Mobile Ecological Momentary Assessment Examines the Impact of an At-Home Physical Activity Program on Older Adults' Depressive Symptoms during COVID-19

by

Amanda M. Webber
Bachelor of Arts (Honours), University of Victoria, 2018

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We acknowledge and respect the lək̓ʷəŋən peoples on whose traditional territory the university stands and the Songhees, Esquimalt and W̱SÁNEĆ peoples whose historical relationships with the land continue to this day.

Supervisory Committee

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Supervisory Committee

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Abstract

Physical activity is a well-known protective factor against poorer mental health outcomes. Feelings of depression, social isolation, and stress have increased since the onset of the COVID-19 pandemic. Public health measures implemented to mitigate the spread of the virus have had some unintended consequences on older adults' physical and mental health. Researchers and government officials recommend physical activity to minimize the negative psychological and physiological impacts of COVID-19. However, older adults have generally shown less moderate-to-vigorous physical activity and positive behavioural adaptations during the COVID-19 pandemic, highlighting a need for physical activity programs and strategies targeted for older adults. Filling this gap, the current study developed and implemented a remote exercise training program for older adults. Employing a measurement burst design with repeated ecological momentary assessments, the current longitudinal randomized control study examined the dynamic relationships of physical activity, depressive symptoms, social isolation, and COVID-19 related stress in older adults. The results from multilevel model analyses showed: (1) the exercise training program was effective in increasing physical activity; (2) sex, age, and group assignment were significant predictors of physical activity; (3) physical activity did not reduce depressive symptoms over time; (4) social isolation is directly associated with depressive symptoms; and (5) COVID-19 stress is inversely associated with depressive symptoms. At-home physical activity programming could be an effective way to increase physical activity among older adults; thus, more research into at-home physical activity programs is needed.

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Introduction

Physical activity is a well-known protective factor against poorer mental health outcomes and ameliorates feelings of depression, social isolation, and stress (Mandolesi, Montuori, Foti, Ferraioli, Sorrentino, & Sorrentino, 2018; Siegmund, Distelhorst, Bena, & Morrison, 2020). More recently, older adults have engaged in less physical activity since the onset of the COVID-19 pandemic (Rhodes, Liu, Lithopoulos, Zhang, & Garcia-Barrera, 2020). More specifically, older adults have generally shown less moderate-to-vigorous physical activity and positive behavioural adaptations during COVID-19, highlighting a need for physical activity programs and strategies targeted for specifically older adults (Rhodes et al., 2020, p. 19; Hammami, Harabi, Mohr, & Krustrup, 2020; Dubey, Biswas, Ghosh, Chatterjee, Dubey, Chatterjee, et al., 2020). Researchers speculate that this is likely because older adults are at a greater risk of developing complications due to COVID-19 and were exercising more caution to minimize exposure (Rhodes et al., 2020). Though the relationship between physical activity and mental health is well documented in the literature, the current research fills a gap by developing and implementing a remote exercise training program designed by professionals for older adults to examine the effectiveness of the program and its impacts on depressive symptoms, social isolation, and COVID-19 stress during the novel COVID-19 pandemic.

On March 12, 2020, the World Health Organization (WHO) declared COVID-19 as a global pandemic. In response, the Canadian government implemented restrictions (e.g., closure of non-essential businesses, social distancing, and orders to stay at home) to mitigate the transmission of the virus (WHO, 2020; Government of Canada, 2020). Previous research on other infectious viruses prior to COVID-19 has informed some of the anticipated outcomes of the current pandemic. For example, a review of studies ($n = 24$) examining the psychological impact of quarantine (i.e., “the separation and restriction of movement of people who have potentially been exposed to a contagious disease to ascertain if they become unwell, so reducing the risk of them infecting others," p. 912) on individuals with SARS, Ebola, and the 2009 and 2010 H1N1 influenza pandemic showed that confinement, disruption or loss of routine, and reduced social and physical contact were frequently shown elicit feelings of isolation from the rest of the world, boredom, and frustration, which was distressing to participants (Brooks, Webster, Smith, Woodland, Wessely, Greenberg & Rubin, 2020, p. 916). Further, post-traumatic stress symptoms were among the most common adverse psychological effects of quarantine (Brooks et al., 2020). Other researchers caution that social and physical distancing measures are risk factors for mental health issues, including, but not limited to, suicide and self-harm, depression, anxiety, and stress (Holmes, O’Connor, Perry, Tracey, Wessely, Arseneault, Ballard, et al., 2020).

Older adults aged 60 years and older were among the vulnerable populations at risk of developing severe complications of COVID-19 and were recommended to take extra precautions (WHO, 2020; Government of Canada, 2020). Additionally, personal concerns about contracting the virus may also explain a decline in physical activity engagement (Rhodes et al., 2020).

While necessary, the pandemic-imposed restrictions implemented to mitigate the transmission of the virus have had some unintended consequences on older adults’ physical and mental health, which the decline in physical activity may exacerbate. For example, the closure of non-essential businesses, including fitness centers, disrupted the routines of many Canadians and may be responsible for the demonstrated reduction in physical activity (Rhodes et al., 2020; Lesser & Nienhuis, 2020). Social distancing behaviours were inversely associated with moderate-to-vigorous physical activity in Canadian adults during the COVID-19 pandemic lockdown beginning in March 2020, suggesting that the pandemic-imposed restrictions impacted individuals' physical activity (Rhodes et al., 2020). Other documented harmful consequences of the COVID-19 pandemic on older adults' well-being include increased depressive symptoms, social isolation, and COVID-19 stress (Hammami et al., 2020; Siegmund et al., 2021; Brooks, Webster, Smith, Woodland, Wessely, Greenberg & Rubin, 2020; Rhodes et al., 2020). In relation to physical activity, a recent study determined that individuals who became less active since COVID-19 were more likely to have worse depressive, anxiety, and stress symptoms (Stanton, To, Khalesi, Williams, Alley, Thwaite, et al., 2020).

Additional strategies to promote physical activity in older adults are needed, given the harmful psychological response to COVID-19 thus far and the established benefits of physical activity on depressive symptoms, social isolation, and stress. Researchers have recommended at-home physical activity programs to counteract the negative impacts of COVID-19 on older adults' physical and mental health. Filling a critical gap, the current study developed and implemented a completely remote 8-week exercise training program for older adults to assess the relationships between the time spent engaging in physical activity, depressive symptoms, social isolation, and COVID-19 stress during the pandemic.

Physical Activity

The WHO (2020) defines physical activity as bodily movements resulting from muscle contractions that require energy expenditure. McEwan (2012) describes physical activity as a "powerful top-down therapy (i.e., an activity, usually voluntary, involving activation of integrated nervous system activity as opposed to pharmacological therapy, which has a more limited target"; p. 17,183). Further, regular moderate-to-vigorous physical activity supports mental and physical health across the lifespan (Rhodes et al., 2017). Both acute (i.e., a single bout of activity for 10 minutes or more at a time) and chronic (i.e., several months) physical activity are associated with mental health and wellness (Mandolesi et al., 2018). Acute physical activity releases neurotrophic factors (e.g., brain-derived neurotrophic factor; BDNF) and neurotransmitters (e.g., serotonin), increases cerebrovascular blood flow, and is associated with improved mood and emotional states (Mandolesi et al., 2018). For example, a single bout of exercise has notable influences on anxiety and depressive symptoms (Dunton, 2017). Chronic physical activity results in structural and functional neuroplastic changes. Additionally, meta-analyses report that aerobic/anaerobic exercise increases peripheral BDNF concentrations (Di Lorito, Long, Byrne, Harwood, Gladman, Schneider, et al., 2020).

The increased expression of BDNF in response to regular physical activity elicits a neuroprotective influence against age-related neurodegeneration through positively promoting white matter structure and integrity (Sexton, Betts, Demnitz, Dawes, Ebmeier, & Johansen-Berg, 2016). BDNF facilitates structural plasticity, and the insulin-like growth factor-1 mediates exercise-induced neurogenesis in the hippocampus (McEwan, 2012). In contrast, physical inactivity is associated with lower levels of peripheral BDNF and worse depressive symptoms (Mandolesi et al., 2018), supporting the relationship between physical activity, BDNF, and mood.

The hippocampus is among brain areas that tend to endure the most damage resulting from age-related degeneration, chronic stress, depression, and isolation (McEwan, 2012). Studies have reported smaller hippocampal or temporal lobe volumes associated with prolonged major depression, chronic stress, and lack of physical activity (McEwan, 2012). There is evidence that the aging brain loses its ability to recover from stress-induced changes (i.e., resilience) and changes caused by isolation and an unhealthy lifestyle (e.g., physical inactivity) that can be improved by top-down interventions, including physical activity (McEwan, 2012). However, studies have shown that hippocampal volume is associated with regular physical activity, suggestive of hippocampal neurogenesis. For example, regularly active participants had larger hippocampal volumes than sedentary adults of the same age range (McEwan, 2012).

Despite its well-known benefits, 88% of older adults ages 60-79 in Canada failed to meet the WHO's recommended physical activity guidelines before the COVID-19 pandemic (Rhodes et al., 2017). The WHO (2010) recommends that older adults perform muscle-strengthening activities at least two days a week, plus at least 150 minutes of moderate-intensity aerobic activity, 75 minutes of vigorous-intensity aerobic activity, or an equivalent combination of moderate and vigorous-intensity activity per week.

Since the onset of COVID-19 and the associated public health measures implemented to combat the transmission of the virus, research has shown an increase in sedentary behaviour, depressive symptoms, social isolation, stress, and decreased moderate-to-vigorous physical activity (Hammami et al., 2020; Siegmund et al., 2021; Rhodes et al., 2020; Stanton et al., 2020). A report by Fitbit data scientists showed a 14% decline in the step count in millions of Canadian Fitbit users during the week of March 22, 2020, compared to data from the same week of the previous year (Fitbit Inc., 2020; Mishra, Park, York, Kunik, Wung, Naik, & Najafi, 2021). Also, a more recent study reported that Canadians perceived that they had decreased 47 minutes of moderate-to-vigorous physical activity per week on average (Rhodes et al., 2020).

Further, a recent study examining the impact of COVID-19 on Canadian adults' (ages 19 years and older) physical activity behaviours and well-being found differences between participants who were categorized as active (≥ 150 minutes of moderate-vigorous physical activity per week) or inactive (< 149.9 minutes of moderate-vigorous physical activity per week) before and during COVID-19 (Lesser & Nienhuis, 2020). Results showed that 40.5% of participants who were 'inactive' before COVID-19 became even more sedentary during COVID-

19; this group reported poorer socioemotional and psychological health and worse anxiety compared to the 33% of participants who were 'inactive' pre-COVID but became more active during COVID-19, demonstrating an inverse association physical activity on mental health.

While not a focus of the current study, it is worth noting that the macro-study integrated cognitively demanding activities within the exercise videos due to its benefit on physical and mental health (described later). Meta-analyses suggest that performing cognitively and physically demanding activities simultaneously produce the most significant physical, mental, and cognitive health benefits compared to delivering cognitive and exercise activities sequentially (Gheysen, Poppe, DeSmet, Swinnen, Cardon, De Bourdeaudhuij, et al., 2018); therefore, older adults' physical, mental, and cognitive health could further benefit from the sequential delivery of cognitive and physical activities developed for the current study.

To initiate physical activity, a high-level review of international research on physical activity identified self-efficacy and the intention to be active as determinants; further, supervision and frequency of contact were associated with the physical activity intervention effectiveness in adults (>59% of studies; Rhodes et al., 2017). Face-to-face interactions were not possible due to the pandemic-imposed restrictions, and thus in-person supervision and interaction were not possible. Therefore, the macro-*eFIT study* was strategically designed to promote adherence and fidelity given the lack of supervision and face-to-face contact. While not a focus of the current study, it is also worth noting that adherence-promoting components were integrated into the macro-study, which includes, but is not limited to, a rewards program (Rhodes et al., 2017) and biweekly progress reports, routine (e.g., surveys sent within the same time window each day), and weekly goal setting and flexibility of physical activity (Active group only; Hancox, Van Der Wardt, Pollock, Booth, Vedhara, & Hardwood, 2019).

Finally, before the COVID-19 pandemic, depression, social isolation, stress, older age, and sex (females) were known correlates of physical inactivity (Mandolesi et al., 2018; Hammami et al., 2020; Brooks et al., 2020; Stanton, To, Khalesi, Williams, Alley, Thwaite, et al., 2020; Rhodes et al., 2017). Recent research has shown that physical activity has declined since the onset of COVID-19, putting older adults at an even higher risk of poor mental health outcomes (Mishra et al., 2021). In addition to examining the effectiveness and fidelity of the *eFIT* exercise program, the current study was interested in examining the impact the program had on insufficiently active older adults' psychosocial factors such as feelings of depressive symptoms, social isolation, and COVID-19 stress.

Psychosocial Factors Impacted by Reduced Physical Activity

The relationship between social isolation and depression in older adults before the COVID-19 pandemic is well-established (Siegmund et al., 2020). Results from a recent study examining psychological distress (depression, anxiety, and stress) and changes in health behaviours showed that individuals who became less active during COVID-19 than before the pandemic were more likely to have significantly higher anxiety, stress, and depressive symptoms (Stanton et al., 2020). Another recent study found that older adults who reported reduced social connectivity during COVID-19 had a 17.24 times higher risk of depressive symptoms (Robb, de Jager, Ahmadi-Abhari, Giannakopoulou, Udeh-Momoh, McKeand, et al., 2020). Similarly, Siegmund and colleagues (2021) identified a large effect of social isolation on depressive symptoms during a period of pandemic-imposed social distancing; during this period, physical inactivity was positively associated with depression as well. Personality psychology research suggests that regular physical activity correlates with hardiness, a personality style that enables an individual "to withstand or cope with stressful situations" (Mandolesi et al., 2018, p. 4), which could potentially be a protective factor against the negative impacts associated with COVID-19.

Depression

Depression is a common illness that affects 5.7% of adults ages 60 years or older worldwide, is more prevalent in women, and is associated with stress (WHO, 2021). People who have experienced adverse life events (e.g., traumatic events or loss of a loved one) are more likely to develop depression. The COVID-19 pandemic is a risk factor for depression. In support of the current study's exercise training program intentions, the WHO (2021) recommends exercise programs as a preventative measure against depression in older adults.

Recent meta-meta-analyses demonstrated that physical activity reduced depression by a standardized mean difference of -0.50 (Rebar et al., 2015; as cited in Rhodes, Janssen, Bredin, Warburton & Bauman, 2017). A review of literature assessing correlates and determinants of physical activity found that individuals with depression showed lower physical activity if their depression was more severe (Vancampfort et al., 2015 as cited in Rhodes et al., 2017). However, results of an EMA study assessing the impact of physical activity on mood showed that the association between physical activity and mood is contingent on an individual's mood at baseline, such that physical activity had less of an effect on individuals who were already reporting a positive mood but had a larger impact on individuals reporting a low mood (Kanning & Schlicht, 2010). Researchers speculate that this outcome could result from a potential ceiling effect, stating that an individual's mood will remain relatively stable if their mood is already positive before engaging in physical activity. Essentially, positive moods are less likely to be significantly improved by physical activity, but negative moods are more likely to be significantly improved by physical activity.

Social Isolation

As previously mentioned, older age was identified as a risk factor for developing severe complications of COVID-19 (WHO, 2020). Therefore, older adults' personal concerns about contracting the virus may have led to increased social isolation. Social isolation, defined as "limited relationships and contact with others, including friends and family," was already an identified correlate of decreased physical activity and worsened depression before the COVID-19 pandemic (Siegmund et al., 2021, p. 1241). During COVID-19, a large effect on depression was found in older adults who reported slightly worse feelings of social isolation than their usual state (Siegmund et al., 2021).

Interestingly, there is evidence that physical activity may be a potential mediator of social isolation on depression. Results from a path analysis examining the relationship between physical activity and depression, and social isolation and depression in community-dwelling older adults during a period of pandemic-imposed social distancing showed the following associations: (1) higher ratings of depression and social isolation, and older age, were associated with less physical activity; and (2) higher ratings of depression were associated with higher social isolation, demonstrating a positive relationship between social isolation and depression (Siegmund et al., 2021). Social isolation and physical activity accounted for nearly half (44%) of the variance in depression. Finally, results also showed a small indirect effect of social isolation on depression through physical activity, suggesting that higher physical activity could reduce the negative impact of social isolation on depression (Siegmund et al., 2021).

COVID-19 Stress

Individuals may experience stress when the "…pressure of an event or situation [e.g., the COVID-19 pandemic] surpasses a person's capability to cope… stress may be defined as an imbalance between demands and an individual's available resources" (Churchill, Riadi, Kervin, Teo, & Cosco, 2021, p. 2). Between March and April 2020, COVID-19 related acute stress and depressive symptoms increased as the rates of COVID-19 positive cases and deaths rose substantially in the United States ((Holman, Thompson, Garfin, & Silver, 2020). Media exposure was identified to be one of the strongest predictors of COVD-19 related stress and depressive symptoms in American adults (Holman et al., 2020). There has been a notable increase in sedentary behaviour among older adults during the COVID-19 pandemic, which is associated with increased TV watching (Hammami et al., 2020). This is of concern because repeated media exposure to information about infectious diseases can exacerbate stress responses (Holmes et al., 2020).

Holman et al. (2020) examined predictors of COVID-19 related stress and depressive symptoms across three cohorts who were assessed at different times of the pandemic in the United States. Each cohort was categorized based on the number of positive COVID-19 cases and deaths, which increased over time. Results showed the following: (1) older people reported lower stress and depressive symptoms; (2) females reported higher acute stress but not depressive symptoms; (3) personal exposure to the outbreak was positively associated with COVID-19 related stress and depressive symptoms; but (4) work-related exposures predicted lower depressive symptoms but not COVID-19 related stress; (5) job and wage losses were positively associated with higher acute stress and depression; and finally, (6) media exposure (e.g., hours of COVID-19 related media consumption, increased media consumption relative to the individual's media consumption behaviour before COVID-19, and higher frequency of exposure to conflicting pandemic-related information) was one of the strongest predictors and positively associated with COVID-19 related stress and depressive symptoms.

Sex and Age as Covariates

Sex and age are well-known correlates of physical activity, depression, social isolation, and stress. More specifically, males and younger age are consistent correlates of physical activity in adults (Rhodes et al., 2017). Recent research completed during the COVID-19 pandemic showed that depression and anxiety are more prevalent in women, young people, and people with low socioeconomic status (Vloo, Alessie & Mierau, 2021). Researchers Vloo et al. (2021) used data from a longitudinal study that included assessments before, during, and after the first COVID-19 lockdown in the Netherlands to examine the impact of lockdown on mental health. Results showed that women had significantly more depressive symptoms and disorders than men, but men had significantly more anxiety and anxiety disorders during the lockdown.

Partially in agreeance with Vloo et al. (2021), Robb and colleagues (2020) found that women were 2.5 times more likely to experience feeling worse depression and anxiety after a pandemic-imposed lockdown in the UK compared to men. Additionally, the risk of feeling worse depressive symptoms after a pandemic-related lock decreased 19% with every five-year increase in age, suggesting that older age is not a risk factor of depression in this study (Robb et al., 2020).

Age Predicts Psychosocial Outcomes in Early COVID-19 Research

As previously mentioned, older adults ages 60 years and older are at risk of developing severe complications of COVID-19; given this risk, older adults were recommended to take extra precautions while adhering to the pandemic-related restrictions (WHO, 2020; Government of Canada, 2020). Personal concerns about contracting the virus may disproportionately isolate older adults (Fields, Kensinger, Garcia, Ford & Cunningham, 2021), which may also explain a decline in physical activity engagement since the onset of COVID-19 (Rhodes et al., 2020). Of concern, physical inactivity is associated with depression, social isolation, and stress. Therefore, it is conceivable that older adults could experience worse depressive symptoms, social isolation, and stress due to reduced physical activity.

However, previous research has demonstrated that older age is often associated with lower negative affect or levels of depression or anxiety symptoms (see review in Piazza & Charles, 2006 as cited in Fields et al., 2021). Additionally, older adults can show resilience when faced with stressors; thus, older age may serve as a protective factor of mental wellbeing during a "sustained and unavoidable stressor," that is, the COVID-19 pandemic (Fields et al., 2021, p. 7).

While early research shows that physical activity has declined in older adults, some evidence suggests that the adverse psychosocial impacts of the COVID-19 pandemic may not have impacted older adults as negatively as it has younger adults. Results from a cross-sectional study examining acute stress and depressive symptoms during COVID-19 showed that age was inversely associated with stress and depression, such that younger adults reported higher stress and worse depressive symptoms (Holman, Thompson, Garfin, & Silver, 2020). Another study concluded that younger adults reported worse depression, anxiety, and stress than older adults ages 65 years and older during COVID-19 (Stanton et al., 2020). Overall, older adults have become less physically active since the onset of the COVID-19 pandemic, which could exacerbate depressive symptoms, social isolation, and stress. However, there is evidence that the positive mental health benefits associated with older age may serve as a buffer against poorer mental health outcomes related to physical inactivity.

Additionally, older adults may need a more structured environment when practicing moderate-to-vigorous physical activity, such as gyms, exercise and fitness classes, or personal training sessions, all of which were closed for at least part of the COVID-19 pandemic. Alternatively, home physical activity equipment and programming are significant correlates of moderate-to-vigorous physical activity during the COVID-19 pandemic (Rhodes et al., 2020). Further, the WHO (2020) recommends exercising at home using technology and exercise videos which are freely available on YouTube. It has also been recommended to replace outdoor exercise regimes/plans with home-based activities, such as bodyweight training (i.e., exercises include activities that involves using one's body as a means of resistance to perform work against gravity, e.g., lunges and jumping jacks) and high-intensity aerobic exercises (e.g., dancing, stationary bikes) to combat the increased feelings of stress and mental distress associated with stay-home orders (Hammami et al., 2020).

In summary, implementing an at-home physical training program during COVID-19 may decrease the negative psychological impact of the COVID-19 pandemic, which is possibly exacerbated by the notable reduction in moderate-to-vigorous physical activity in older adults (Hammami et al., 2020; Rhodes et al., 2020). Therefore, the current study developed and implemented an exercise training program designed specifically for older adults. The anticipated increase in older adults' physical activity will combat depressive symptoms, social isolation, and stress.

Rationale

Executive Function Improvement Training (eFIT) is a 13-week randomized control trial study involving 8-weeks of self-directed aerobic activity and guided anaerobic training with cognitively demanding activities. *eFIT* employs a multimodal approach to assess the impact of an exercise training program on various aspects of insufficiently active older adults' well-being (e.g., cognitive, mental, and physical health), including a longitudinal assessment battery, computerized cognitive assessments, and ecological momentary assessment (EMA) captured with a measurement burst design (i.e., frequent, closely spaced assessments that are then repeated over longer intervals; Sliwinski, 2008). The current study focuses on the latter.

Utilizing a smart-phone based EMA platform, participants were measured 2 times a day for 7 days over three measurement bursts. The morning and evening surveys assessed various psychosocial factors that may impact individuals' level of physical activity during the novel pandemic, including depressive symptoms, social isolation, and COVID-19 related stress.

Traditional 'single-shot' assessments fail to account for within-person variability and contextual factors influencing behaviours. Through the application of EMA (i.e., repeated sampling of individuals' current behaviours and experiences in real-time and in their natural environments) and implementation of a measurement burst design, *Ethica Data* affords the opportunity to capture individuals' experiences and behaviours in their natural environment, emphasizing ecological validity, and enabling the examination of contextual affective and state factors that influence physical activity engagement and behaviour in real-world contexts over time. This allows researchers the unique opportunity of modeling long-term changes in one's average physical activity levels and feelings of depressive symptoms, social isolation, and COVID-19 stress in fine-grained temporal relationships that can only be measured on a daily or momentary basis (Sliwinski, 2008).

Given the repeated measurement design inherent to EMA, researchers must be careful in deciding how many items to include in daily surveys not to burden the participant and result in attrition. Because of its brevity, EMA has been criticized for having issues with content validity

(Degroote, DeSmet, De Bourdeaudhuj, Van Dyck, & Crombez, 2020). However, the current study carefully selected short-form measurement scales that have demonstrated good psychometric properties and content validity.

Some advantages of using EMA over in-person testing or single-shot assessments include the following: (1) EMA questions ask about one's current state, which reduces recall biases (e.g., a participant will be more accurate in answering questions pertaining to their current state versus if asked in a survey assessing one's usual state in a typical week); (2) EMA maximizes ecological validity and is more generalizable because data is collected in naturalistic settings; (3) EMA gathers intraindividual data which enables researchers to compare an individual's performance at different time points during the study (e.g., sessions, days, weeks, etc.) using their own personal mean as a comparison; and (4) repeated daily measures capture fluctuations in variables and afford a more precise 'true' average in behaviours and states across time while disentangling stable from dynamic sources of variability in within-person processes (Sliwinski, 2008; Dunton, 2017).

Other advantages of using mobile technology to collect data include its ability to mitigate geographic, spatial, and personnel constraints imposed by in-person testing, affording the opportunity to obtain a large, geographically diverse sample (e.g., across Canada) and access to under-represented and difficult to reach populations (e.g., older adults in rural communities), especially during the COVID-19 pandemic where face-to-face interactions are limited. Additionally, the frequency of repeated testing using mobile technology is convenient for participants, enabling frequent assessments which improve measurement reliability and allow for the characterization of dynamic features of physical activity.

In summary, employing a smartphone-based EMA measurement burst design has several advantages, including the following: (1) it permits the detection of change through repeated measures in real-time; mitigates some challenges that traditional in-person 'single shot' assessments experience; and allows examining within-person and between-person variability in physical activity while simultaneously assessing contextual factors known to fluctuate and may impact physical activity.

The Current Study

The current study uses a smartphone-based EMA platform (i.e., a custom-built integrated EMA mobile assessment platform), *Ethica Data*, to examine real-world relationships of physical activity, depressive symptoms, social isolation, and COVID-19 stress within, and between, healthy, insufficiently active older adults. Following an RCT design, the participants were randomly assigned to the Active or Waitlist Control group. The purpose of this study was to evaluate the impacts that the remote *eFIT* exercise training program had on moderate-intensity (or equivalent) physical activity (MPA) engagement and depressive symptoms while controlling for group assignment, sex, age, social isolation, and COVID-19 stress. Taking into account the impact that the novel COVID-19 pandemic has had on research, resulting in no face-to-face contact, the goals of the current—and completely remote—study are to assess the following:

(i) differences in depressive symptoms between the Active and Waitlist Control group over time;

(ii) the time-varying covariation of depressive symptoms, COVID-19 stress, and social isolation on physical activity; and

(iii) the time-varying covariation of physical activity, COVID-19 stress, and social isolation on depressive symptoms.

It was hypothesized that there would be (i) differences in depressive symptoms between the Active and Waitlist Control groups at mid-point and immediately after the exercise training program concluded, such that depressive symptoms decrease in the Active group but remain stable in the Waitlist Control group; (ii) an inverse association between depressive symptoms, COVID-19 stress, and social isolation on physical activity, such that participants who completed more physical activity would report less depressive symptoms, COVID-19 stress, and social isolation over time; and (iii) an inverse association of MPA on depressive symptoms and a direct association of social isolation and COVID-19 stress on depressive symptoms, such that reduced feelings of social isolation and COVID-19 stress would result in reduced depressive symptoms.

Methods

Individuals were eligible to participate in the study if the following criteria were met: (1) age 65 years or older; (2) relatively 'sedentary' or insufficiently active (i.e., perform less than 150 minutes of moderate-intensity aerobic physical activity per week, 75 minutes of vigorous-intensity aerobic physical activity per week, or an equivalent combination of moderate- and vigorous-intensity aerobic physical activity per week; WHO, 2010); (3) currently live in Canada; (4) able to speak and read English; (5) have access to stable internet at home; (6) have access to a smartphone that can download and support the *Ethica Data* app for assessments; (7) do not have a history of neurological disorders (e.g., stroke, epilepsy) or substance abuse; and (8) do not have a diagnosis of moderate to severe traumatic brain injury. Individuals were not excluded based on sex, gender, or race.

Individuals who expressed interest in the study were then sent an assessment screening for the above criteria, as well as: (9) a Health Contribution Score of 23 units or less on the Godin-Shephard Leisure-Time Exercise Questionnaire (GLTEQ)[1]; and (10) completion of the Physical Activity Readiness Questionnaire for Everyone (PAR-Q+) deeming them physically capable of participating in physical activity. Individuals who completed the PAR-Q+ and were deemed ineligible, but still wanted to participate, were required to obtain a letter from their

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[1] Initially, participants were excluded from the study if their Godin-Scale score was greater than 13 units. However, this criterion was too strict as very few individuals scored less than 13 units. For example, an individual who takes an easy walk for more than 15 minutes a day, 7 times a week, would receive a Godin-Scale score of 21 units, excluding them from the study. Therefore, shortly after recruitment began, the inclusion criterion was adjusted. Health Contribution Scores (i.e., scores that only include moderate and strenuous exercise) less than 23 units (i.e., insufficiently active) were eligible to participate. A Health Contribution Score of 24 units or more is considered 'active' by the Godin-Shephard Leisure-Time Exercise Questionnaire (Amireault & Godin, 2015).

physician approving their capacity to participate[2]. After successfully completing the initial screening assessment, participants were randomly assigned to the (1) Active group (n = 48; M_{age} = 69.9 years; 73.5% female) or (2) Waitlist Control group (n = 37; M_{age} = 68.4 years; 70.3% female). Following random assignment, 13 individuals assigned to the Waitlist Control group and 9 assigned to the Active group declined to participate in the study (*note:* the individuals who declined to participate were not included in the sample sizes reported above).

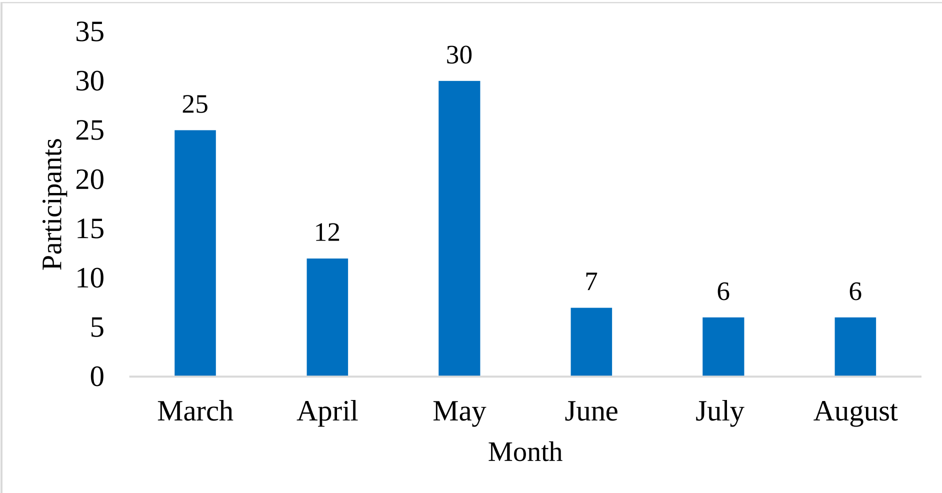
Participants

Participants (N = 85; M_{age} = 68.7 years; age range: 65 – 81 years old; 75.6% female) were healthy, insufficiently active community-dwelling adults ages 65 years and older who were recruited from communities across Canada via research participation listservs (Sports for Life, Institute on Aging and Lifelong Health, and Tall Tree Integrated Health), social media (e.g., Twitter, Facebook, Instagram), radio, newspapers, and REACH BC (i.e., an online platform linking participants to health research). The sample consisted of individuals from British Columbia (n = 56; 67%), Ontario (n = 13; 15%), Quebec (n = 3; 4%), Prince Edward Island (n = 3; 4%), Nova Scotia (n = 2; 2%), Yukon (n = 2; 2%), and New Brunswick (n = 1; 1%). Figure 1 represents a distribution of months when participants joined the *eFIT* study and completed the first measurement burst.

[2] Only 2 participants provided letters from their physicians approving their capacity to participate.

Figure 1

Distribution of Participants Completing the Baseline Measurement Burst by Month



Note. The number of participants completing the baseline measurement burst per month.

Procedure

Recruitment for the macro-*eFIT* study began at the end of February 2021. It will continue recruiting on a rolling basis until November 2021 or when the target number of participants is met. New cohorts of participants began the study every Monday as a result of the rolling recruitment strategy. For data analysis for the current study, the last participant was recruited at the beginning of August 2021.

All participants were required to log into their "*eFIT* Participant Dashboard" via the web-based platform, *Moodle*. Information about other assessments pertaining to the macro-study was accessible here, as well as the *eFIT* exercise videos which released one video per week to the Active group during the 8-week training period. Additionally, all participants were requested to download the *Ethica Data* app to receive EMAs on their smartphones.

Mobile Ecological Momentary Assessments

All participants downloaded the *Ethica Data* app to complete mobile EMAs. Participants received 2 surveys (morning and evening) per day, for 7 days, across three measurement bursts. Notifications were sent to participants' smartphones, informing them that the surveys were available in the *Ethica Data* app; the notifications were sent randomly between 06:30 – 08:30 (morning survey) and again between 18:30 – 20:30 (evening survey). Given the variability in individuals' sleep/wake times, the survey expired 4 hours after the notification was sent.

Figure 2

eFIT Study Measurement Burst Schedule and Timeline

Each measurement burst was strategically selected around the following milestones associated with the *eFIT* exercise training program: (1) at baseline (i.e., 7 days before the exercise training program began); (2) midway (i.e., 3.5 weeks into the exercise training program); and (3) post (i.e., immediately following the exercise training program; see Figure 2 for a visual of the measurement burst schedule and *eFIT* study timeline, and Table 1 for a detailed description of the measurement bursts' summary and sample size per group by burst).

Table 1

Description of Measurement Bursts, Exercise Training Program Milestones, and Group Samples

	Burst 0	Burst 1	Burst 2
Time in study	Weeks 0 - 1	Weeks 3.5 - 4.5	Weeks 9 - 10
Study milestone	Baseline	Mid-exercise training	Immediately post-exercise training
Active Group (*n*)	48	38	28
Waitlist Control Group (*n*)	37	29	27

Physical Activity Requirements (Active Group Only)

Following the first measurement burst at baseline, the Active group was instructed to complete two 30 minute *eFIT* guided anaerobic exercise videos (see *eFIT Guided Exercise Videos* described in detail below), plus an additional 120 minutes of self-directed MPA per week for 8 weeks. The 120 minutes of self-directed exercise were flexible. Participants were asked to engage in enjoyable aerobic exercise (e.g., walking, biking, dancing, etc.) for 1 hour at a moderate intensity twice a week. In contrast, the Waitlist Control group did not gain access to the *eFIT* workout videos until week 14, when they completed all of the macro-study's assessments. Finally, the Waitlist Control group was recommended to maintain or not change their physical activity levels throughout the study.

eFIT Guided Exercise Videos

Each week during the *eFIT* training program (i.e., Weeks 1-9; see above Figure 2 for reference), a new *eFIT* exercise video was posted in the Active groups' *eFIT* Participant Dashboard, which was accessible via *Moodle*. The *eFIT* exercise videos were carefully crafted by kinesiologists and made specifically for this study by our collaborators at Tall Tree Integrated Health. The team is trained to develop appropriate routines for older adults and contain minimal risk for injury. Given the remote nature of the study, the participants were to exercise without supervision and therefore reminded to perform the exercises carefully and properly.

Safety was a top priority. Therefore, participants were asked to refrain from overexerting themselves and instead were encouraged to reduce the intensity of their exercise and take breaks as needed. In the videos, the instructor reminds participants to stop and rest if they experience any potential risk warning signs (e.g., chest pain, lightheadedness, numbness, difficulty breathing, and joint pain) and seek medical attention if the symptoms do not resolve after a period of rest. It was recommended that participants inform someone close to them (e.g., in the household) that they were engaging in physical exercise weekly or have someone near them while exercising, especially if they had not exercised in a while.

The exercises are intended to be challenging and test their strength and fitness levels at their own pace (i.e., finding a level of intensity that is challenging for themselves and not necessarily at the same pace as the instructor). To accommodate this, the instructor first demonstrates a particular variation of an exercise, describing various parts of the body involved, and then shows other variations to increase or decrease the intensity. Using the lunge exercise as an example, the instructor holds onto a chair for support and performs a lunge where the back leg bends about halfway down to the ground, and the front knee bends to approximately a 90-degree angle. Next, they demonstrate variations of the lunge to adjust the intensity of the exercise; to increase the intensity, participants can perform a deeper lunge by bending their back leg until it's touching the ground or performing a lunge without holding onto stabilizing supports (e.g., a chair); and to decrease intensity, participants can reduce the depth of their lunge by only bending both legs slightly while holding onto stabilizing supports. Participants are asked to pause the video, find a lunge variation that works for them, and then complete two sets of 10 repetitions on each leg. They are then encouraged to take a quick rest before unpausing the video and moving on to the next exercise.

Some other examples of the at-home anaerobic exercises include lateral raises (i.e., raising arms from their sides until parallel with the shoulders) with household items as weights (e.g., holding a can of soup in each hand), V-Sit (i.e., sitting on the edge of a chair, leaning back and alternating touching both sides of the chair by twisting the trunk), squats, Rocket Jumps (i.e., bending at the waist to reach the floor then reach up to the ceiling), jumping jacks, and others.

All the different exercise videos adhere to the same following structure, such that participants: (1) learn four different exercises and complete a set of each; (2) perform intervals of the same four exercises (e.g., 45 seconds of lunges, a 15 second break, and then 45 seconds of another exercise); and (3) complete the exercises with a deck of cards, adding a cognitively demanding element on top of an already physically demanding task. In the “Deck of Cards” part of the study, the instructor assigns each one of the four exercises to a card suit, which participants are asked to remember and recall later. The instructor then flips a card from the deck. The card's suit determines the exercise, and the card's value specifies the number of repetitions. For example, if a lunge was assigned to a heart suit and 10 hearts were pulled, the participant would complete 10 lunges.

Physical Activity Measures

Godin-Shephard Leisure-Time Exercise Questionnaire (GLTEQ)

The GLTEQ is a widely used self-report physical activity instrument that assesses weekly frequencies of strenuous- (i.e., heartbeats rapidly, e.g., running, jogging, hockey, football, and others), moderate- (i.e., not exhausting, e.g., fast walking, easy bicycling, badminton, and others); and (3) mild/light- (i.e., minimal effort, e.g., bowling, golf, easy walking, and others) intensity activities completed for more than 15 minutes at a time during a typical 7 day period (Godin & Shephard, 1997; Godin, 2011). Next, each frequency score is then multiplied by a corresponding Metabolic Equivalent of Task (MET) value (9, 5, and 3, respectively). Those values are then summed to obtain a total leisure activity score which is interpreted as follows: (1) 24 units or more: Active; (2) 14 to 24 units: Moderately active; and (3) less than 14 units: Insufficiently active (Amireault & Godin, 2015).

However, it has been recommended to only use the moderate and strenuous components of the GLTEQ to compute a Health Contribution Score (i.e., the frequency of moderate-intensity activity multiplied by 5 plus the frequency of vigorous activity multiplied by 9), arguing that activities listed in the 'mild' intensity category (e.g., walking and golf) are not significant contributors to health or fitness benefits (Godin, 2011, p. 19). Both weekly frequency and energy expenditure from moderate-to-vigorous physical activity associated with health and fitness benefits were considered when selecting the cutoff differentiating active and insufficiently active scores (Amireault & Godin, 2015). Individuals who scored a Health Contribution Score of 24 units or more would likely meet the physical activity guidelines (i.e., ≥ 150 minutes of MPA per week), and therefore, should be classified as ‘active’; in contrast, individuals who scored 23 units or less were unlikely to meet with physical activity guidelines, and therefore, should be classified as ‘insufficiently active’ (see Amireault & Godin, 2015, p. 3). In the current study, individuals with a Health Contribution Score of 23 units or less were eligible to participate.

EMA Daily Diary

Physical activity was measured once a day in the evening burst survey. While still a part of the EMA survey administered via the *Ethica Data* app, physical activity was measured utilizing a daily diary method (i.e., an assessment frequency of once per day that employs a retrospective coverage strategy; Shiffman, Stone, & Hufford, 2008, p. 17); whereas the other psychosocial variables used an EMA method assessing current state (see *Psychosocial Measures* described below).

Participants were prompted to reflect on their activity over the course of the day. Next, they were asked to enter the number of hours they spent engaging in (1) sedentary (e.g., no effort, such as watching TV, sitting, reading a book); (2) light (e.g., minimal effort with normal breathing and regular movement, such as walking, golfing, cleaning, etc.); (3) moderate (e.g., moderate effort with increased breathing and quicker movements, such as fast walking, casual biking, etc.); and (4) hard/vigorous (e.g., effortful, with heard breathing and quick, fast movements such as running, fast-paced sports, aerobic classes, etc.) activity; the EMA items are available in Appendix A). The various descriptions of activity intensity were adapted from the GLTEQ described above. The hours increased by 0.5 hour increments (e.g., 0.5 hours = 30 minutes) in the *Ethica Data* app.

As mentioned earlier, the WHO (2010) recommends that older adults should perform at least 150 minutes of moderate-intensity aerobic physical activity, 75 minutes of vigorous-intensity aerobic activity (2x the effort of moderate-intensity), or an equivalent combination of moderate and vigorous-intensity aerobic activity per week. Therefore, the current study calculated an MPA value by multiplying the number of hours spent in vigorous-intensity activity by 2 and then summing this value with the number of hours spent in moderate-intensity activity:

Moderate-intensity (or equivalent) physical activity in hours per week =

*Vigorous-intensity*2 + Moderate-intensity*

The final value can be interpreted as the total number of hours each participant spent in MPA per burst.

Psychosocial Measures

Depressive Symptoms and Social Isolation

The National Institutes of Health Patient-Reported Outcomes Measurement Information System (PROMIS) adult depression and social isolation short-form instruments, consisting of 4-items each, were used to measure each construct, respectively. PROMIS originates from large item banks that measure a plethora of patient-reported outcomes; the correlations between the short-form version (4-item) and the entire item banks for depression and social isolation are all above .90 (Cella, Choi, Condon, Schalet, Hays, & Rothrock, 2019), demonstrating good psychometric properties which have been rigorously tested (Moore, Depp, Wetherell & Lenze, 2016; Cella et al., 2019). Additionally, both the 4-item depression (Cronbach's α = .93; Kroenke, Yu, Wu, Kean & Monahan, 2014) and social isolation (Cronbach's α = .88; Greenberg, Mace, Popok, Kulich, Patel, Burns et al., 2020) scales demonstrate good internal reliability (i.e., Cronbach's α > 0.80).

For both constructs, participants were instructed to rate their feelings in the past 15 minutes on a 5-point scale ranging from 1 = *Not at all* to 5 = *Very much*. Similar to a study by Moore et al. (2016), the frame of reference in the PROMIS scales were adapted to reflect one's state in the past 15 minutes, as opposed to summarizing their feelings of depressive symptoms and social isolation over the past 7 days as instructed by the original scales. For example, the PROMIS item "In the past 7 days I felt hopeless" from 1 = *Never* to 5 = *Always* was adapted to state: "In the past 15 minutes I felt hopeless" from 1 = *Not at all* to 5 = *Very much* (see adapted PROMIS items in Appendix A). Higher scores in the depression and social isolation scales reflect poorer outcomes (i.e., worse depressive symptoms and social isolation). Depressive symptoms and social isolation were assessed twice a day during each 7 day measurement burst. The depressive symptom and social isolation scores were aggregated at each measurement burst.

COVID-19 Stress

Stress specifically related to COVID-19 was measured twice a day during each 7 day measurement burst. The single survey item asks the participants how stressed they currently are about COVID-19 (see Appendix A). The item is rated on a 10-point slide scale ranging from 1 = *Not at all stressed* to 10 = *Extremely stressed*. COVID-19 stress ratings were aggregated at each measurement burst.

Additional Predictors

Time

Time was captured by measurement burst (0, 1, 2). All variables were measured across three measurement bursts except for age, sex, and group assignment (see Table 1 above for reference).

Demographics

Using Qualtrics, demographic variables were captured in the baseline assessment, and age and sex were used as level-2 predictors.

Analysis Strategy

Longitudinal repeated measurement designs are examples of a nested dataset where repeated measurements (i.e., the level-1 units) are nested within individuals (i.e., the level-2 units; Peugh, 2009, p. 100). An issue with nested data structures is that they violate the independence assumption necessary for traditional statistical analyses such as ANOVAs (Analysis of Variance) and ordinary least-squares multiple regression (Peugh, 2009, p. 86). The response variable scores of a given individual are likely to be more correlated than to the scores of other individuals; for example, students' scores from the same school are likely to be more correlated than students' scores from different schools because they share the same environment or, in other words, are nested within the same context (Peugh, 2009). Violating the independence assumption in traditional analyses can inflate Type I errors and bias parameter estimates. Multilevel models, a powerful statistical model with the capability of separating multiple sources of variation that may be present due to dependencies (e.g., nestedness) in data, control for such violations.

Multilevel modelling (Raudenbush & Bryk, 2002) was applied to examine associations between changes in MPA and changes in psychosocial factors over the *eFIT* exercise training program over time, between the Active and Waitlist Control groups. These multilevel models allowed for simultaneous assessment of the within-person variation in predictor variables (level-1) and between-person differences in predictor variables (level-2) on MPA and depressive symptoms. As previously mentioned, the daily measures of MPA, depressive symptoms, social isolation, and COVID-19 stress captured by EMA were aggregated to generate a burst-level score. Therefore, changes in MPA and psychosocial factors are examined across bursts.

With MPA as the dependent variable, time, and within-person and between-person psychosocial factors (depressive symptoms, social isolation, and COVID-19 stress), group assignment (Active or Waitlist Control), and demographic (age and sex) predictors were added to the model. The models examined the average change in MPA across the three bursts (fixed slope effects) and whether trajectories of change varied across individuals (random slope coefficients). With depressive symptoms as the dependent variable, time, MPA, psychosocial variables (social isolation and COVID-19 stress), group assignment (Active or Waitlist Control), and demographic (age and sex) predictors were added to the model. The models examined the average change in depressive symptoms across the three bursts (fixed slope effects) and whether trajectories of change varied across individuals (random slope coefficients).

The models described above were fit using the *nlme* package in R Version 1.2 1335 (R Core Team, 2018). A *p*-value of < 0.05 was considered statistically significant. Parameters in these models were estimated with full information maximum likelihood (FIML) for robust standard errors. FIML estimation enables researchers to use available data instead of implementing listwise deletion or imputation; it assumes that the multilevel model regression coefficients are known population parameters, adding no additional parameters to be estimated (Peugh, 2009).

Data management, cleaning, restructuring, descriptive statistics, assessment of data missing completely at random (MCAR), and outlier detection (e.g., univariate boxplots, minimum/maximum scores input errors) were also performed in R Version 1.2 1335 (R Core Team, 2018). The MCAR assumption was empirically tested using Little's MCAR test (Little, 1988). A nonsignificant result (p > 0 .05) suggests that the missing values are MCAR (i.e., there is no relationship between data missingness and the variables in the data set). Patterns of missing data were examined prior to completing primary analyses.

Overview of Models

Unconditional Means Model

Multilevel modelling was used to fit unconditional means models with MPA and depressive symptoms as the dependent variable. The unconditional means models were analyzed to (1) confirm that multilevel modelling analyses are appropriate for this dataset by calculating the Intraclass Correlation Coefficient (ICC); and (2) determine the variance decomposition across participants' MPA and depressive symptoms (Garson, 2008).

The ICC is an estimate of the proportion of variance in the dependent variable that is between-person versus the total variation present (Finch et al., 2014); it is calculated by dividing the between-person variance (σ^2_0) by the total variance ($\sigma^2_0 + \tau^2_0$). It ranges from 0 to 1, with higher values indicating greater variation between-persons (level-2; Finch et al., 2014). Finally, ICC values that exceed .40 are common in longitudinal social research studies (Peugh, 2009, p. 102).

Conditioned on Time, Group, Sex, and Age

Multilevel models were fit to estimate MPA and depressive symptoms, controlling for time (burst 0, 1, 2), group assignment (Active or Waitlist Control), sex (female or male), and age. MPA and depressive symptoms were measured daily with EMA and were aggregated to capture a burst-level score. The changes in MPA and depressive symptoms were examined across bursts. As presented in Table 1, the bursts represent specific time points during the exercise training program.

Comparing changes in MPA and depressive symptoms across bursts, controlling for group assignment, enables the examination of the effectiveness of the exercise training program. For example, significant changes in MPA across bursts in the Active group suggest adherence to the exercise training program. More specifically, a substantial increase in MPA between burst 0 and burst 1 reflects study fidelity. A significant increase between burst 0 and burst 2 indicates that participants remained more active than their baseline assessment, even after the exercise training program concluded.

Finally, changes in depressive symptoms are examined across bursts as well. Physical activity research demonstrates that increased physical activity is associated with fewer depressive symptoms. Therefore, the current study hypothesized that the Active group's depressive symptoms would improve across bursts 1 and 2 compared to burst 0, assuming they completed the exercise training program. Multilevel models were fit to estimate the time-varying covariation of MPA on depressive symptoms and depressive symptoms on MPA to examine this relationship more closely.

Time-Varying Covariation Models

Finally, multilevel models were fit to estimate time-varying covariation of within- and between-person depressive symptoms, COVID-19 stress, and social isolation on MPA. Multilevel models were also fit to assess time-varying covariation within- and between-person MPA, COVID-19 stress, and social isolation on depressive symptoms.

Multilevel models with time-varying predictors enable a better understanding of within-person change and the relationships between variables over time (Kowalski, MacDonald, Yeates, Tuokko, & Rhodes, 2018). The level-1 predictor variables were person-mean centered, allowing for the examination of within-person change across bursts. Further, including the level-2 predictor variables into the model enables examination of between-person change across bursts. Kowalski et al. (2018) recommend distinguishing within- from between-person variance in statistical models to understand predictors' distinct sources of influence on outcome variables.

As mentioned previously, examining change MPA and depressive symptoms across bursts affords claims to be made regarding distinctive time-points during the exercise training program (see Table 1 for reference). Disentangling the within- from between-person sources of variance affords examination of both intraindividual and interindividual change across bursts, respectively. Linking back to the previous example, a participant may feel less or more depressed during bursts when they complete more or less MPA than their average MPA level measured across bursts, respectively. Finally, the level-2 model can inform whether individuals reporting higher or lower MPA also report lower or higher depressive symptoms across the bursts, respectively.

Results

Between-person intercorrelations with confidence intervals of the aggregated burst variables are presented in Table 2. Means, standard deviations, medians, range, and minimum and maximum scores for the aggregated burst variables are presented in Table 3. Little's MCAR test determined that data was MCAR ($\chi 2$ (30) = 35.070, p= 0.240), demonstrating no relationship between data missingness and the variables measured. The aggregation of variables across bursts is also advantageous in terms of data missingness; as such, only 2.2% of the data was missing.

Figure 3 shows histograms representing the GLTEQ Health Contribution Scores and MPA hours during the first measurement burst. The modes of the GLTEQ screener assessment and MPA at baseline were both 0. Of the total sample (N= 85), 38% of the participants completed less than 150 minutes of MPA during the first measurement burst.

The multilevel models fit to estimate MPA, and depressive symptoms followed the same sequence: (1) unconditional means models; (2) MPA and depressive symptoms controlled for time, group, age, and sex; and (3) time-varying covariation of psychosocial factors on MPA and depressive symptoms. Therefore, MPA and depressive symptoms will be discussed separately at each stage of model fitting, and the results are separated into two tables: MPA in Table 4 and depressive symptoms in Table 5. The final estimation of the fixed effects includes robust standard errors.

Table 2

Between-Person Intercorrelations with Confidence Intervals of Aggregated Burst Variables

Variable	1	2	3	4	5	6	7	8
1. Time								
2. GLTEQ	-.05 [-.19, .09]							
3. MPA	.06 [-.07, .20]	.12 [-.03, .26]						
4. Depressive symptoms	.06 [-.08, .19]	-.15* [-.29, -.01]	-.10 [-.24, .03]					
5. Social isolation	.03 [-.10, .17]	-.15* [-.29, -.00]	-.11 [-.24, .02]	.73** [.66, .79]				
6. COVID-19 stress	-.06 [-.19, .08]	-.16* [-.29, -.01]	.01 [-.12, .15]	.34** [.21, .45]	.42** [.31, .53]			
7. Age	-.05 [-.19, .10]	-.06 [-.21, .09]	.04 [-.10, .18]	-.06 [-.20, .08]	-.12 [-.26, .02]	-.12 [-.26, .02]		
8. Sex	.05 [-.09, .19]	-.32** [-.45, -.18]	-.18* [-.32, -.04]	.00 [-.14, .15]	-.03 [-.17, .11]	-.14 [-.28, .00]	.19** [.05, .33]	
9. Group	-.04 [-.18, .10]	-.06 [-.21, .08]	.13 [-.01, .26]	-.20** [-.32, -.06]	-.17* [-.30, -.03]	.01 [-.12, .15]	-.04 [-.18, .10]	.01 [-.14, .15]

Note. Values in square brackets indicate the 95% confidence interval for each correlation. The confidence interval is a plausible range of population correlations that could have caused the sample correlation (Cumming, 2014). * indicates $p < .05$. ** indicates $p < .01$. Time = burst; GLTEQ = Godin-Shepard Leisure Time Questionnaire Health Contribution Score; MPA = Total hours spent in moderate-intensity (or equivalent) physical activity per burst; Sex: Female = 0, Male = 1; Group: Waitlist Control =0, Active =1

Table 3

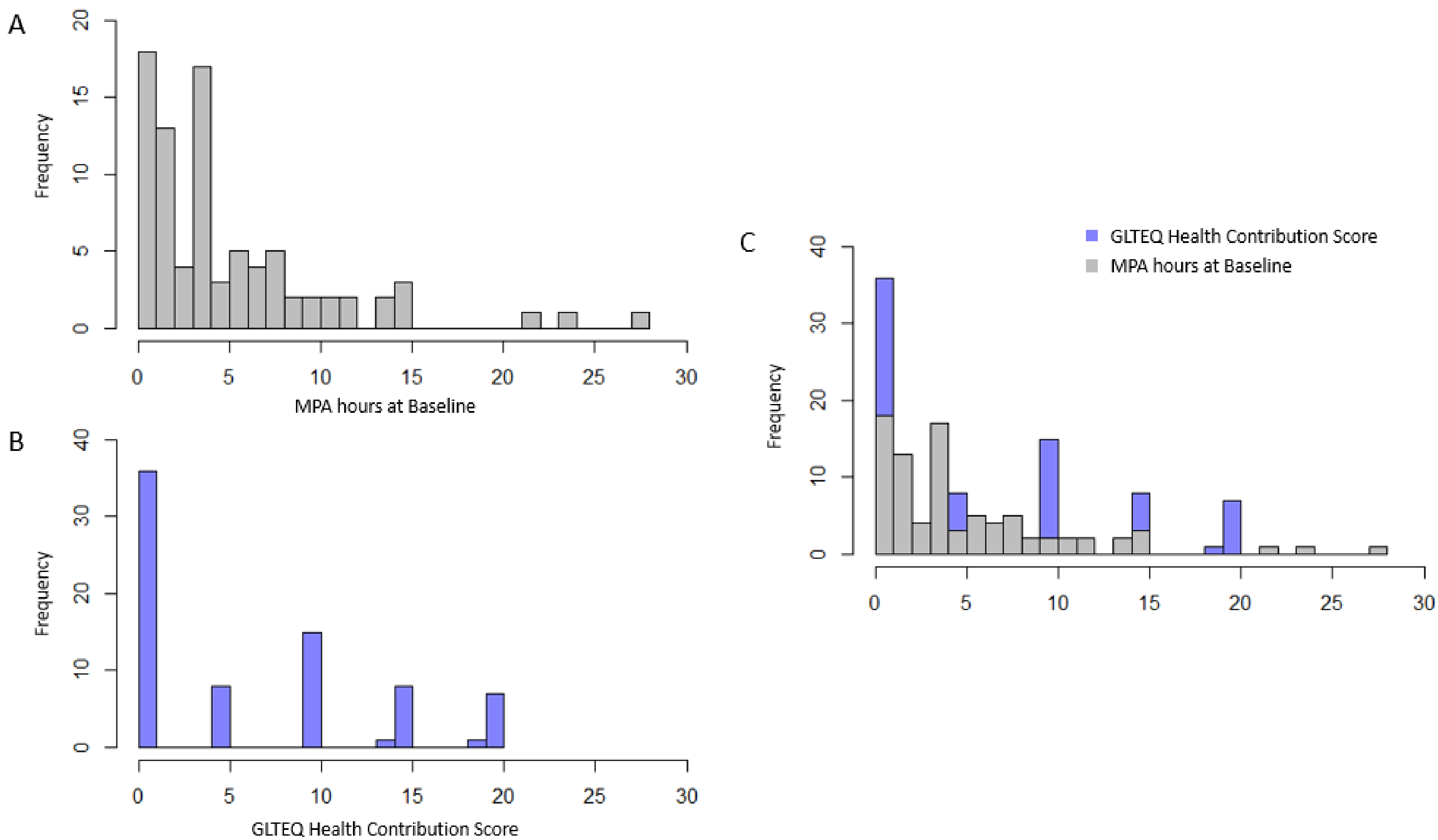
Means, Standard Deviations, Medians, Range, and Minimum and Maximum Values

Variable	Mean (SD)	Median	Range	Min.	Max.
GLTEQ	6.36 (7.11)	5.00	0 - 23	0	20
MPA	5.17 (5.41)	3.50	≥ 0	0	27.50
Depressive symptoms	4.69 (1.47)	4.00	4 - 20	4	12.43
Social isolation	5.36 (2.64)	4.17	4 - 20	4	18.57
COVID-19 stress	2.82 (1.96)	2.17	1 - 10	1	8.71
Age	68.92 (3.67)	68.00	≥ 65	65	81

Note. GLTEQ = Godin-Shepard Leisure Time Questionnaire Health Contribution Score; MPA = Total hours spent in moderate-intensity (or equivalent) physical activity per burst

Figure 3

Frequency of MPA Hours Measured in the Screener Assessment and Baseline Measurement Burst



Note. The histograms above represent the frequencies of (A) MPA hours measured at baseline (first measurement burst); (B) Health Contribution Scores calculated with the GLTEQ from the screener assessment; and (C) overlapping Figures 3A and 3B.

Model 1: Unconditional Means Model

First, unconditional means models were fit with MPA and depressive symptoms as outcomes, separately. The unconditional means model enables the decomposition of within- and between-person variance on the dependent variables, which can then be used to calculate the ICC. The unconditional means model is as follows (Peugh, 2009; Singer & Willet, 2003):

Level 1: $$Y_{ti} = \beta_{0i} + r_{ti} \quad (1a)$$

Where Y_{ti} is either MPA or depressive symptoms for participant *i* on time *t*; β_{0i} is the mean-level for participant *i*, across the three measurement bursts; plus r_{ti}, a residual within-person variance term that reflects the differences between participant *i*'s observed and predicted MPA or depressive symptoms (i.e., fluctuations around their personal mean).

Level 2: $$\beta_{0i} = \gamma_{00} + u_{0i} \quad (1b)$$

Where γ_{00} is the grand-mean MPA or depressive symptoms (i.e., a fixed effect of mean), plus a term, u_{0i}, which represents person-specific deviations of participant *i*'s mean from the grand-mean (i.e., between-person variability; Peugh, 2009, p. 101).

First, the ICC was calculated and demonstrated that 52% of the total variance in MPA was within-persons and 48% was between-persons. While almost equally proportionate, the partitioning of variance suggests that participants' MPA varied less from one another (i.e., less interindividual variability) and more within themselves (i.e., greater intraindividual variability). Next, the ICC was calculated from the unconditional means model predicting depressive symptoms and demonstrated that 29% of the total variance in depressive symptoms was within-persons and 71% was between-persons. This suggests that participants' depressive symptoms varied more from one another (i.e., greater interindividual variability) than from within themselves (i.e., less intraindividual variability). Finally, the ICC values of each unconditional means model demonstrate nestedness within the dataset, violating the assumption of independence for ordinary-least squares analyses, and warrants the use of multilevel modelling.

MPA

Y_{ti} is the total MPA hours for person *i* on time *t; t* refers to time (bursts; level-1 units) obtained from *i* participants (level-2 units) over time (Peugh, 2009, p. 101). The results from the unconditional means model estimating MPA are presented in Table 4, Model 1. As seen in Table 4, results showed that participants' mean MPA (i.e., the average MPA hours across all measurement bursts) significantly varied around the grand mean (i.e., between-persons), and there were significant differences between participant *i*'s observed and predicted MPA (i.e., within-persons; *ps* < 0.0001). Figure 4 represents the between- and within-persons variability in MPA across the three measurement bursts.

Figure 4

Between- and Within-Person Variability in MPA Hours over Three Measurement Bursts

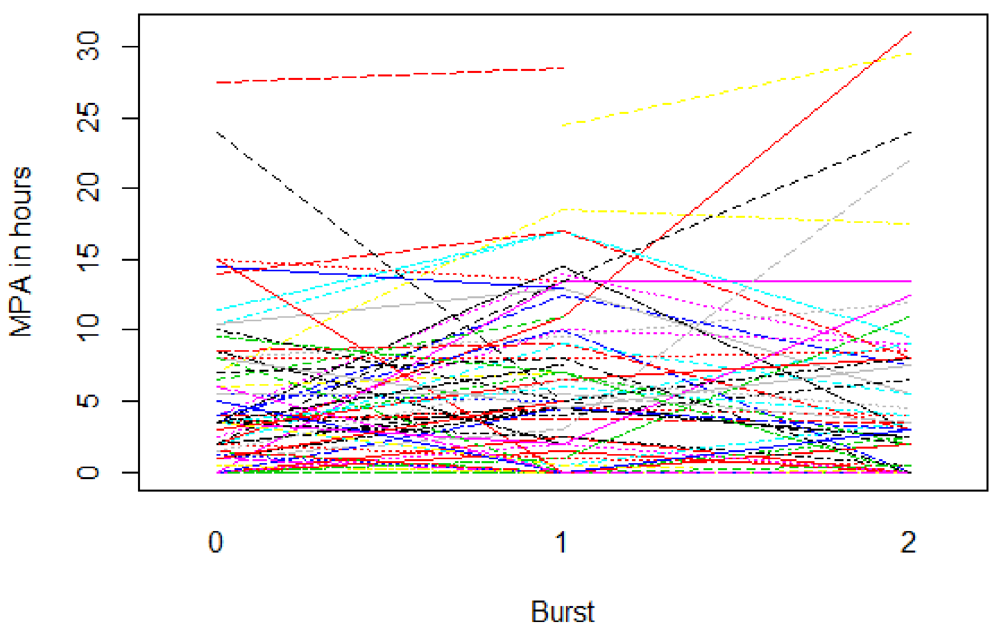


Table 4

Multilevel Model Analyses of the Associations of Time, Group, and Psychosocial and Demographic Covariates on MPA

	Estimate	*SE*	*SD*	*p*	*95% CI*	
					Lower	Upper
Model 1						
Regression coefficient - Fixed effects						
Intercept (MPA; γ_{00})	6.021***	0.577	-	0.000	4.881	7.161
Variance components - Random effects						
Intercept (BP; τ_{00})	19.085***	-	4.369	<0.001	3.445	5.540
Residual (WP; σ^2_0)	20.400***	-	4.517	<0.001	3.976	5.131
Model 2						
Regression coefficient - Fixed effects						
Intercept (γ_{00})	5.094***	1.011	-	0.000	3.132	7.057
Time (γ_{10})	-0.023	0.895	-	0.979	-1.756	1.713
Group (γ_{01})	-0.286	1.069	-	0.790	-2.371	1.799
Sex (γ_{02})	-4.079**	1.300	-	0.002	-6.616	-1.544
Age (γ_{03})	0.321*	0.148	-	0.033	0.032	0.610
Time x Group (γ_{11})	1.956*	0.960	-	0.044	0.094	3.817
Time x Sex (γ_{12})	1.082	1.132	-	0.346	-1.124	3.268
Time x Age (γ_{13})	-0.116	0.145	-	0.427	-0.399	0.166
Variance components – Random effects						
Intercept (BP; τ_{00})	11.073***	-	3.328	<0.001	2.345	4.721
Residual (WP; σ^2_0)	11.381***	-	3.374	<0.001	2.808	4.052
Slope (τ_{11})	6.657***	-	2.580	<0.001	1.759	3.784
Model 3						
Regression coefficient - Fixed effects						
Intercept (γ_{00})	5.360***	0.595	-	0.000	4.205	6.515
BP Depressive symptoms (γ_{01})	0.077	0.576	-	0.894	-1.041	1.195
BP COVID-19 stress (γ_{02})	0.127	0.323	-	0.697	-0.501	0.754

BP Social isolation (γ_{03})	-0.487	0.344	-	0.160	-1.156	0.181
Time (γ_{10})	0.787	0.505	-	0.122	-0.195	1.769
WP Depressive symptoms (γ_{20})	0.226	0.726	-	0.756	-1.183	1.636
WP COVID-19 stress (γ_{30})	0.484	0.632	-	0.445	-0.742	1.711
WP Social isolation (γ_{40})	0.209	0.481	-	0.665	-0.726	1.144
Variance components – Random effects						
Intercept (BP; τ_{00})	17.528***	-	4.187	<0.001	3.173	5.524
Residual (WP; σ^2_0)	12.088***	-	3.477	<0.001	2.891	4.181
Slope (τ_{11})	8.807***	-	2.968	<0.001	2.079	4.236

† *p* <0.10; **p* <0.05; ***p* <0.01; ****p* <0.001; *SE* = robust standard errors; MPA = moderate-intensity (or equivalent) physical activity; WP = within-person; BP = between-person; 95% CI: lower 95% confidence interval; upper 95% confidence interval

Depressive Symptoms

Y_{ti} is the aggregate depressive symptoms score for person *i* on time *t; t* refers to time (bursts; level-1 units) obtained from *i* participants (level-2 units) over time (Peugh, 2009, p. 101). The results from the unconditional means model predicting depressive symptoms are presented in Table 5, Model 1. As seen in Table 5, results showed that participants' mean depressive symptom score (i.e., the average depressive symptom score across all measurement bursts) significantly varied around the grand mean (i.e., between-persons), and there were significant differences between participant *i*'s observed and predicted depressive symptom scores (i.e., within-persons; *ps* < 0.0001; see the between- and within-persons variability in depressive symptoms across the three measurement bursts in Figure 5).

Figure 5

Between- and Within-Person Variability in Aggregate Depressive Symptom Scores across Three Measurement Bursts

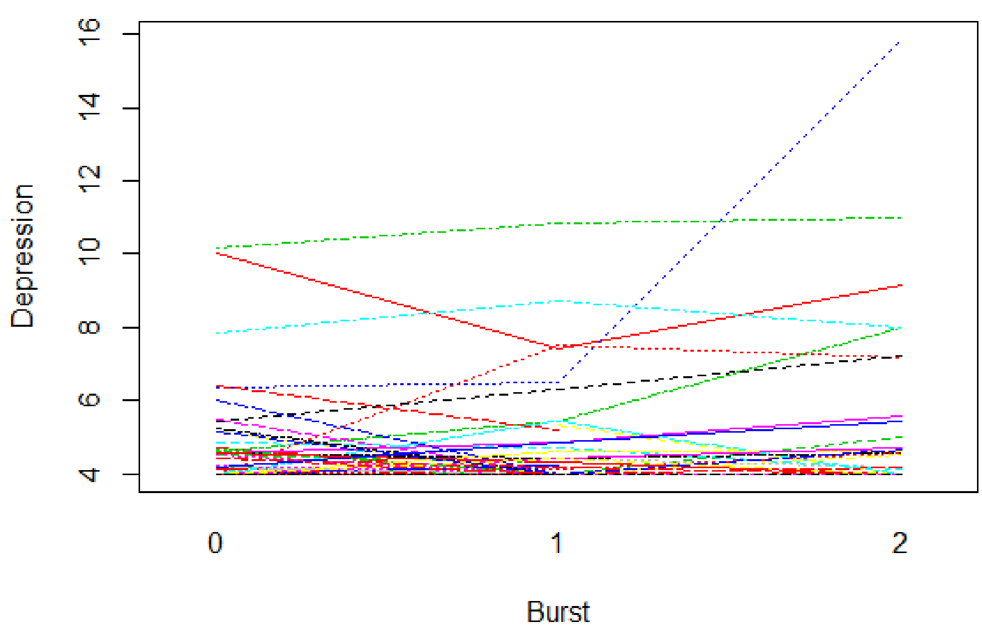


Table 5

Multilevel Model Analyses of the Associations of MPA, Time, Group, and Psychosocial and Demographic Covariates on Depressive Symptoms

	Estimate	*SE*	*SD*	*p*	*95% CI*	
					Lower	Upper
Model 1						
Regression coefficient - Fixed effects						
Intercept (Depressive symptoms; γ_{00})	4.724^{***}	0.161	-	0.000	4.405	5.042
Variance components - Random effects						
Intercept (BP; τ_{00})	1.859^{***}	-	1.364	<0.001	1.142	1.628
Residual (WP; σ^2_0)	0.767^{***}	-	0.876	<0.001	0.773	0.992
Model 2						
Regression coefficient - Fixed effects						
Intercept (γ_{00})	5.094^{***}	0.315	-	0.000	4.484	5.705
Time (γ_{10})	$0.356^{\dagger}$	0.190	-	0.064	-0.013	0.724
Group (γ_{01})	$-0.579^{\dagger}$	0.332	-	0.086	-1.227	0.069
Sex (γ_{02})	-0.154	0.405	-	0.705	-0.944	0.636
Age (γ_{03})	-0.007	0.046	-	0.878	-0.097	0.083
Time x Group (γ_{11})	-0.307	0.204	-	0.134	-0.702	0.088
Time x Sex (γ_{12})	0.179	0.240	-	0.458	-0.287	0.646
Time x Age (γ_{13})	-0.043	0.031	-	0.170	-0.103	0.017
Variance components – Random effects						
Intercept (BP; τ_{00})	1.923^{***}	-	1.387	<0.001	1.017	1.500
Residual (WP; σ^2_0)	0.148^{***}	-	0.385	<0.001	0.551	0.789
Slope (τ_{11})	0.393^{***}	-	0.627	<0.001	0.412	0.779
Model 3						
Regression coefficient - Fixed effects						
Intercept (γ_{00})	4.722^{***}	0.101	-	0.000	4.526	4.918
BP MPA (γ_{01})	0.013	0.018	-	0.470	-0.021	0.047
BP COVID-19 stress (γ_{02})	-0.006	0.055	-	0.919	-0.113	0.102

BP Social isolation (γ_{03})	0.446***	0.041	-	0.000	0.365	0.526
Time (γ_{10})	0.011	0.091	-	0.903	-0.166	0.189
WP MPA (γ_{20})	-0.009	0.021	-	0.675	-0.051	0.033
WP COVID-19 stress (γ_{30})	-0.232*	0.100	-	0.023	-0.427	-0.037
WP Social isolation (γ_{40})	-0.036	0.064	-	0.580	-0.160	0.089
Variance components – Random effects						
Intercept (BP; τ_{00})	0.594***	-	0.771	<0.001	0.615	0.966
Residual (WP; σ^2_0)	0.251***	-	0.501	<0.001	0.501	0.602
Slope (τ_{11})	0.373***	-	0.611	<0.001	0.476	0.784

† *p* <0.10; **p* <0.05; ***p* <0.01; ****p* <0.001; *SE* = robust standard errors; MPA = moderate-intensity (or equivalent) physical activity; WP = within-person; BP = between-person; 95% CI: lower 95% confidence interval; upper 95% confidence interval

Model 2: Conditioned on Time, Group, Sex, and Age

Time, group, sex, and age were added as level-2 between-person predictors to explain intercept and slope variance in MPA or depressive symptoms between groups. Group assignment was dummy-coded (Waitlist Control = 0, Active = 1) to examine the anticipated differences between the Waitlist Control and Active groups' MPA across bursts. Sex was dummy-coded (female = 0, male = 1) to examine differences in MPA or depressive symptoms between male and female participants. Age was centered at 65; each participant's age was subtracted from 65, establishing a meaningful 0 to improve interpretability (e.g., 65 – 65 = 0; 67 – 65 = 2). Equations 3a-c represent the multilevel models fit to estimate MPA or depressive symptoms are described below:

Level 1:

$$Y_{ti} = \beta_{0i} + \beta_{1i}\,(TIME_{ti}) + r_{ti} \qquad (3a)$$

Level 2:

$$\beta_{0i} = \gamma_{00} + \gamma_{01}\,(\text{GROUP}_i) + \gamma_{02}\,(\text{SEX}_i) + \gamma_{03}\,(\text{AGE}_i) + u_{0i} \qquad (3b)$$

$$\beta_{1i} = \gamma_{10} + \gamma_{11}\,(\text{GROUP}_i) + \gamma_{12}\,(\text{SEX}_i) + \gamma_{13}\,(\text{AGE}_i) + u_{1i} \qquad (3c)$$

The intercept parameter estimate (γ_{00}) is the mean MPA or depressive symptoms score at baseline (burst=0), controlling for group, sex, and age (i.e., group, sex, and age = 0). The slope parameter estimate (γ_{10}) is the average change across bursts of MPA or depressive symptoms, controlling for group, sex, and age. Coefficients γ_{01} through γ_{03} are the effects of group, sex, and age on MPA or depressive symptoms at baseline, respectively (i.e., the average difference for a 1 unit increase in X for burst=0). The cross-level interaction coefficients, γ_{11} through γ_{13} represent the effects of group, sex, and age on the time slope of MPA or depressive symptoms (i.e., the average difference for a 1-unit increase in X per unit increase in time); and u_{0i} and u_{1i} represent individual variations from average intercepts and slopes (i.e., the random effects).

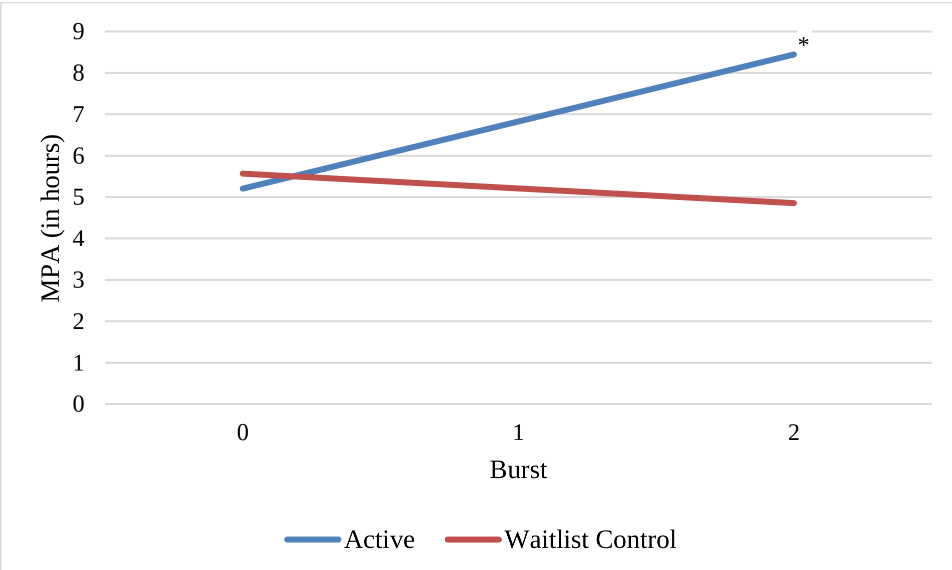
MPA over Time Controlled for Group, Sex, and Age

The results of the multilevel models fit to estimate changes in MPA across bursts, controlling for group, sex, and age, are presented in Table 4, Model 2. Results showed that there were no significant differences in MPA between the Active and Waitlist Controls at baseline (p=0.790), as anticipated given the study's RCT design; however, the cross-level interaction of group and time showed there was a significant direct association between group assignment and MPA over time ($\gamma_{11} = 1.956$, $p = 0.044$), indicating that the Active group completed MPA for nearly 2 more hours per increase in burst than the Waitlist Control group. As presented in Figure 6, the Active group does not significantly differ from the Waitlist Control group at baseline, but their MPA significantly increases over the course of the study compared to the Waitlist Controls.

Additionally, post-hoc t-tests were analyzed to determine if the differences between the Active and Waitlist Control groups' MPA were significant at burst=1 and burst=2; results indicate that the Active group (M = 7.96 hours) did complete significantly more MPA at burst=2 (p = 0.036) than the Waitlist Control group (M = 3.91 hours) but the differences in MPA at burst=1 were not significant (p = 0.095).

Figure 6

Active vs. Waitlist Control Group: MPA Hours across Three Measurement Bursts

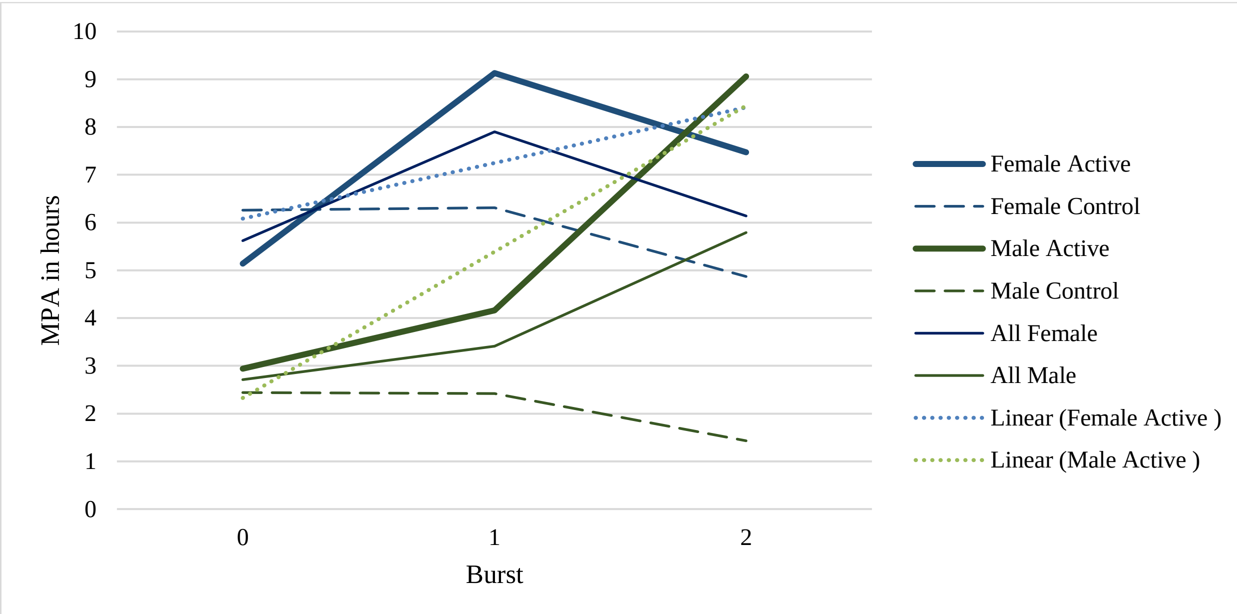


Note. Active (1) versus Waitlist Control (0) group: MPA hours across 3 bursts; * $p < 0.05$.

Furthermore, results also showed that sex was a significant predictor of MPA at baseline (γ_{02} = -4.079; *p*=0.002), such that female participants reported approximately 4 more hours of MPA than male participants during the first measurement burst. The interaction between sex and time did not significantly predict MPA (*p*= 0.306). Figure 7 represents the mean MPA for male and female Active and Waitlist Controls over time. Post-hoc t-tests were performed to determine if the differences between the female and male participants' MPA were significant at burst=1 and burst=2; results indicate that female participants (*M* = 7.90 hours) did complete significantly more MPA at burst=1 (*p* = 0.017) than the male participants (*M* = 3.41 hours). The difference in MPA between females (*M* = 6.14 hours) and males (*M* = 5.79 hours) at burst=2 was not significant (*p* = 0.881).

Figure 7

MPA Means per Measurement Burst based on Group and Sex



Note. The mean MPA (in hours) between female and male participants in the Active and Waitlist Control group over three measurement bursts.

Age was also a significant predictor of MPA at baseline (γ_{02} = 0.321; p=0.032), demonstrating that MPA increased by approximately 18 minutes (0.3 hours) per 1 year increase in age from 65 years old, which was centered at 0. For example, the estimated MPA for a 66 year old participant at baseline would be ([5.094 + 0.321] = 5.415 hours) 5 hours and 25 minutes. The interaction between age and time did not significantly predict MPA (p= 0.374).

Moreover, between-person, within-person, and slope variance component estimates were significant (ps < 0.0001). Pseudo-R^2 (i.e., an effect size statistic quantifying the proportional reduction in level-1 and level-2 variance) was calculated for significant predictors (Peugh, 2009, p. 107). Pseudo-R^2 was computed to calculate the proportional reduction in slope variance by comparing the slope variance estimates from the linear time model (Model 2) and the current time-by-group assignment model. Results showed level-2 slope variance decreased by 11% after adding the time-by-group interaction to the level-2 slope model. Additionally, results from pseudo-R^2 computations calculating between-person variance for sex and age showed level-2 between-person intercept variance decreased by 15% after adding sex to the level-2 intercept model, and an additional 7% reduction after adding age to the level-2 intercept model.

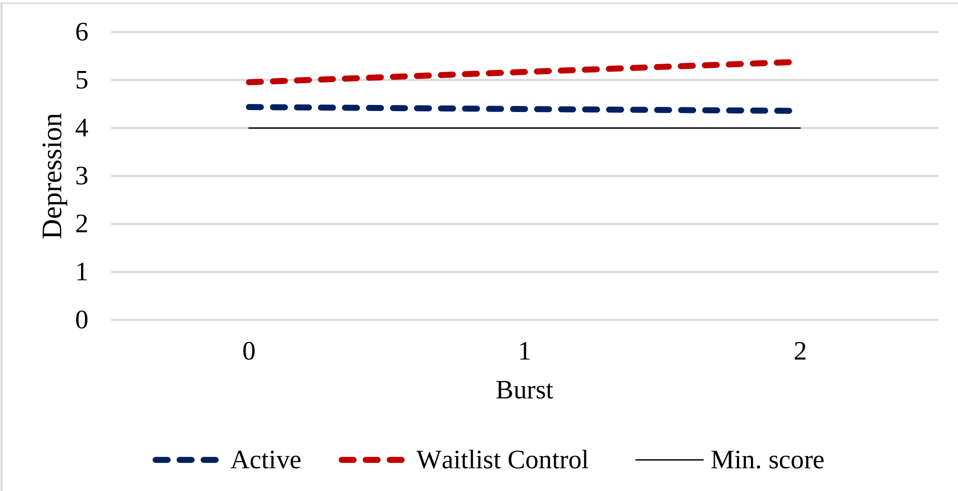
Depressive Symptoms over Time Controlled for Group, Sex, and Age

The results of the multilevel models fit to estimate changes in depressive symptoms, controlling for group, sex, and age, are presented in Table 5, Model 2. Results showed no significant differences in depressive symptoms at baseline based on group assignment, sex, or age ($ps > 0.05$). Additionally, the cross-level interactions between group assignment and time, sex and time, and age and time were not significant ($ps > 0.05$).

As presented in Figure 8, there are no significant group differences in aggregate depressive symptoms scores at baseline or over time; additionally, both groups approximate the minimum score (possible range: 4 to 20). Finally, ad-hoc t-tests were performed and determined that there were no significant differences between groups' aggregate depressive symptoms scores at burst =2 (i.e., immediately post-training; t (53) = 1.58, p = 0.119).

Figure 8

Active vs. Waitlist Control Group: Aggregate Depressive Symptom Scores across Three Measurement Bursts



Model 3: Time-Varying Covariation

Finally, multilevel models were estimated to examine whether psychosocial factors (COVID-19 stress and social isolation) showed significant time-varying covariation with MPA or depressive symptoms. Level-1 psychosocial estimates were person-mean centered (i.e., aggregate value at each burst minus the participant's average level across all measurement bursts), such that level-1 psychosocial parameter estimates represent the effect of variation around each participant's own mean social isolation and COVID-19 stress on MPA or depressive symptom outcomes (within-person effect; Kowalski et al., 2018). Additionally, MPA was person-mean centered and added as a level-1 predictor to the multilevel model estimating depressive symptoms; and depressive symptom scores were person-mean centered and added as a level-1 predictor to the multilevel model estimating MPA.

The multilevel model fit to estimate time-varying covariation of depressive symptoms, COVID-19 stress, and social isolation on MPA is described below in equations 5a – 5f (*note*: the multilevel model fit to estimate time-varying MPA, COVID-19 stress, and social isolation on depressive symptoms ($Depression_{ti}$) substituted within-person (WP) MPA at β_{2i} (equation 5a) and between-person (BP) MPA at γ_{01} (equation 5b):

Level 1:

$$MPA_{ti} = \beta_{0i} + \beta_{1i}(TIME_{ti}) + \beta_{2i}(Depression_{ti} - PM\ Depression) + \beta_{3i}(COVID\text{-}19\ stress_{ti} - PM\ COVID\text{-}19\ stress) + \beta_{4i}(Social\ isolation_{ti} - PM\ Social\ isolation) + r_{ti} \quad (5a)$$

Where β_{0i} represents the mean of MPA when time =0 (baseline) for participant i; β_{1i} is the effect (slope) of time on MPA for participant i; β_{2i} - β_{4i} is the effect (slope) of person-mean centered depressive symptoms, COVID-19 stress, and social isolation on MPA for participant i, respectively; Depression/COVID-19 stress/Social isolation$_{ti}$ represents the aggregate depressive symptoms/COVID-19/social isolation score for participant i at time t; PM Depression/COVID-19 stress/Social isolation is participant i's personal-mean; and r_{ti} represents the residual within-person variance in MPA.

Level 2:

$$\beta_{0i} = \gamma_{00} + \gamma_{01}(Depression_{it}) + \gamma_{02}(COVID\text{-}19\ stress_{it}) + \gamma_{03}(Social\ isolation_{it}) + u_{0i} \quad (5b)$$

$$\beta_{1i} = \gamma_{10} + u_{1i} \quad (5c)$$

$$\beta_{2i} = \gamma_{20} + u_{2i} \quad (5d)$$

$$\beta_{3i} = \gamma_{30} + u_{3i} \quad (5e)$$

$$\beta_{4i} = \gamma_{40} + u_{4i} \quad (5f)$$

Where γ_{00} represents the mean MPA at time=0 controlling for depressive symptoms, COVID-19 stress, and social isolation (i.e., a value of depressive symptoms, COVID-19, and social isolation = 0); γ_{10} is the average time slope of MPA; γ_{01} - γ_{03} represents the between-person effect of depressive symptoms, COVID-19 stress, and social isolation on MPA, respectively; γ_{20} - γ_{40}

represents the time-varying effect of depressive symptoms, COVID-19 stress, and social isolation on MPA, respectively (i.e., the predicted MPA during bursts when participants are above/below their personal mean score); u_{0i} represents person-specific deviations of participant *i*'s baseline MPA from the grand-mean (i.e., between-person variability); and u_{0i} through u_{4i} represents variations from participant *i*'s average intercepts and slopes (i.e., random effects).

Time-Varying Covariation: MPA as an Outcome

Results for the time-varying covariation model estimating MPA over time are presented in Table 4, Model 3. Results indicate no significant within-person or between-person effects of depressive symptoms, COVID-19 stress, or social isolation on MPA; additionally, the association between time and MPA was also not significant (*ps* > 0.05).

Time-Varying Covariation: Depressive Symptoms as an Outcome

Results for the time-varying covariation model estimating depressive symptoms over time are presented in Table 5, Model 3. Results showed a significant direct between-person relationship of social isolation and depressive symptoms, such that individuals with higher or lower feelings of social isolation also reported more or less depressive symptoms across the bursts, respectively ($\gamma_{03} = 0.446$; $p < 0.001$). Additionally, results showed a significant inverse within-person association of COVID-19 stress and depressive symptoms ($\gamma_{30} = -0.232$, 446; p =0.023), such that during bursts when participants reported lower or higher COVID-19 stress than typical for them, their depressive symptoms were higher or lower, respectively. There were no significant associations between depressive symptoms and time, between-person COVID-19 stress, within-person social isolation, or within-person and between-person MPA (*ps* > 0.05).

Additionally, between-person, within-person, and slope variance component estimates were significant (*ps* < 0.0001). Pseudo-R^2 results showed level-1 within-person variance decreased by 1% after adding person-mean centered COVID-19 stress to the level-2 model estimating time-varying covariation on depressive symptoms; results also showed level-2 between-person variance decreased by 3% after adding between-person social isolation to the level-2 intercept model estimating depressive symptoms.

Discussion

The impact of physical inactivity on poorer health outcomes, including depression, social isolation, and stress, are well-documented in the literature. Before COVID-19, older age was already a well-known risk factor for physical inactivity, depression, social isolation, and stress (Rhodes et al., 2017; Siegmund et al., 2021). The COVID-19 pandemic disrupted the physical activity routines of many Canadian older adults. Therefore, it is possible that older adults are at a higher risk of feeling depressed, socially isolated, and stressed, which may have been exacerbated by the decline in physical activity since the pandemic. Researchers have highlighted a need for physical activity programs and strategies specific to older adults during the pandemic (Rhodes et al., 2020; Hammami et al., 2020). Filling this gap, the current study developed and implemented a remote exercise training program created specifically for older adults during the COVID-19 pandemic.

The primary aim of the current study was to examine the impact of the *eFIT* exercise training program on the associations between MPA, depressive symptoms, social isolation, and COVID-19 stress in insufficiently active older adults during COVID-19. A longitudinal EMA measurement burst design was employed and captured a more precise 'true' average of older adults' MPA, depressive symptoms, social isolation, and COVID-19 stress across time. The mobile app, *Ethica Data*, allowed the continuation of data collection during the COVID-19 pandemic despite the impact of the pandemic-imposed restrictions disallowing face-to-face data collection.

The current research hypothesized that physical activity would increase in the Active group over time, which would improve depressive symptoms, social isolation, and COVID-19 stress commonly experienced by many older adults during COVID-19. Physical activity in the Waitlist Control group was to remain stable, and thus, physical activity-related improvements to depressive symptoms, social isolation, and COVID-19 stress were not anticipated. Further, the time-varying covariations of depressive symptoms, social isolation, and COVID-19 stress on physical activity were examined. It was hypothesized that depressive symptoms, social isolation, and COVID-19 stress would be inversely associated with physical activity over time. For example, during times when a participant reported better/worse feelings of depressive symptoms, social isolation, and COVID-19 stress compared to their typical state, they would also report increased/decreased MPA. Between-persons, individuals who experienced fewer feelings of depressive symptoms, social isolation, and COVID-19 stress would also report more MPA than others who reported greater feelings of depressive symptoms, social isolation, and COVID-19 stress. Finally, the time-varying covariations of physical activity, social isolation, and COVID-19 stress on depressive symptoms were examined. An inverse association of MPA on depressive symptoms and direct associations of social isolation and COVID-19 stress on depressive symptoms were hypothesized. For example, during times when a participant experienced better/worse feelings of social isolation and COVID-19 stress compared to their typical state, it was expected that they would also report better/worse feelings of depressive symptoms. Between-persons, individuals who reported fewer feelings of social isolation and COVID-19 stress would also experience fewer depressive symptoms than others experiencing higher feelings of social isolation and COVID-19 stress.

Of note, only 38% of participants were insufficiently active (i.e., completed $\leq$ 150 minutes of MPA during the first measurement burst). The current study established its hypotheses with the expectation that the sample would not meet the recommended physical activity guidelines. Therefore, more significant improvements in depressive symptoms, social isolation, and COVID-19 stress would be apparent. This interesting and unexpected outcome may have impacted the interpretation of the current study's results. The results from multilevel analyses support the following conclusions: (1) the Active group completed significantly more MPA than the Waitlist Control group over time, and the Waitlist Control group's physical activity remained stable, demonstrating the effectiveness of the exercising training program; (2) despite this notable difference in MPA, there were no significant differences in depressive symptoms between the groups or within the Active group over time; (3) changes in depressive symptoms, social isolation, and COVID-19 stress within- and between-persons did not impact MPA over time; (4) a direct between-person association of social isolation and depressive symptoms, such that individuals who reported better/worse feelings of social isolation also reported better/worse depressive symptoms; (5) an inverse within-person association of COVID-19 stress on depressive symptoms, such that during bursts when a participant reported better/worse COVID-19 stress than typical for them, their depression were worse/better; (6) sex and age did not significantly predict depressive symptoms; and (7) older female participants completed the most MPA during the first measurement burst.

High MPA at Baseline

As mentioned earlier, individuals were excluded from participating in the study if their GLTEQ Health Contribution Score classified them as 'active' in the screener assessment. Therefore, all recruited participants were classified as insufficiently active by the GLTEQ. The rolling recruitment enabled participants to begin the study typically within a week of passing the screener assessment; this was true for most participants, except a few who requested to delay their start time. Overall, there was very little lag between a participants' classification as 'insufficiently active' by the screener assessment and the EMA daily diary measurement of MPA during the first measurement burst.

Contrary to recent research reporting a reduction in older adults' physical activity engagement during the pandemic (Rhodes et al., 2020), it appears that the current study's participants are not as insufficiently active as expected. Interestingly, the sample's mean MPA measured with EMA during the first week of the study was just over 5 hours; this classifies them 'active' and violates the inclusion criteria (*M* = 5.89; *Mode* = 0; see Table 3 for more descriptive statistics and Figure 3B for a histogram representing MPA at baseline). It is unclear why there is such a discrepancy between the GLTEQ Health Contribution Score classification and the MPA measured with EMA during the first burst. Still, it may be partly attributed to the recall time and biases, a fresh start effect, or reactance to the repetitive nature of the EMA.

Recall and Other Biases

Self-report measures are inherently subject to recall bias, but shorter recall time can reduce recall bias (Knell, Gabriel, Businelle, Shuval, Wetter & Kendzor, 2017; Dunton, 2017). Therefore, the EMA measures of MPA should better approximate participants' physical activity, given that the recall assessment period is shorter than the GLTEQ. In support of this claim, researchers Knell et al. (2017) completed a validation study comparing a continuous accelerometer measure of moderate-to-vigorous physical activity to EMA and traditional self-report instruments with varying periods of assessment including (1) the 'past 24 hours' using EMA; (2) a 'usual week' using the Behavioural Risk Factor Surveillance System; and (3) the 'past 7-days' using the International Physical Activity Questionnaire. Results showed that EMA performed better than the traditional self-report measures in the areas of correlation and agreement, supporting that EMA better approximated the accelerometer measurement of moderate-to-vigorous physical activity.

All measures, including EMA, over-reported moderate-to-vigorous physical activity compared to the accelerometer data, but the amount of over-reporting between tools was substantially different. EMA ('the past 24 hours') indicated over-reporting of an average of 1 hour and 12 minutes per week; the Behavioural Risk Factor Surveillance System ('a usual week') indicated over-reporting of an average of 7 hours and 45 minutes per week; and the International Physical Activity Questionnaire ('past 7-days') indicated over-reporting of an average of 15 hours and 2 minutes per week. Researchers speculate that this discrepancy may be explained by recall but conclude that mobile EMA may be a reasonable alternative to accelerometers (Knell et al., 2017). EMA has better ecological validity and greater measurement precision than retrospective self-report measures (Dunton, 2017). Therefore, the recall time length may explain some discrepancies between self-reporting instruments compared to the accelerometer estimates, supporting that shorter recall time reporting moderate-to-vigorous physical activity is more accurate than self-report instruments than accelerometer data.

However, Knell et al.'s (2017) validation study contradicts the current study's results. Instead of over-reporting MPA in the GLTEQ screener assessment, it appears that the sample may have under-reported given that they met the insufficiently active criteria but completed over 5 hours of MPA during the first measurement burst. Perhaps participant bias contributes to the discrepancy between the moderate-intensity physical activity estimates from the GLTEQ screener and the EMA captured across the measurement bursts. The *eFIT study* recruitment materials (e.g., poster, website, and social media) clearly stated that researchers were seeking individuals who were “looking to be more active” (see Appendix C for the recruitment poster). The current study requested participants to maintain their current physical activity behaviours at baseline. But, perhaps the participants over-reported their physical activity estimates because they believed that researchers were expecting an increase in physical activity throughout the study and inadvertently over-estimated their physical activity during the first measurement burst (Knell et al., 2017). Social desirability bias (i.e., the participant's desire to present the best version of themselves) may also contribute to the potential over-reported MPA, such that the participants over-reported their physical activity to be perceived as active.

Fresh Start Effect

The fresh start effect may have influenced measures of physical activity during the first week of the study. It is a phenomenon whereby people are more likely to engage in aspirational behaviours following temporal landmarks such as calendar cycles (e.g., the start of a new week, month, or year), holidays, and birthdays (see Dai, Milkman, & Riss, 2014). Participants agreed to join the *eFIT* study with the expectation or understanding that they would increase their physical activity behaviours. In the current study, the temporal landmark coincides with the first measurement burst. Therefore, it is conceivable that all participants were more active during the first week than a typical week due to the fresh start effect. Although not significant, the Waitlist Control groups' physical activity decreases over time. In contrast, the Active groups' physical activity significantly increases over time, highlighting that the changes in physical activity occurred as a result of the exercise training program.

Reactance

EMA studies aim to observe behaviour without influencing it. A noted challenge of using EMA in physical activity studies is a potential reaction to survey questions. By nature of the repetitiveness of EMA and measurement burst designs, there is a possibility that being asked about engagement with physical activity repeatedly may have caused participants to think about the behaviour differently or change their behaviour (Dunton, 2017). Based on this theory, participants' physical activity behaviours may have changed due to the repeated EMAs.

Of note, there were no significant group differences in MPA at baseline. However, MPA continually increased across bursts in the Active Group while MPA in the Waitlist Control group showed a non-significant decline in MPA over time. Both groups were repeatedly asked to reflect on their physical activity engagement at the end of each burst survey. The influence of reactance to repeated EMAs would be evident if both groups MPA increased over time due to the repeated physical activity questions at the end of each survey. Given the group differences over time, it is unlikely that participants' physical activity behaviours changed due to the repeated EMAs, and thus the theory of reactance is not supported.

Adherence to the Exercise Training Program

Recent physical activity research has demonstrated that at-home physical activity programs were positively associated with moderate-to-vigorous physical activity completed by older adults during the COVID-19 pandemic (Rhodes et al., 2020). The current study supports this finding, such that results from the multilevel analyses showed that the Active group completed more physical activity than the Waitlist Control group over time, supporting the hypothesis.

Acknowledging that the Waitlist Control groups' physical activity did not increase over time, the changes in the Active group's physical activity indicate adherence to the exercise training program. The fidelity of the exercise training program is likely due to the other known adherence promoting techniques embedded in the macro-study, which include a rewards program, biweekly status reports, routine, weekly goal setting, and flexibility in physical activities (Rhodes et al., 2017; Hancox et al., 2019). The current study's results support the recommendation of previous researchers, such that physical activity programming created for older adults would mitigate the notable reduction in physical activity during the pandemic (Rhodes et al., 2020; Hammami et al., 2020).

Group Differences in Physical Activity and Depressive Symptoms

Physically active individuals generally experience less depression than insufficiently active individuals (Lesser & Nienhuis, 2020); further, regular physical activity is an effective antidepressant (McEwan, 2012). Participants in the Active group were expected to complete 180 minutes of MPA per week over the 8-week exercise training program. Therefore, it was expected that the Active group would be significantly more active than the Waitlist Control group and thus, would report fewer depressive symptoms over time. The Active group completed approximately 2 hours more than the Waitlist Control group over the measurement burst at the midpoint assessment and 4 more hours immediately after the exercise training program concluded. However, although the Active group completed significantly more physical activity than the Waitlist Control group over time, they did not report lower depressive symptom ratings. Thus, the current study's hypothesis was not supported.

Additionally, depressive symptoms remained relatively stable in the Active group despite the increase in physical activity over time; arguably, this is because the sample's average depressive symptom rating was less than 1 unit above the minimum score ([4.69 – 4] = 0.69) at baseline, indicating that there was little room for improvement (e.g., a floor effect). This result aligns with Kanning & Schlicht (2010), who stated that positive mood states are less impacted by physical activity. Considering the high physical activity and low depressive symptom scores at baseline, it is unsurprising that the association between physical activity and depressive symptoms was not significant.

Time-Varying Covariation on Physical Activity and Depressive Symptoms

Previous research has shown that higher depression, social isolation, and stress were associated with reduced physical activity before COVID-19 (Rhodes et al., 2017; Lesser & Nienhuis, 2020) and during COVID-19 (Hammami et al., 2020; Churchill et al., 2021). For example, social distancing behaviours were inversely associated with moderate-to-vigorous physical activity in Canadian adults during the COVID-19 pandemic (Rhodes et al., 2020). The current study hypothesized inverse within- and between-person associations of depressive symptoms, social isolation, and COVID-19 stress on physical activity, such that improved or worsened depressive symptoms, social isolation, and COVID-19 stress would increase or decrease in physical activity over time, respectively. However, the relationships were not significant; thus, the hypothesis was not supported. As mentioned previously, the mean MPA measured at baseline exceeded the WHO's (2010) recommended physical activity guidelines, categorizing the sample as active rather than insufficiently active. Therefore, this result may reflect the positive benefits associated with being active (e.g., less depressed, socially isolated, and stressed), explaining the absence of an effect. In addition to the depressive symptom scores, the perceived floor effect may also influence the impact of social isolation and COVID-19 stress on physical activity and depressive symptoms.

Similar to the depressive symptom scores, the sample's social isolation (M = 5.36; [5.36–4] = 1.36 units) and COVID-19 stress (M = 2.82; [2.82– 1] = 1.82 units) during the first measurement burst approximated each scales' minimum score of 4 and 1, respectively, suggesting a floor effect. However, in support of the hypothesis and alignment with the literature, results from multilevel analyses showed a significant direct between-person association of social isolation on depressive symptoms over time. The relationship between social isolation and depression in older adults has been well-documented in the literature before COVID-19. Recent research has evidenced that the COVID-19 pandemic has exacerbated this relationship. For example, a study by Robb et al. (2020) found that older adults who reported reduced social connectivity during COVID-19 had a 17.24 times higher risk of depression symptoms.

Similarly, Siegmund and colleagues (2021) identified a large effect of social isolation on depressive symptoms during a period of pandemic-imposed social distancing; during this period, physical inactivity was positively associated with depressive symptoms as well. However, the current study hypothesized an inverse association of physical activity on depressive symptoms, but results from the multilevel models did not support this claim. It has been suggested that the magnitude of the impact of physical activity on mood states is dependent on one's baseline mood (Kanning & Schlicht, 2010); therefore, the lack of support for the association of physical activity on depressive symptoms is likely due to the low mean depressive symptoms score and high MPA at baseline.

Further, although results demonstrated a significant time-varying covariation of COVID-19 stress on depressive symptoms, the relationship was in the opposite direction than hypothesized; and thus, the hypothesis was rejected. Interestingly, results showed a significant inverse within-person association of COVID-19 stress and depressive symptoms, such that, during bursts when participants reported less or more COVID-19 stress than typical for them, their depressive symptom ratings were worse or improved, respectively. Perhaps this result is associated with the point of time during the COVID-19 pandemic and its associated levels of restrictions that the current study took place. Many participants were recruited after some pandemic-imposed restrictions were less strict (described in greater detail in the next section). Therefore, participants' depressive symptoms may have decreased while COVID-19 stress increased due to the consistent presence of COVID-19 in the media, especially given that high media exposure is one of the strongest predictors of COVID-19 stress (Holmes et al., 2020; Holman et al., 2020).

The floor effect in depressive symptoms, social isolation, and COVID-19 stress may be explained by Dunton (2017), who states that participant burden can impact the quality of data collected in EMA research. Due to the repetitive nature of EMA measurement burst designs, participants may have chosen the first survey option every time to finish the survey faster. The lowest score in depressive symptoms, social isolation, and COVID-19 stress measures was the first option, which, by Dunton's theory, would explain the potential floor effect. However, there are indicators of validity in the current research. For example, the variability in MPA does not support this theory (see Figure 4). The first option in the EMA items assessing MPA was a value of 0 hours. MPA items were assessed after the psychosocial items at the very end of the survey. Therefore, if a participant selected the first option to finish the EMA faster, we would expect the MPA, the last survey item, response to be the first option (e.g., 0 hours). Presented earlier, Figure 4 shows variability in the MPA variable measured over three measurement bursts, and the variability does not align with the theory proposed by Dunton (2017). Therefore, it is more likely that participants' low ratings of depressive symptoms, social isolation, and COVID-19 stress reflect their actual state and not just the first option entered to finish the survey quicker.

Similar to the current study's design, Fields et al. (2021) conducted a longitudinal repeated measure study assessing adults' affective experience during COVID-19. Over 21 weeks, participants ages 18-90 completed repeated surveys assessing multiple affective variables in real-time, including depressive symptoms. Results showed a significant inverse association of age and depressive symptoms, such that older adults reported less depressive symptoms than younger adults. More specifically, the mean depressive symptom scores for adults aged 65 years old approximated the first quintile, and adults aged 70 years and older were within the first quintile.

Given its longitudinal repetitive real-time assessment design, Fields et al.'s (2021) study shares many similarities with the current study. Interestingly, results from both studies showed that older adults' mean depressive symptom scores were distributed in the lower end of the scales. Additionally, previous research has demonstrated that older age is often associated with lower negative affect or levels of depression or anxiety symptoms (Fields et al., 2021). Therefore, it is conceivable that the low depressive symptom scores in the current study are reflective of a participants' actual state.

Sex and Age as Covariates

Contrary to earlier studies that showed women had significantly more depressive symptoms during the pandemic than men (Vloo et al., 2021), the current study did not find any differences in depressive symptoms between female and male participants.

Also, the current study's results showed that age was not a significant predictor of depressive symptoms. Again, the high MPA at baseline and low depressive symptom rating likely explain the insignificant result. The hippocampus is a brain area vulnerable to age-related neurodegeneration, prolonged major depression, and chronic stress. Further, BDNF is a molecule associated with both physical activity and depression. Physical activity increases BDNF (Sexton et al., 2016), and physical inactivity is associated with lower levels of peripheral BDNF and worse depressive symptoms (Mandolesi et al., 2016). Increased BDNF in response to regular MPA elicits a neuroprotective influence against age-related neurodegeneration of the hippocampus (Sexton et al., 2016).

Studies have also shown that hippocampal volume is associated with regular physical activity, and regularly active participants had larger hippocampal volumes than sedentary adults of the same age range (McEwan, 2012). Therefore, the absence of an effect of age on depressive symptoms may be due to the sample's high average MPA throughout the study, which serves as a neuroprotective factor against hippocampal degeneration and depression.

Moreover, sex and age were significant covariates predicting physical activity. Interestingly, the association between age and sex on physical activity contrasts with Rhodes et al.'s (2017) review of international physical activity research, which identifies males and younger age as consistent correlates of physical activity in adults (Rhodes et al., 2017). The current study showed that females and older age were correlates of physical activity, such that female participants reported approximately 4 more hours of MPA than males at baseline. Additionally, age predicted physical activity at baseline. Results demonstrated an increase of roughly 19 minutes per 1-year increase in ages above 65 years old. For example, the estimated mean physical activity measured at baseline for 65 year old participants was approximately 5 hours and 6 minutes and 5 hours and 25 minutes for 66 year old participants). The sex differences may be due to the sample being disproportionately female (75.6%).

Point of Time in the COVID-19 Pandemic and Associated Restrictions

The literature suggests that public health measures implemented to protect people resulted in decreased physical activity and increased depressive symptoms, social isolation, and stress. However, the results from the current study demonstrated that participants were exceeding the recommended physical activity guidelines and reporting low feelings of depressive symptoms, social isolation, and COVID-19 stress during the baseline measurement burst. As mentioned previously, the current study recruited most of the sample as the pandemic-related restrictions were much less strict than when first implemented. For instance, the first cohort of participants began the study during the first week of March 2021, nearly one year after Canada declared a public health state of emergency and implemented strict public health measures due to COVID-19. Most of the participants are from British Columbia (67%). Therefore, British Columbia's COVID-19 'Restart Plan' (i.e., the phased approach to reducing restrictions and carefully returning to normal) is used to explain the perceived impact of the point in time of the pandemic on the current study's results (see British Columbia’s COVID-19 ‘Restart Plan’ materials in Appendix B). By the end of May 2020, British Columbia's government initiated Phase 1 of the Restart Plan, which allowed British Columbians to gather in groups (with restrictions on the number of people), attend low-intensity indoor fitness classes, enjoy indoor dining, and others.

Further, Canadian adults ages 60 years and older were eligible to receive their first COVID-19 vaccine by mid-April 2021 (Government of Canada, 2021). Nearly 60% of the total sample was recruited after the COVID-19 vaccine became available (see Figure 1). After April 2021, individuals may have returned to their regular physical activity routines and felt less isolated by visiting with friends and family and stressed about the complications of COVID-19 as a result of vaccines. In sum, Canadians may not feel the same level of social isolation, depressive symptoms, or COVID-19 stress as when the pandemic-imposed restrictions were initially implemented.

Limitations

While there are many strengths of the current study that advance research in physical activity and programming for older adults during the COVID-19 pandemic, several limitations need to be considered. One of the pandemic-imposed challenges was the limited supervision and inability to interact with the participants face-to-face. Previous physical activity meta-analyses have identified supervision and frequent communication as contributors to effective physical activity interventions (Rhodes et al., 2017). While supervision was lacking, the current study's researchers frequently communicated with the participants via email, phone, and biweekly status reports. The *eFIT* exercise training program developed specifically for older adults is a significant strength in the current study; even with the lack of supervision and face-to-face interaction due to COVID-19, physical activity increased only in the Active group, demonstrating adherence to the remote exercise training program.

Another challenge associated with the limitation of face-to-face interaction with the participants was the inability to demonstrate/troubleshoot issues with the multitude of technological tools used in the current study. Some participants experienced difficulty navigating the technology (e.g., the *Ethica Data* app, *Moodle*, *Qualtrics*, and others). Meeting in person would allow the opportunity to set up and demonstrate each technological component of the study; it would also strengthen rapport. Technological difficulties were anticipated given the remoteness of the current study. Therefore, participants were given step-by-step guides with screenshots to mitigate such challenges and facilitate retention. In contrast, the inability to meet with participants face-to-face also served as a strength of the current study, especially during COVID-19. The application of EMA and the ability to run a study entirely remotely increased the diversity of the sample by mitigating geographic, spatial, and personnel constraints often experienced by traditional in-person testing.

Another limitation of the study is the lack of an objective measurement of physical activity (e.g., accelerometers) to compare against the self-reported data captured with mobile EMA. Accelerometers can directly capture accumulated ambulatory physical activity across multiple days of observation (Knell et al., 2016). They measure the time spent engaging at different activity-intensities and capture intermittent activity, not just bouts of activity, which self-reported measures capture (Knell et al., 2016). Additionally, once put on, wrist-worn accelerometers (e.g., Fitbit) are convenient for participants and reduce the burden of completing repeated assessments, reducing the likelihood of missing an assessment. However, evidence supports the use of EMA in physical activity research over other self-report instruments, especially given its high ecological validity. EMA can capture contextual factors influencing behaviours and manipulate recall time compared to other self-report instruments. The current study's physical activity recall assessment period was 'over the course of the day'. Despite the shorter recall period, EMA is still susceptible to bias. Compared to accelerometer data, the discrepancy between EMA (e.g., 24-hours) and self-report instruments of lengthier recall periods (e.g., a 'typical week' or the 'past 7 days') in over-reporting moderate-to-vigorous physical activity is much less in EMA (Knell et al., 2017). While all self-reporting instruments are susceptible to recall bias, research has demonstrated that EMA with shorter recall periods performs closer to accelerometers.

Further, EMA and measurement burst designs may burden participants and impact retention; therefore, researchers must be thoughtful about the number of survey items and frequency of assessments. However, the repeated assessments are also a strength of EMA, allowing capturing fluctuations in variables and approximating a more precise ‘true’ average in behaviours and states over time (Sliwinski, 2008; Dunton, 2017).

Another major strength of mobile EMA is its ability to capture contextual factors influencing behaviours in real-time, which is a limitation of accelerometry (Dunton, 2017; Knell et al., 2017). In summary, there are strengths and weaknesses to both mobile EMA and accelerometry in physical activity research; future studies could employ both tools to obtain a more fulsome and holistic measure of physical activity.

Future Directions and Conclusions

In response to a notable gap in home-based physical activity programming for older adults during the COVID-19 pandemic, the current study employed a remote exercise training program. It examined physical activity engagement and psychosocial well-being within- and between-older adults during the COVID-19 pandemic. To my knowledge, the current study is the first to apply a longitudinal measurement burst mobile EMA RCT design to examine the impact of a unique remote exercise training program specific to older adults on insufficiently active older adults during the COVID-19. The hypotheses regarding depressive symptoms, social isolation, COVID-19 stress, and physical activity were informed by previous research, which has identified the most significant gains or improvements in formerly sedentary participants who begin participating in regular physical activity. However, most of the current sample exceeded the recommended physical activity guidelines, likely impacting the results (WHO, 2010). Future studies can replicate the current EMA measurement burst design but utilize the MPA data from the first measurement burst as an additional screener assessment and exclude those who exceed the recommended physical activity guidelines from participating further. This additional check will ensure that the recruited participants are insufficiently active. Future studies could add another week to the first measurement burst and only utilize data collected in the second week of assessment to mitigate the 'fresh start effect' on the baseline physical activity assessment. This method has successfully diminished the potential upward bias in higher estimates of physical activity during the initial week of a physical activity study (Patel, Small, Harrison, Fortunato, Oon, Rareshide, et al., 2019).

If available, future studies can employ objective activity measurement tools (e.g., Fitbits) to complement the mobile EMAs to improve precision and ecological validity while capturing both contextual and ambulatory measurements of physical activity (Knell et al., 2017). Employing both EMA and ambulatory measures of physical activity allows monitoring for over-reporting, potentially confounded by social desirability and participant bias. Finally, the combination of both tools during an extended baseline assessment (e.g., a 2 week-long measurement burst) could identify potential reactance to survey questions that may have increased physical activity during the first measurement burst.

In conclusion, the current study's exercise training program proved to be an effective means of increasing physical activity in older adults. The exercise training program did not impact participants' feelings of depressive symptoms, social isolation, or COVID-19 stress. Of note, the sample's mean MPA was two times more than the recommended 150 minutes of MPA per week for older adults, and ratings of depressive symptoms, social isolation, and COVID-19 stress demonstrated a positive skew (i.e., the scores approximated the minimum score for each construct). The current research established its hypotheses with the expectation that the sample was insufficiently active, which likely contributed to the absence of an effect of the exercise training program on depressive symptoms, social isolation, and COVID-19 stress. Therefore, at-home based physical exercise programs may still be an inexpensive and viable means of mitigating poorer physical and mental health outcomes associated with physical inactivity in insufficiently older adults, especially those experiencing worse depressive symptoms, social isolation, and COVID-19 stress. Researchers should consider employing mobile EMA measurement burst designs in physical activity research to capture contextual factors influencing physical activity behaviours, mitigate limitations of traditional in-person testing, detect within-person and between-person change, and characterize the dynamic features of physical activity over time. Finally, to complement mobile EMA, an objective measurement tool (e.g., accelerometers) could mitigate recall bias and over-reporting inherent to self-report instruments while complementing mobile EMA capacity to capture contextual factors that influence physical activity behaviours.

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Appendices

Appendix A

EMA Burst Items

Morning Survey (~6:30 to 8:30 AM)

Socioemotional factors:

The next questions ask about your feelings during the past 15 minutes.
To what extent were you feeling… (slider: 1= not at all to 5 = very much)

***PROMIS Emotional Distress—Depression—Short-Form* (adapted)**

1. Worthless
2. Helpless
3. Depressed
4. Hopeless

***PROMIS- Social Isolation—Short-Form* (adapted)**

5. Left out
6. That people barely know you
7. Isolated from others
8. That people are around you but not with you

COVID-19 stress

1. Right now, how stressed are you about COVID-19? (slider: 1 Not at all stressed to 10 Extremely stressed)

End of Day Survey (~6:30 to 8:30 PM)

Note: some questions from the morning survey are repeated in the end of day survey.

Socioemotional factors:

The next questions ask about your feelings during the past 15 minutes.
To what extent were you feeling… (slider: 1= not at all to 5 = very much)

***PROMIS Emotional Distress—Depression—Short-Form* (adapted)**

9. Worthless
10. Helpless
11. Depressed
12. Hopeless

***PROMIS- Social Isolation—Short-Form* (adapted)**

13. Left out
14. That people barely know you
15. Isolated from others
16. That people are around you but not with you

COVID-19 stress

2. Right now, how stressed are you about COVID-19? (slider: 1 Not at all stressed to 10 Extremely stressed)

Physical activity

The next few questions are interested in your activity over the course of the day. To the best of your memory, approximately how much time did you spend participating in sedentary, light, moderate, or hard activities over the course of your day?

Please answer all four activity-intensities. Enter '0' if you spent no time participating in one of the four activity levels.

Over the course of the day, approximately how much time was spent participating in each one of the following activity levels …

Sedentary activity (e.g., no effort, such as watching TV, sitting, reading a book)

Light activity (e.g., minimal effort with normal breathing and regular movement, such as walking, golfing, cleaning, etc.)

Moderate activity (e.g., moderate effort with increased breathing and quicker movements, such as fast walking, casual biking, etc.)

Hard activity (e.g., effortful, with heard breathing and quick, fast movements such as running, fast-paced sports, aerobic classes, etc.)

Appendix B

British Columbia's Restart Plan beginning May 25, 2020

STEPS	Criteria	PHO Guidance	Personal Gatherings	Organized Gatherings	Travel	Sports & Activities	Businesses	Offices & Workplaces
1 MAY 25	C: stable H: stable D1: 60%	Masks mandatory, indoor public spaces Physical distancing If sick, stay home and get tested	Outdoor personal gatherings – up to 10 people Indoor visitors – up to 5 people or 1 household	Indoor seated organized gatherings – up to 10 people Outdoor seated organized gatherings – up to 50 people	Recreational travel within your zone Non-essential travel between zones restricted	Low-intensity indoor fitness classes Outdoor local team games and practices for all ages – no spectators	Indoor & outdoor dining – up to 6 people Liquor service - 10PM Existing WorkSafeBC Safety Plans remain in place	Start gradual return to workplaces and offices Existing Safety Plans remain in place
2 JUNE 15	C: declining H: declining D1: 65%	Masks mandatory, indoor public spaces Physical distancing If sick, stay home and get tested	Outdoor personal gatherings – up to 50 people Indoor visitors – up to 5 people or 1 household Playdates	Indoor seated organized gatherings – up to 50 people Sector consultations on next steps on indoor and outdoor gatherings	BC recreational travel BC Transit and BC Ferries – increased services as needed	High-intensity indoor fitness classes - reduced capacity Indoor team games for all ages – no spectators Spectators for outdoor sports – up to 50 people	Liquor service – midnight Banquet halls reopen – limited capacity, Safety Plans Sector consultations on next steps on easing of restrictions	Continue return to work Small in-person meetings
3 JULY 1 (Earliest date)	C: low H: declining D1: 70%	Masks – recommended Careful social contact If sick, stay home and get tested	Return to usual on indoor and outdoor personal gatherings Sleepovers	Increased capacity, indoor and outdoor gatherings – Safety Plan Fairs and festivals with Safety Plan	Canada recreational travel	All indoor fitness classes – increased capacity Limited spectators for indoor sports	Dining – no group limit Casinos and nightclubs – limited capacity Operate based on new Safety Plans	Seminars and bigger meetings Operate based on new Safety Plans
4 SEPT 7 (Earliest date)	C: low H: low D1: 70%+	Masks – personal choice Normal social contact If sick, stay home and get tested	Normal social contact	Increased capacity on large organized gatherings (i.e. concerts)	Canada recreational travel	Increased indoor and outdoor spectators Return of normal sport competitions – Safety Plans	Continue to operate based on new Safety Plans	Fully re-opened offices and workplaces

C: C-19 case counts **H:** C-19 hospitalizations **D1:** minimum % of people 18+ with dose 1

BRITISH COLUMBIA

BC'S RESTART: A PLAN TO BRING US BACK TOGETHER

Appendix C

Example of the *eFIT* Study's Recruitment Poster