42**	.35**	–.13	–.17	–.13	–.05	–.20	–.33**	–.25*	.18
7. Frequency of exercise function use (%)	25.14 (*32.73*)							.17	.36**	.04	.39**	.23*	–.04	.03	.00	.14	–.21*
8. Frequency of social function use (%)	79.98 (*28.97*)								.23*	–.18	.08	.01	–.03	.04	–.24*	–.12	.11
9. Overall portable ICT use (total hours)	22.41 (*19.42*)									–.11	–.02	.13	–.14	.01	–.18	–.06	–.08
10. Posttracking vigorous-intensity physical activity	3.55 (*6.63*)										.32**	.31**	–.12	–.05	.21	.14	–.01
11. Posttracking moderate-intensity physical activity	5.29 (*8.45*)											.23*	–.07	.16	.13	.22	–.33**
12. Posttracking walking	6.78 (*5.31*)												–.01	–.04	.04	.20	–.04
13. Posttracking time spent sitting	4.17 (*3.07*)													–.04	–.11	–.13	.13
14. Posttracking social loneliness	2.06 (*0.78*)														.29*	.01	–.13
15. Posttracking emotional loneliness	1.71 (*0.86*)															.30*	–.14
16. Posttracking trail-making B score	118.56 (*73.15*)																–.37**
17. Posttracking animal-naming score	12.68 (*3.70*)																

Note. Frequency of exercise and social function use are the percentage of measurements (during the 6-month tracking period) in which the participant indicated using the respective functions in the past 2 weeks. Overall portable ICT use is the average number of hours participants reported using a portable ICT device in the past 2 weeks, across all biweekly questionnaires. Physical activity variables are in hours, loneliness variables are on a 5-point scale, trail-making B score is completion time in seconds, and animal-naming score is the total number of animals listed in one minute. Sample size varies because of missing data on certain variables. $^{*}p < .05$, $^{**}p < .01$.

Table 2. Lagged confirmatory regression path analyses predicting physical activity, loneliness, and cognitive functioning over a 6-month period using full information maximum likelihood estimation, N = 92 individuals

	Model 1: Posttracking physical activity				Model 2: Posttracking loneliness		Model 3: Posttracking cognitive function	
	Vigorous-intensity PA	Moderate-intensity PA	Walking	Time spent sitting	Social loneliness	Emotional loneliness	Trail-making B	Animal-naming
	b (*SE*) β, *p*	*b* (*SE*) β, *p*	*b* (*SE*) β, *p*	*b* (*SE*) β, *p*	*b* (*SE*) β, *p*	*b* (*SE*) β, *p*	*b* (*SE*) β, *p*	*b* (*SE*) β, *p*
Intercept	2.08 (2.02) 0.32, 0.304	0.97 (2.17) 0.12, 0.657	**7.43** (1.53) **1.42**, .000	**4.77** (0.86) **1.54**, .000	**1.21** (0.27) **1.61**, .000	**0.70** (0.34) **0.82**, 0.037	**115.5** (5.52) **1.59**, .000	**13.06** (0.25) **3.56**, .000
Age	−0.09 (0.09) −0.11, 0.317	0.07 (0.09) 0.08, 0.436	−0.05 (0.07) −0.08, 0.491	−0.01 (0.04) −0.02, 0.844	−0.00 (0.01) −0.03, 0.743	−0.01 (0.01) −0.11, 0.239	−0.62 (0.69) −0.08, 0.371	−0.62 (0.69) −0.08, 0.371
Sex (women)	2.68 (1.53) 0.20, 0.079	**3.59** (1.69) **0.21**, 0.033	−0.65 (1.17) −0.06, 0.578	−0.32 (0.63) −0.05, 0.610	−0.27 (0.14) −0.17, 0.056	0.21 (0.18) 0.12, 0.234	1.29 (5.04) 0.02, 0.799	**−0.51** (0.24) **−0.13**, 0.034
Relationship status (in a relationship)	−0.08 (1.65) −0.01, 0.962	**4.80** (1.79) **0.28**, 0.007	0.37 (1.20) 0.04, 0.758	−0.56 (0.66) −0.09, 0.401	0.10 (0.15) 0.07, 0.495	−0.03 (0.20) −0.02, 0.870	−8.51 (5.59) −0.11, 0.128	−0.40 (0.26) −0.11, 0.115
Ethnicity (European/White)	0.63 (1.60) 0.05, 0.695	−0.81 (1.72) −0.05, 0.635	0.07 (1.20) 0.01, 0.953	−0.15 (0.65) −0.02, 0.812	−0.23 (0.15) −0.15, 0.110	0.13 (0.18) 0.07, 0.473	1.07 (5.60) 0.01, 0.848	0.47 (0.26) 0.12, 0.071
Education (some college/university)	−0.80 (1.48) −0.06, 0.589	−1.43 (1.62) −0.08, 0.377	−0.84 (1.13) −0.08, 0.460	0.07 (0.62) 0.01, 0.912	0.24 (0.14) 0.16, 0.087	−0.15 (0.18) −0.09, 0.389	−1.13 (5.62) −0.02, 0.841	0.32 (0.25) 0.08, 0.205
Previous tablet experience	−0.43 (0.83) −0.07, 0.600	−1.53 (0.92) −0.19, 0.096	−0.68 (0.60) −0.13, 0.261	0.39 (0.35) 0.13, 0.267	−0.15 (0.08) −0.20, 0.056	−0.11 (0.10) −0.12, 0.292	−9.74 (5.84) −0.14, 0.095	0.09 (0.25) 0.03, 0.715
Outcome at pretracking[a]	0.25 (0.15) 0.17, 0.108	**0.34** (0.13) **0.26**, 0.009	**0.21** (0.070) **0.36**, 0.002	**0.66** (0.12) **0.57**, .000	**0.40** (0.07) **0.49**, .000	**0.61** (0.11) **0.55**, .000	**1.07** (0.11) **0.83**, .000	**0.71** (0.07) **0.73**, .000
Frequency of exercise function use	0.01 (0.02) 0.03, 0.777	**0.07** (0.03) **0.28**, 0.007	0.03 (0.02) 0.18, 0.101	**0.03** (0.01) **0.30**, 0.008	0.00 (0.00) 0.02, 0.866	−0.00 (0.00) −0.05, 0.634	−0.08 (0.17) −0.04, 0.647	−0.01 (0.01) −0.05, 0.418
Frequency of social function use	−0.03 (0.03) −0.15, 0.222	0.02 (0.03) 0.08, 0.426	0.00 (0.02) 0.01, 0.928	−0.00 (0.01) −0.03, 0.742	**0.01** (0.00) **0.20**, 0.042	−0.01 (0.00) −0.19, 0.078	−0.01 (0.18) −0.01, 0.941	0.00 (0.01) 0.00, 0.958
Overall portable ICT use	−0.03 (0.04) −0.09, 0.480	−0.06 (0.05) −0.15, 0.153	0.01 (0.03) 0.05, 0.702	**−0.06** (0.02) **−0.37**, 0.002	0.00 (0.00) −0.07, 0.522	0.00 (0.01) −0.01, 0.92	0.46 (0.28) 0.12, 0.100	−0.01 (0.01) −0.04, 0.543
Residual variance	**37.33** (5.76) **0.87**, < .001	**41.72** (6.56) **0.61**, < .001	**21.53** (3.27) **0.79**, < .001	**6.52** (1.00) **0.68**, < .001	**0.36** (0.05) **0.63**, < .001	**0.40** (0.07) **0.55**, < .001	**1752.10** (266.10) **0.33**, < .001	**4.00** (0.59) **0.30**, < .001
R^2	.13	.39	.21	.32	.38	.45	.67	.70
Model fit indices	Model 1: CFI = .682, RMSEA = .172, SRMR = .050				Model 2: CFI = .944, RMSEA = .154, SRMR = .023		Model 3: CFI = .995, RMSEA = .069, SRMR = .007	

Note. PA = Physical activity (hours). Social and emotional loneliness scored from 1 to 5. Continuous variables are grand mean centered; dichotomous variables are dummy-coded (0, 1). Unstandardized (*b*) and standardized (β) path coefficients are reported. Bold font denotes significant coefficients. [a]Outcome at pretracking is the value of the outcome measure for the model in question before the 6-month tracking period (i.e., vigorous- or moderate-intensity physical activity, walking, or time spent sitting at Pretracking Session 1, or social loneliness, emotional loneliness, trail-making B, or animal-naming at Pretracking Session 2).

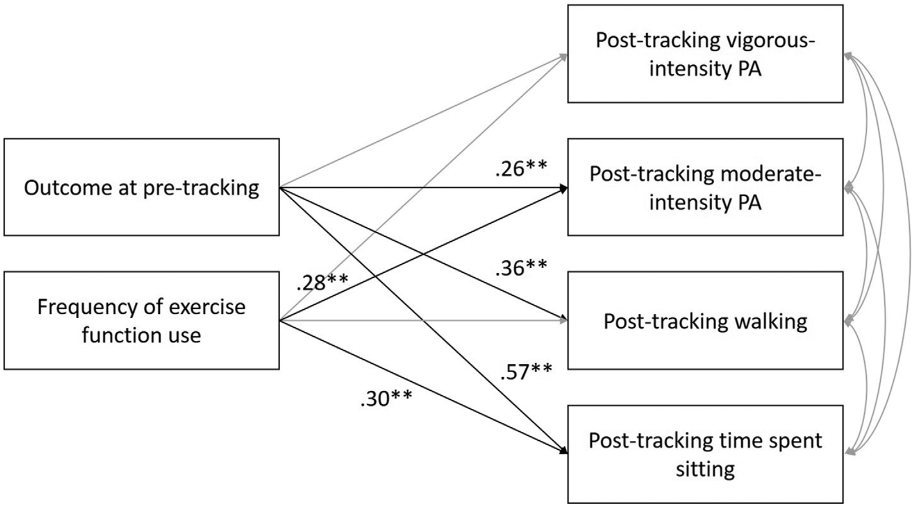

Figure 1. Depiction of main findings from the physical activity path model (Model 1). Path coefficients are from the full model (Table 2), but only variables of interest are shown in the figure for simplicity. Gray lines represent non-significant paths, and black lines represent significant paths. Standardized coefficients for significant associations are displayed; *$p < .05$, **$p < .01$. PA = physical activity.

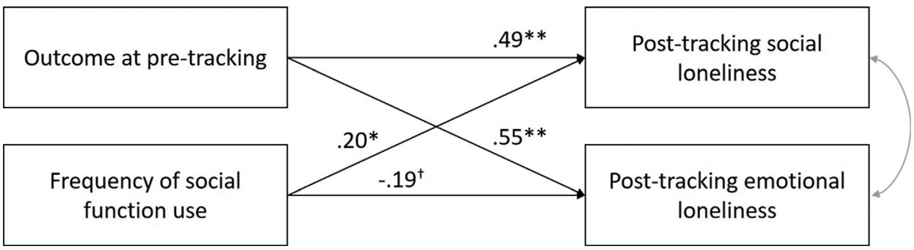

Figure 2. Depiction of main findings from the loneliness path model (Model 2). Path coefficients are from the full model (Table 2), but only variables of interest are shown in the figure for simplicity. Standardized coefficients for significant associations are displayed; †$p < .10$, *$p < .05$, **$p < .01$.

$p < .01$, $f^2 = .10$, $\Delta R^2 = .07$; see Figure 1) at posttracking, controlling for pretracking levels.[6] Frequency of exercise function use showed no significant association with vigorous-intensity activity or walking time. Social and emotional loneliness scores did not change on average over the 6-month period (see ESM 2, Table 2). More frequent use of social functions was associated with more social loneliness ($\beta = 0.20, p = .04, f^2 = .04, \Delta R^2 = .03$), and there was a trend in the direction of a relationship with less emotional loneliness ($\beta = -0.19, p = .08, f^2 = .04, \Delta R^2 = .02$; see Table 2 and Figure 2), controlling for pretracking levels. Participants' animal-naming scores increased significantly from pretracking to posttracking; trail-making B performance did not change on average (see ESM 2, Table 2). Frequency of exercise and social function use showed no association with the cognitive measures. Model fit indices can be found in Table 2.

Discussion

The current study examined the potential of tablet technology for improving physical, social, and cognitive functioning in older age. We found more frequent exercise function use to be associated with more moderate-intensity physical activity, but also with more time spent sitting. More frequent social function use was associated with more social loneliness and a trend in the direction of less emotional loneliness. Usage frequency of these functions was not associated with executive functioning.

Portable ICT Use and Physical Activity

Participants reported using exercise functions in 25% of biweekly reports, on average. More frequent exercise function use was associated with more moderate-intensity physical activity posttracking. This is in line with previous research suggesting that access to exercise applications or fitness-related information online helps older adults to be more physically active (Ammann et al., 2013; Crandall & Shake, 2016). Frequency of exercise function use showed no association with vigorous-intensity physical activity posttracking, perhaps because of preferences for less-intense activities, fear of injury, and health conditions preventing vigorous activity among older adults (Macera, Cavanaugh, & Bellettiere, 2017).

[6] Biweekly questionnaires also asked how much moderate-to-vigorous physical activity (MVPA) participants had engaged in over the past 2 weeks. Follow-up analysis using multilevel models revealed a trend in the direction of an association between exercise function use and MVPA; participants tended to report greater MVPA when they had used their tablets more frequently for exercise functions in the last 2 weeks ($b = 1.85$, $p = .064$).

This study extends previous intervention work focusing on specific programs/applications by showing how individual differences in the use of choice-based exercise applications are associated with changes in everyday physical activity. Frequently reported barriers to physical activity among older adults include lack of transportation, motivation/interest, opportunities, and supportive companionship (Moschny, Platen, Klaassen-Mielke, Trampisch, & Hinrichs, 2011). New technology may help to overcome such barriers by incorporating features like positive reinforcement, goal-tracking, gamification, and social support, which enhance compliance with exercise plans in old age (Bickmore et al., 2013; Crandall & Shake, 2016; Dasgupta et al., 2016). Furthermore, older age tends to be accompanied by losses in primary control or the ability to change external circumstances (Heckhausen et al., 2010). Portable ICT may help compensate for losses in primary control by, for example, offering customization for specific functional limitations, thereby increasing self-efficacy (Schulz et al., 2015). Greater self-efficacy, in turn, plays an important role in initiating and maintaining exercise among older adults (Neupert, Lachman, & Whitbourne, 2009). Future studies should investigate whether self-efficacy may mediate potential beneficial effects of portable ICT use on physical activity.

This study also underscores that portable ICT use may be linked with more time spent being sedentary; more frequent use of exercise functions was associated with more time spent sitting posttracking. Tablet-based programs (e.g., exercise videos) might be especially appealing if they allow individuals to exercise from home rather than going to a class in the community (Delbaere et al., 2015). However, more time at home in front of a device may also result in more sitting. For instance, Fennell, Barkley, and Lepp (2019) showed that high-volume cell-phone users engaged in 79 minutes more sedentary behavior on average per day than low-volume cell-phone users. Another explanation could be that increased physical activity brings greater need for rest (Bogdanis, 2012). Future research needs to examine the conditions under which tablet use contributes to active versus sedentary behavior (King et al., 2016).

Portable ICT Use and Loneliness

ICT use may reduce loneliness in older adults (Cotten, Anderson, & McCullough, 2013; Sims et al., 2017). Participants frequently reported using portable ICT for social functions, including messaging, email, social networking, and finding or contacting community groups/programs/events (in about 80% of biweekly reports). There was a marginal effect showing that more frequent social function use may be associated with less emotional loneliness posttracking. Socioemotional selectivity theory posits that older adults are more motivated than younger adults to prioritize emotionally meaningful interactions with close others (Carstensen et al., 2003). It is possible that subjective feelings of isolation, or emotional loneliness, decreased in the present study because older adults used social functions including video chat to connect with friends and family (Vroman et al., 2015). Previous research found that using social functions including email and video chat/messaging is associated with higher self-rated health, higher affective well-being, and fewer chronic illnesses, and that these effects are mediated by decreased loneliness (Chopik, 2016).

It is also conceivable that the use of technology for social functions, such as social networking, may make older adults feel like they are missing out or lead them to negatively evaluate their own social relationships because of social comparison (Burke & Kraut, 2016). This aligns with our finding that adults who more frequently used social functions showed more social loneliness posttracking. Older adults may be particularly vulnerable to feelings of missing out because of the higher priority they place on positive, emotionally meaningful social interactions (Carstensen et al., 2003). Indeed, previous research linked social network use with decreased psychological well-being (Hardy & Castonguay, 2018; Shakya & Christakis, 2017). Further research is needed to investigate the kinds of portable ICT use (e.g., use of which social functions, and for what duration) that may mitigate rather than exacerbate loneliness.

Portable ICT Use and Executive Functioning

Frequency of use of specific portable ICT functions showed no association with executive functioning posttracking. Previous research points to cognitive benefits associated with both overall hours of technology use and specific function use (Chan et al., 2016; Lee et al., 2016). However, findings regarding certain abilities (e.g., processing speed, working memory) are inconsistent across studies, and other work has suggested a lack of cognitive improvement (Slegers, van Boxtel, & Jolles, 2009). It may be that unstructured, everyday tablet use is insufficient for improving executive functioning; tablet-based interventions directly targeting executive functions may be necessary to produce such benefits. Furthermore, associations between ICT use and cognitive performance may be stronger in older adults who have had more previous experience with ICTs (de Souza, da Silva, da Silva, Roazzi, & da Silva Carrilho, 2012) or who have cognitive impairment (Van der Wardt, Bandelow, & Hogervorst, 2013). Our sample, like many samples in studies using tablet technology, was relatively healthy and high-functioning and hence may not have been at a stage when technology training would be beneficial for cognition. Finally, it is conceivable that, while portable ICT use may not improve cognitive functioning as captured by standardized testing, it may help older adults to better allocate their cognitive resources in everyday life (Schulz et al., 2015). In line with the model of selective optimization with compensation (Baltes & Baltes, 1990), technology may help individuals select important goals (e.g., navigating public transit), optimize goal-directed actions (e.g., managing finances using a receipt scanning app), and compensate for cognitive losses (e.g., using appointment reminders). Further research is needed to determine when and for whom tablet technology promotes cognitive functioning by examining tablet use and cognitive performance in a daily life context.

Strengths, Limitations, and Future Directions

This study was not a randomized controlled intervention. Instead, it examined naturally occurring technology use as older adults engaged in their everyday lives. By having older adults choose which ICT functions to use and when, this project prioritized individual needs and choices over a one-size-fits-all approach (Peek et al., 2016), thereby maximizing ecological validity. However, because we did not manipulate participants' access to, or training on, different types of tablet functions – nor was there a control group of participants without access to tablets – results are correlational and do not allow us to draw causal inferences. For example, more frequent use of social functions may result in increased social loneliness, but at the same time, individuals with high social loneliness may make greater use of these functions to mitigate their loneliness. Future studies should randomize participants to higher- versus lower-frequency use of portable ICT functions to address causal mechanisms. Further research is also needed to examine potential mediating mechanisms linking portable ICT use with positive aging outcomes, such as meeting socioemotional goals, orchestrating different control strategies, and navigating gains and losses (Carstensen et al., 2003; Heckhausen et al., 2010; Lang, Rohr, & Williger, 2011).

Another project strength is the socioeconomic diversity of the sample. The participants reflected Vancouver's diverse population in terms of ethnicity and education level. We also captured the experiences of individuals with limited financial and social resources (e.g., recent immigrants), who may particularly benefit from new technology (Anderson & Perrin, 2017; Czaja et al., 2018; Fang, Chau, Wong, Fung, & Woo, 2018). However, because of the small sample size, we were unable to examine differences in age, ethnicity, or socioeconomic status as moderating variables. Future research should examine whether, for example, correlates of technology use differ at age 60 as compared to age 80. Including adults aged 50+ allowed us to investigate correlates of technology use across a broad age range. However, our use of an urban community-dwelling (nonclinical) sample of mainly older adults who were motivated to use ICT limits the generalizability of the study findings to this demographic group. Future studies need to extend the investigation of everyday portable ICT use to other groups who may derive special benefit from this technology, such as adults over age 85, those living in rural contexts, and those with specific health limitations (Czaja et al., 2018; Fang et al., 2018; Ramprasad et al., 2017).

We identified predictors of physical and social functioning following an approximately 6-month period of tablet use, a commonly chosen time frame in previous research. However, there is initial evidence that the benefits of technology use may wane over longer periods (Bickmore et al., 2013; Czaja et al., 2018), calling for the use of multiple longitudinal assessments. Moreover, we captured our key dependent variables at two timepoints (pretracking and posttracking) rather than repeatedly over the tracking period; further research is needed to examine dynamic couplings of ICT use and physical/social/cognitive functioning over time. The reported associations between portable ICT function use and changes in physical activity and loneliness had small effect sizes (f^2 = 0.04–0.10, ΔR^2 = 0.02–0.07). Further research needs to replicate these initial findings. Lastly, our measures of technology use and physical activity were self-reports and should be supplemented with objective measures (e.g., tablet use monitoring, accelerometry; Bickmore et al., 2013; Cotten, 2017; King et al., 2016).

Conclusions

Because ICT is becoming more widely used in daily life, technology has been recognized as a major contextual factor influencing current and future aging (Wahl & Gerstorf, 2018). This study underscores that tablet technology may promote positive aging, with tablets being particularly appealing for older adults because of their user-friendly interface (Dasgupta et al., 2016). Technology has the potential to help older adults maintain independence, social and physical functioning, and goal pursuit, thereby promoting aging "in place" (Schulz et al., 2015). We and others have shown that older adults with limited experience can learn to use mobile and tablet devices (Hoppmann & Blanchard-Fields, 2011; Vaportzis et al., 2017). Most of our participants wanted to keep their tablets and found them easy to use and helpful in everyday life. Taking an individualized approach, we allowed participants to choose which ICT funtions to use, based on the idea that a one-size-fits-all approach would work less well given older adults' heterogeneous preferences, abilities, and social and physical contexts

(Dasgupta et al., 2016). Our findings suggest that empowering older adults to use ICT in their daily lives and connecting them with a digitally conversant world may carry tangible physical and social benefits (more moderate-intensity physical activity, less emotional loneliness). However, our findings are nuanced and also show the potential negative effects of portable ICT use (more sitting, more social loneliness). Future research on technology and aging needs to consider risks as well as benefits of ICT.

Electronic Supplementary Material (ESM)

The electronic supplementary material is available with the online version of the article at https://doi.org/10.1024/1662-9647/a000208

ESM 1. Overview of Project and Technology Workshops

ESM 2. Participant demographics and Pretracking to Posttracking Outcome Change

ESM 3. Biweekly Technology Use Questionnaire

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History
Received March 13, 2019
Accepted June 27, 2019

Authorship
Theresa Pauly and Jennifer C. Lay share first authorship.

Conflict of Interest
The authors declare no conflicts of interest.

Funding
This work was supported by the Vancouver Foundation (UNR12-0926, UNR13-0484 to Christiane Hoppmann, Sandra Petrozzi, Atiya Mahmood, and Peter Graf). Christiane Hoppmann gratefully acknowledges the support of the Michael Smith Foundation for Health Research and the Canada Research Chairs Program. The German Academic Scholarship Foundation provided a stipend to Theresa Pauly, the Social Sciences and Humanities Research Council of Canada to Jennifer Lay, and the Natural Sciences and Engineering Research Council of Canada to Pavel Kozik.

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