PAIN AND LONELINESS AS OBSTACLES TO PHYSICAL ACTIVITY: TIME SAMPLING DURING THE COVID-19 PANDEMIC

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Abstract

The COVID-19 pandemic has threatened physical and mental health across the lifespan and highlighted the importance of safe everyday behaviours that individuals may engage in to maintain health and wellbeing. One health-promoting behaviour that has been encouraged by health officials during the pandemic is physical activity; however, research indicates that physical activity behaviours have decreased significantly during this time. The current study aimed to extend research on between-person differences in physical activity behaviours and barriers to physical activity by examining self-reported pain and loneliness on active vs. less-active days. To capture life as it is lived, time-varying associations of loneliness, subjective pain, and physical activity indicators were examined as participants went about their daily lives. It was hypothesized that individuals who reported more loneliness or subjective pain on a particular day would take fewer steps and engage in less moderate-to-vigorous physical activity that same day. Data were collected from April 2020 to August 2020. The sample included 139 community-dwelling Canadian adults (M \(\text{age} = 40.65\) years, \(SD = 18.37\), range = 18-83 years). Each evening for up to 10 consecutive days, participants reported their loneliness, subjective pain, number of steps, and minutes of moderate-to-vigorous physical activity. In line with the above hypotheses, loneliness and physical activity were significantly linked on a day-to-day basis, such that individuals who felt lonelier on a particular day engaged in less moderate-to-vigorous physical activity that same day. However, we did not find any significant relationships between pain and physical activity. From an intervention perspective, our findings may suggest that it is promising to tackle loneliness on a day-to-day basis to increase physical activity one day at a time. This may be especially relevant during times of mandated social-distancing, such as the COVID-19 pandemic, but also at other times when individuals experience greater feelings of loneliness.
**Lay Summary**

The present study provides evidence of loneliness as a potential barrier to physical activity for adults during the COVID-19 pandemic. This main finding builds on past literature indicating that individuals who report more loneliness on average engage in less physical activity on average; and it extends these results to day-to-day life in a community sample. By exploring potential barriers to physical activity in the daily lives of adults, we aim to shed light on potential targets of intervention that may be particularly useful during times of challenge. Findings from this research may extend to other particularly challenging times, where “normal” social contact is not possible. This builds on literature highlighting the importance of social connectedness and social interaction for health and wellbeing across the lifespan.
Preface

The data used in this study were collected in the Health and Adult Development Lab, with Dr. Christiane Hoppmann as principal investigator. Collaborators on this project include Dr. Denis Gerstorf (Humboldt University Berlin, Germany) and Dr. Theresa Pauly (University of Zuerich, Switzerland). All procedures and methods were approved by the University of British Columbia Behavioural Research Ethics Board [certificate number: H17-01249].

My intellectual contributions involved creating a conceptual framework for the project, data cleaning and analyses, data presentation, and manuscript development. This project was pre-registered on Open Science Framework in June 2021 (View pre-registration: https://osf.io/dvqrt/?view_only=bd39c2a276c84b27aefe77bb7bb64df31). Christiane Hoppmann is the senior author on this project and manuscript feedback was given by Yoonseok Choi and Elizabeth Zambrano.
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1 Introduction

Times of challenge that threaten physical and mental health, such as the COVID-19 pandemic (Creese et al., 2020; Wettstein et al., 2021; Zheng et al., 2021), uniquely highlight the importance of safe everyday behaviors that individuals may engage in to maintain their health and wellbeing (Adams et al., 2021; Holmes et al., 2020). One health-promoting behaviour that has been encouraged by health officials during the pandemic is physical activity (CDC, 2021). Importantly, physical activity has the potential to be adjusted according to social distancing measures and worked into the lives of individuals of all ages to promote both physical and mental health. However, emerging research indicates that physical activity behaviours have decreased significantly during the pandemic (Adams et al., 2021; Maltagliati et al., 2021). The current research aims to better understand salient barriers to physical activity in day-to-day life to support wellbeing during times when “normal” life is interrupted by extenuating circumstances.

Research examining physical activity as a health behaviour typically looks at between-person differences in number of steps or moderate-to-vigorous physical activity (Creese et al., 2020; Maltagliati et al., 2021). Yet, we know that there is also significant variation in physical activity engagement at the within-person level (Pauly et al., 2020). To gain a deeper understanding of this key health behaviour and design effective interventions, it is paramount that we understand what differentiates a good physical activity day from a bad physical activity day. The current research aimed to examine life as it is lived using repeated daily life assessments in a lifespan sample of 139 adults residing in Canada (M\text{age} = 40.65 \text{ years}, SD = 18.37, \text{range} = 18-83 \text{ years}). Participants completed evening questionnaires for 10 consecutive days, where they provided daily reports of potential barriers to physical activity, such as pain and loneliness, as well as their daily number of steps and minutes of moderate-to-vigorous physical
activity. This allowed us to examine time-varying relationships between loneliness, pain, and physical activity that may have been exacerbated during the pandemic.

1.1 Physical activity as a key health behaviour

Even pre-pandemic, only approximately 49% of adults aged 18 to 79 years meet Canadian physical activity guidelines of engaging in at least 150 minutes of moderate-to-vigorous intensity physical activity per week (Statistics Canada, 2021). Recent research also indicates that adults have engaged in less physical activity during the pandemic as compared to pre-pandemic activity levels (Giuntella et al., 2021; Naughton et al., 2021). This decrease in physical activity is concerning given that physical activity is a well-recognized factor that promotes physical and psychological health across the lifespan (Clemente-Suarez et al., 2022). With this in mind, it is essential that we identify salient barriers to everyday physical activity that may be targeted in health behaviour interventions.

Most research examining physical activity as a health behaviour looks at between-person differences in number of steps or moderate-to-vigorous physical activity (Creese et al., 2020; Maltagliati et al., 2021); however, repeated daily life assessments also show that individuals vary significantly in their physical activity behaviors across days (Pauly et al., 2020). This creates a need to better understand what differentiates a good day from a bad day, including salient barriers to physical activity in adults’ everyday lives. To maximize ecological validity and identify targets for real-world intervention, the current research uses repeated daily life assessments (Bolger et al., 2003). This measurement-intensive design allows us to capture variation in one’s thoughts, feelings, and behaviors across several days. Embracing the meaningful insights gained from getting a snapshot into one’s daily life, this method was employed to better understand the relationships between pain, loneliness, and physical activity to
contribute to our understanding of physical and mental health during times of social distancing and beyond.

1.2 Loneliness and physical activity

One potential barrier to physical activity that has become particularly salient during the varying degrees of restrictions throughout the COVID-19 pandemic is loneliness (Ernst et al., 2022; Holt-Lunstad & Perissinotto, 2022). Pandemic circumstances may have incurred more loneliness for individuals who do not typically report feeling lonely (O’Sullivan et al., 2021); however, at one point or another, almost all individuals will experience some loneliness in their day-to-day life (Surkalim et al., 2022). Psychological research defines loneliness as the subjective perception of lacking desired social contact and maintains that it is conceptually distinct from feelings of poor social support, perceived stress, depression, or hostility (Cacioppo et al., 2015). Research indicates that elevated loneliness is associated with negative health outcomes, such as depression and anxiety symptoms (Pels & Kleinert, 2016), and that it also has consequences for risk of diseases such as cardiovascular disease and insomnia (Petitte et al., 2015). Psychological theories on loneliness posit that individuals who report feeling lonelier engage in fewer health-promoting social interactions and report fewer positive emotions, resulting in impaired self-regulation and less physical activity engagement over time (Hawkley et al., 2009).

Unsurprisingly, several recent studies have indicated that self-reported loneliness has increased during the COVID-19 pandemic (Elran-Barak & Mozeikov, 2020; Son et al., 2021). During these unprecedented times of social distancing, increases in social isolation may have promoted feelings of social threat, giving rise to a “loneliness loop” where people continue to distance themselves from others (Hawkley & Cacioppo, 2010). This, with the understanding that
physical activity engagement is supported by social engagement and positive emotionality (Hawkley et al., 2009), begs the question as to whether there is a significant relationship between day-to-day fluctuations in loneliness and daily physical activity behaviours, especially during times of challenge. The current study used repeated daily life assessments to better understand the time-varying relationship between loneliness, steps, and moderate-to-vigorous physical activity as individuals engaged in their everyday environments during the first year of the pandemic. We hypothesized that individuals who experience more loneliness on average will engage in less physical activity. In addition, we expected individuals who experience more loneliness on a particular day to engage in less physical activity that same day.

1.3 Pain and physical activity

Pain is another well-recognized barrier to physical activity that has become particularly salient during the pandemic (Consonni et al., 2021; Dassieu et al., 2021). Contemporary definitions of pain emphasize its subjective nature (Craig, 2009) and recognize that it is a particularly isolating experience with significant impacts on behaviour, even before the onset of the COVID-19 pandemic (Karos et al., 2020). Given that personal and social cognitions are closely tied to the subjective pain experience (Craig & MacKenzie, 2021), mandated social distancing may have intensified the experience of pain for many individuals. Pre-pandemic, chronic pain was listed as the number one cause of disability in Canada (Statistics Canada, 2013). Given that pain is a common experience for adults (Craig, 2009), it is important to understand how pain interacts with other health behaviors such as physical activity to better support these individuals in living active and engaged lives.

To understand pain in the context of the current study, it is important to note that there is a large range of pain experiences, both acute and chronic (Craig, 2009). The experience of pain
is not only rooted in biological injury or tissue damage; instead, it is also heavily influenced by both interindividual and intraindividual factors (Craig, 2009). Craig (2009) proposes The Social Communication Model of Pain, in which the experience of pain and social reactions to that pain form feedback loops that make appraising and understanding an individual’s pain particularly complex. Anchored in this psychological definition of pain, the current study examines subjective overall pain perceptions, rather than behavioural or clinically-assessed pain ratings.

In addition, the relationship between pain and physical activity may differ at the within-and between person levels. For example, research indicates that individuals who are more physically active on average have a lower risk of experiencing chronic pain (Law & Sluka, 2017); however, on days when individuals engage in more physical activity (i.e. more steps and more moderate-to-vigorous physical activity), they may also experience increased daily pain (Ho et al., 2016). In addition, there is abundant evidence indicating that individuals who experience more pain engage in less physical activity on average (Geneen et al., 2017; van den Berg-Emons et al., 2007). Subjective pain is a dynamically changing variable that is impacted by not only physical pain sensitivity but also psychological processes such as the perceived consequences of the pain, importance of the pain, or perceived partner support (Gathchel & Oordt, 2003; Pow et al., 2018). As a result, individuals who experience daily fluctuations in pain may also adjust psychologically, which potentially impacts their ability to engage in physical activity. We hypothesized that adults who report more subjective pain on a particular day will engage in less physical activity that same day.

1.4 Loneliness and pain

The conceptual link between pain and loneliness has been highlighted by individual experiences during the COVID-19 pandemic. Even outside of the context of the pandemic,
subjective pain can be particularly isolating as it is reinforced by loneliness and restricts access to social connection opportunities (Gillsjö et al., 2021). Recent research has examined the experience of pain during the COVID-19 pandemic and found that social distancing measures have reinforced the vulnerability of individuals experiencing pain (Dassieu et al., 2021). In particular, social distancing measures have increased social threats (i.e. isolation) among individuals experiencing chronic pain and exacerbated their pain experience (Consonni et al., 2021; Karos et al., 2020). A recent study found that both social exclusion and self-reported loneliness significantly predict both acute and chronic pain (Allen et al., 2020).

To further disentangle the relationship between pain and loneliness to guide practical interventions that mitigate these barriers to physical activity, we examined the relationship between pain and loneliness in the current study. We hypothesized that on days when individuals reported feeling more lonely than typical, they would also experience more pain than is typical.

1.5 Current research aims

Embracing that salient barriers to physical activity, such as pain and loneliness, have increased due to the COVID-19 pandemic (Adams et al., 2021; Hwang et al., 2020), the overall purpose of this project was to disentangle the relationships these barriers have with adults’ daily physical activity. This study was launched in April 2020, shortly after the onset of the COVID-19 pandemic, and participants completed daily questionnaires for 10-consecutive days to get a snapshot into their thoughts, feelings, and behaviors during these unique times. We hypothesized that adults who experienced more loneliness or pain on particular days would also engage in less physical activity that day, and that loneliness would show a positive relationship to pain. All analyses controlled for variables known to be associated with physical activity, including age, sex, and weekday versus weekend effects (Bauman et al., 2016; Bellettiere et al., 2015;
Burchartz et al., 2022). This project and associated hypotheses were pre-registered on Open Science Framework and can be accessed at the following link:
https://osf.io/dvqrt/?view_only=bd39c2a276c84b27aeefe77bb7bb64df31
2 Methods

2.1 Participants

A total of 139 participants (M_{age} = 40.65 years, SD = 18.37, range = 18-83 years) were included in the final analyses of this project. The sample self-identified as 80% female, 74% white, 60% having a university degree, and being generally healthy (M_{health} = 3.32, SD = 0.94; on a 1-5 scale). Out of the original 169 participants who completed the daily diary portion of this study, five were removed because they did not provide sex or age data, 24 participants were removed for completing only one evening questionnaire, and two were removed for never reporting any physical activity data (moderate-to-vigorous physical activity or steps).

2.2 Procedure

From April 2020 to August 2020, data were collected online. Participants were recruited through online advertisement (e.g. Facebook, Craigslist), newspaper outlets in Canada, and via past participant pools. Individuals interested in participating in the study completed an eligibility screening through an online survey. Participants were eligible for the study if they were 18 years or older, living in Canada, and had access to a computer or mobile device with internet connection to complete the questionnaires.

Eligible participants received a link via email to complete the baseline questionnaire, which involved questions on sociodemographic characteristics, social and personality constructs, physical activity behaviors, and questions specific to the COVID-19 pandemic. Following the initial questionnaire, participants were invited to complete brief online morning and evening questionnaires for 10 consecutive days. These questionnaires involved questions on affect, context, and activities that day. Participants were asked to self-report their daily number of steps and minutes of moderate-to-vigorous physical activity each evening by either estimating or, if
available, using data from their personal fitness watch or smart device. The average participant completed 6.70 evening questionnaires ($SD = 2.81$), and 73% of participants completed 5 or more evening questionnaires.

All participants were entered to win a $50.00 Amazon gift card for completing the initial questionnaire (1:10 chance of winning), and then entered again for completing 80% of the daily questionnaires (1:5 chance of winning). All procedures were conducted virtually, via email and the Qualtrics survey platform. The study was approved by the UBC ethics board [certificate number: H17-01249], and all participants provided informed consent.

2.3 Measures

2.3.1 Physical Activity

Physical activity was operationalized using number of daily steps and number of minutes of moderate-to-vigorous physical activity. Each evening, participants were asked how many steps they took that day ($M = 5412$ steps, $SD = 5525$). Participants were prompted to use step data from a personal activity watch or smartphone if they had access to one. Participants also reported minutes of moderate-to-vigorous physical activity during each evening questionnaire ($M = 37.61$ minutes, $SD = 45.32$). Moderate-to-vigorous physical activity was based on subjective self-reports and defined to participants as: “the type [of activity] that makes your heart beat more”.

2.3.2 Loneliness

Daily loneliness was assessed during each evening questionnaire for the 10-day study period ($M = 24.72$, $SD = 27.72$). Participants were asked to report and answer to “How lonely did you feel today?”. Responses were recorded on a visual analog scale from 0 (Not at all) to 100 (Very Much).
2.3.3 Subjective Pain

Daily subjective pain was measured via self-report during each evening questionnaire for the 10-day study period (M = 19.71, SD = 24.55). Participants were asked to report an answer to the following question: “How much pain were you in today?” Responses were not guided by any other information defining pain, and they were recorded on a visual analog scale from 0 (Not at all) to 100 (Very Much).

2.4 Control Variables

Overall health, household size, day in study, sex, and age were included as control variables in all analyses. Overall health was measured during the initial questionnaire, where participants were asked to rate their overall health on a five-point scale (1 = Poor, 2 = Fair, 3 = Good, 4 = Very Good, 5 = Excellent; M = 3.32, SD = 0.94). Household size was also assessed at the baseline questionnaire; participants were asked how many people lived in their household including themselves (M = 2.71, SD = 1.57, range: 1-9) and whom they lived with. Day in study was included as a control variable to account for weekday and weekend behavioural differences in physical activity. Sex was included as a dichotomous female/male variable. Finally, age was included as a control variable and as a moderator variable in exploratory analyses described below.

2.5 Statistical Plan

Given the nested nature of the data underlying this project, a multilevel modelling approach with two levels was used: day level and person level. For all analyses, age, self-reported health, household size, and day in study were grand mean centered, and gender was included as a dichotomous variable. Multilevel models were run to examine the relationship between loneliness, pain, and physical activity. Moderate-to-vigorous physical activity and
number of steps were examined as separate day-level outcome variables. To account for within-and between-person variation, person means for loneliness and pain were included, and these variables were person-centered.
3 Results

Descriptive statistics and bivariate correlations are presented in Table 1. Bivariate analyses indicated that participants who self-identified as female reported less loneliness ($r = -.10, p < .01$), lower evening pain ($r = -.15, p < .01$), and worse overall health ($r = -.09, p < .05$) than men in the sample. At the bivariate level, loneliness was significantly negatively associated with number of steps ($r = -.16, p < .01$) and there was a negative relationship that was not nominally significant between evening moderate-to-vigorous physical activity and loneliness ($r = -.05, p = .14$). In addition, loneliness was significantly positively associated with daily pain ($r = .29, p < .01$). Bivariate analyses also indicated a negative trend between evening pain and number of steps ($r = -.10, p = .10$), but no significant relationship between pain and minutes of moderate-to-vigorous physical activity ($r = -.01, p = .87$).

Intraclass correlation coefficients (ICC’s) were calculated for both number of steps and minutes of moderate-to-vigorous physical activity. In total, 64% of the variance in number of steps was due to between-person differences (ICC = 0.64) and 36% due to within person differences (see Figure 1). For moderate-to-vigorous physical activity, 37% of variance was due to between-person differences (ICC = 0.37) and 63% due to within-person differences (see Figure 2).

3.1 Loneliness and Physical Activity

To examine the relationships between loneliness and physical activity at both the within- and between-person levels, multilevel models were fit such that loneliness was a level-1 predictor variable for physical activity. Number of steps and minutes of moderate-to-vigorous physical activity were examined as outcome variables in separate models. Age, overall loneliness, self-reported health, and day in study were grand mean centered, and sex was
included as a dichotomous variable (0 = male, 1 = female) at level 2. To disentangle within- and between-person variation, person means were created for evening loneliness, and loneliness was person-mean centered.

In line with our hypotheses, individuals who felt lonelier on a particular day engaged in less MVPA (\(\text{estimate} = -0.23, p = .02\)) and took fewer steps (\(\text{estimate} = -16.52, p = .05\)) that same day. However, there was no significant relationship between overall loneliness on physical activity engagement at the between-person level (see Table 2).

### 3.2 Pain and Physical Activity

To examine the relationships between pain and physical activity at both the within- and between-person levels, multilevel models were fit such that self-reported pain was a level-1 predictor variable for physical activity. Number of steps and minutes of moderate-to-vigorous physical activity were examined as outcome variables in separate models. Age, overall self-reported health, and day in study were grand mean centered, and sex was included as a dichotomous variable (0 = male, 1 = female). To disentangle within- and between-person variation, person means were created for evening pain, and subjective pain was person-mean centered. Results are displayed in Table 2.

Our hypotheses specified that subjective pain would show a negative relationship with physical activity. However, we did not find any significant within- or between-person effects for pain on number of steps or moderate-to-vigorous physical activity. Exploratory analyses below were used to better understand the expected associations.

### 3.3 Loneliness and Pain

Further analyses explored the relationship between pain and loneliness in our sample. In this model, loneliness was treated as the main outcome variable, and pain was the main predictor
variable of interest. Age, self-reported health, and day in study were grand-mean centered and sex was included as a dichotomous variable. Table 2 highlights that individuals who, on average, experienced more pain also reported more loneliness (estimate = 0.28, p < .01); in addition, individuals who reported more pain on a particular day also reported feeling lonelier that same day (estimate = 0.17, p < .01).

3.4 Additional Analyses

3.4.1 Physical activity pre-pandemic vs. during pandemic

Analyses further explored self-reported differences in physical activity pre-pandemic and during the pandemic. During the baseline questionnaire, participants were asked how much moderate-to-vigorous physical activity they typically engaged in pre-pandemic and how much moderate-to-vigorous physical activity they currently engaged in. Consistent with other research emerging during the pandemic, participants indicated that they engaged in 29% less moderate-to-vigorous physical activity since the beginning of the pandemic (MVPA pre-pandemic: M = 62.24 minutes/day, SD = 65.89; MVPA during pandemic: M = 44.23 minutes/day, SD = 47.30).

3.4.2 Age as a moderator

Age was explored as a moderating variable between pain and physical activity and loneliness and physical activity. As highlighted in Table 3, we did not find any significant cross-level interactions between age and our main predictor variables. In other words, the association between study variables did not significantly differ by age.

3.4.3 Subjective pain in the sample

Given that our sample was relatively young, with only 24 participants 65 years or older, we examined the effects of pain on physical activity in a sub-sample of participants who reported pain over 25/100 at some point during the daily diary portion of the study. Only 78 participants
ever reported pain over 25. The above described analyses between pain and physical activity (number of steps and moderate-to-vigorous physical activity) were conducted on this subset of participants, and no significant results were found.

### 3.4.4 Time ordering of results

We first explored morning loneliness and pain as predicting evening self-reported physical activity in our sample. After accounting for between-person differences in age, health, day-in-study and sex, there was no significant relationships between morning loneliness or pain and same-day number of steps or moderate-to-vigorous physical activity. Time-lagged analyses were also run such that the relationship between previous day loneliness and pain and next-day physical activity was examined with physical activity indicators as the main outcome variables. Consistent with previous analyses, age, overall health, and day in study were controlled for, and gender was included as a dichotomous variable. There were no significant results from the lagged analyses between loneliness or pain and number of steps or moderate-to-vigorous physical activity at the within- or between-person levels.
4 Discussion

The present study used repeated daily life assessments to examine how daily loneliness and pain were related to daily physical activity during the COVID-19 pandemic. Specifically, we examined whether adults who reported more loneliness or pain on a day-to-day basis would engage in less physical activity that same day. Findings indicate that individuals who reported feeling lonelier on a particular day engaged in less physical activity that same day. However, there were no significant results for pain and physical activity at the within- or between-person levels. Further analyses revealed that individuals who report feeling lonelier on a particular day also report greater pain experiences that same day.

4.1 Physical Activity as a Health Behaviour

In the context of the COVID-19 pandemic, evidence suggests that physical activity could be an important coping strategy that mitigates the impact of mandated social-distancing on wellbeing (Manuel et al., 2021). Consistent with emerging literature indicating that physical activity engagement decreased during the pandemic (Adams et al., 2021; Maltagliati et al., 2021), results from the current study found that adults reported 29% less moderate-to-vigorous physical activity compared to pre-pandemic times. To better understand potential barriers to physical activity during the pandemic, we further explored the relationship between loneliness and physical activity and pain and physical activity. Findings from this research may extend to other particularly challenging times, where “normal” social contact is not possible. Although the pandemic has been a time of unprecedented challenges, it has also been a common stressor in everyone’s lives and may have highlighted experiences, like pain and loneliness, that are also particularly salient for individuals facing health crises, natural disasters, or other stressful life events.
Contrary to pre-pandemic research, we found that age was significantly positively associated with moderate-to-vigorous physical activity in the present sample at the bivariate level ($r = 0.12, p < .01$). Although this finding is not consistent with previous work, it does raise an interesting question about how physical activity behaviours may have changed for different age groups during the pandemic. One potential reason for why older adults may have engaged in more physical activity than younger adults may be that their everyday physical activity routines may have been less impacted by social distancing measures than those of younger adults’. For example, adults between the ages of 18 and 54 years old make up 60.60% of gym members around the world (The Global Health and Fitness Association, 2022) and older adults report walking, gardening, and home exercise as the top physical activities they engage in (The Canadian Fitness and Lifestyle Research Institute, 1996). As a result, older adults may have been less impacted by the closing of fitness facilities than younger adults and found their routines less disrupted. In addition, older adults are often retired and may not have experienced a large increase in sedentary behavior due to work or classes being moved to a virtual environment.

### 4.2 Loneliness and Physical Activity

A growing body of literature indicates that loneliness is associated with several negative health and wellbeing outcomes. Notably, loneliness is associated with less positive emotions, which may explain why lonely individuals engage in less physical activity over time (Hawkley et al., 2009). Since physical activity is a protective factor for physical health and mental wellbeing, loneliness may act as a risk-factor for decreased physical activity and a myriad of adverse health outcomes. Hawkley & Cacioppo’s (2010) Loneliness Model suggests that perceived social isolation promotes feelings of social threat, which may spur a self-fulfilling prophecy whereby lonely people continue to distance themselves from others. In turn, this may cause a “loneliness
loop”, which results in adverse health outcomes over time (Hawkley & Cacioppo, 2010). This raises the question as to whether day-to-day fluctuations in loneliness may also impact daily physical activity behaviours. The current study found that on days when individuals experienced more loneliness, they were less likely to engage in moderate-to-vigorous physical activity. From an intervention perspective, it may be more feasible to target loneliness on a day-to-day basis by encouraging individuals to engage in activities that make them feel less lonely, such as a phone call with a friend or connection with a family member, rather than providing broad statements on how to reduce loneliness such as establishing new close friend connections or moving to a location that facilitates more social interaction. This may be especially relevant during times of mandated social-distancing, such as the COVID-19 pandemic, but also at other times when individuals experience greater feelings of loneliness throughout their life such as during a health crisis where they find themselves immunocompromised (ex. While undergoing chemotherapy treatment for cancer), or during turbulent life or world events.

### 4.3 Pain and Physical Activity

Contrary to our pre-registered hypotheses, the current study did not find any significant associations between pain and physical activity. However, current literature suggests that pain has a significant negative relationship with physical activity behaviours such that individuals who experience more pain engage in less physical activity (Geneen et al., 2017; van den Berg-Emons et al., 2007). With this in mind, we further explored the data in the current study to better understand why we did not find evidence to support this past research. The present study involved a lifespan sample, including only 24 adults aged 65 years or older. However, older adults experience more chronic pain conditions (Schofield, 2007) and are more likely to report daily pain (Craig, 2009). Thus, with our relatively young and healthy sample, the present
research may not have tapped into a population that is particularly affected by daily pain experiences. In addition, the mean pain level of all participants was low in this sample (M = 19.71, SD = 24.55; rating on a scale from 0 to 100) and only 78 participants ever reported pain greater than 25/100 throughout the repeated-daily-life-assessment portion of the study. In future research, it may be more relevant to explore the relationship between pain and physical activity in a clinical or older-adult sample.

4.4 Loneliness and Pain

Despite not finding a relationship between physical activity and pain, we did find that individuals who reported more subjective pain on a particular day also reported significantly higher feelings of loneliness that same day. This is consistent with the current literature, which indicates that individuals who experience chronic pain are at higher risk of social isolation and feelings of loneliness (Gillsjö et al., 2021). Our findings suggest that on days when individuals experience elevations in subjective pain, they may also be at greater risk for experiencing same-day loneliness. Our study highlights that even in a non-clinical sample, daily pain may be a risk factor for increased loneliness, and ultimately decreased physical activity. In order to further explore this relationship at the intersection of physical health and psychological wellbeing (Craig, 2009), future research may focus on an older adult sample, which experiences more pain than a younger adult sample. In addition, future work could examine these relationships in a clinical sample, as exemplified by other work in the health psychology field (Pow et al., 2018).

4.5 Limitations

It is important to note that the current study was conducted entirely online given the COVID-19 restrictions. Because of these circumstances, the participants who expressed interest in the study may be considered a convenience sample, which was likely healthier than the
population average. In addition, physical activity was assessed via self-report, without the use of “objective” measurement instruments such as step counters or accelerometers, which provide data that can later be examined in-lab. In future research, we would ideally include the use of an activity tracker to gain better insight into differences in daily “objective” vs. “subjective” number of steps and moderate-to-vigorous physical activity measures.

We did not find any significant relationships between pain and physical activity indices in our sample. As mentioned above, the current study included a lifespan sample, which was made up of mainly young and middle-aged adults who reported little daily pain experiences. This limit in our sample may have restricted our findings using subjective pain variables. In addition, although we analytically differentiated between overall pain intensity and daily elevations in pain, we did not differentiate between chronic and acute pain in our sample, and we assessed pain using a daily evening question: “how much pain were you in today?”. In future research, we would like to gain a more comprehensive understanding of pain in the daily lives of participants by including more differentiated daily assessments. For example, we have included questions about where in their body participants experience pain, frequency, duration, and intensity of daily pain, and how pain interacts with physical activity engagement in an ongoing repeated-daily life assessment study. This study will also include a larger sample of older adults, which will allow us to better understand the complex relationship between pain and physical activity in this particularly vulnerable population.
5 Conclusion

The present study indicates a time-varying negative relationship between loneliness and physical activity for adults during the COVID-19 pandemic. This main finding builds on past literature indicating that loneliness and physical activity have a negative relationship at the between-person level; and it extends these results to a community sample using repeated daily life assessments. Although we did not find any significant relationships between pain and physical activity at the within- or between-person levels, we intend to examine this relationship in future research with an older adult sample, and using more comprehensive pain measurements. This may allow us to further disentangle the complex relationship between pain and physical activity in a daily context. By identifying potential barriers to physical activity that play a role in the daily lives of adults, we aim to shed light on potential targets of intervention that may be particularly useful during times of challenge.
### Table 1

**Means, Standard Deviations, and Intercorrelations of Central Study Variables (N = 139)**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean (SD)</th>
<th>1.</th>
<th>2.</th>
<th>3.</th>
<th>4.</th>
<th>5.</th>
<th>6.</th>
<th>7.</th>
<th>8.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Age</td>
<td>40.65 (18.37)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Sex</td>
<td>0.80 (0.40)</td>
<td>-.07*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Overall Health</td>
<td>3.32 (0.94)</td>
<td>.03</td>
<td>-.09*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1 – 5 scale)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Household Size</td>
<td>2.71 (1.57)</td>
<td>-.33**</td>
<td>-.03</td>
<td>-.06</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Day in Study</td>
<td>-</td>
<td>.04</td>
<td>.01</td>
<td>-.01</td>
<td>-.03</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Evening Loneliness</td>
<td>24.72 (27.72)</td>
<td>-.06</td>
<td>-.10**</td>
<td>-.14**</td>
<td>.02</td>
<td>-.10**</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Evening Pain</td>
<td>19.71 (24.55)</td>
<td>.05</td>
<td>-.15**</td>
<td>-.42**</td>
<td>-.04</td>
<td>.00</td>
<td>.29**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. Daily MVPA (mins.)</td>
<td>37.61 (45.32)</td>
<td>.12**</td>
<td>-.05</td>
<td>.05</td>
<td>.08*</td>
<td>.07</td>
<td>-.05</td>
<td>-.01</td>
<td></td>
</tr>
<tr>
<td>9. Daily Steps</td>
<td>5412 (5525)</td>
<td>.01</td>
<td>.02</td>
<td>.10**</td>
<td>.08*</td>
<td>.08*</td>
<td>-.16**</td>
<td>-.10**</td>
<td>.58**</td>
</tr>
</tbody>
</table>

*Note. SD = standard deviation, MVPA = moderate-to-vigorous physical activity. Sex was coded as 0 = male, 1 = female.  
* p < .05, ** p < .01*
Table 2

Results from Multilevel Models Exploring the Relationships Between Physical Activity (Steps and MVPA), Loneliness, and Pain

<table>
<thead>
<tr>
<th>Variable</th>
<th>Outcome: Steps</th>
<th></th>
<th></th>
<th>Outcome: MVPA</th>
<th></th>
<th></th>
<th>Outcome: Loneliness</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Estimate</td>
<td>SE</td>
<td>p</td>
<td>Estimate</td>
<td>SE</td>
<td>p</td>
<td>Estimate</td>
<td>SE</td>
</tr>
<tr>
<td>(intercept)</td>
<td>5844</td>
<td>1114</td>
<td>&lt;.001***</td>
<td>36.62</td>
<td>7.31</td>
<td>&lt;.001***</td>
<td>22.79</td>
<td>4.89</td>
</tr>
<tr>
<td>Age</td>
<td>3.58</td>
<td>22.30</td>
<td>.893</td>
<td>0.35</td>
<td>0.15</td>
<td>.021*</td>
<td>-0.13</td>
<td>0.10</td>
</tr>
<tr>
<td>Sex</td>
<td>88.03</td>
<td>977.98</td>
<td>.930</td>
<td>-3.52</td>
<td>6.47</td>
<td>.587</td>
<td>-3.87</td>
<td>4.61</td>
</tr>
<tr>
<td>Overall Health</td>
<td>527.08</td>
<td>485.16</td>
<td>.270</td>
<td>4.53</td>
<td>3.16</td>
<td>.154</td>
<td>-0.65</td>
<td>2.25</td>
</tr>
<tr>
<td>Household Size</td>
<td>91.14</td>
<td>278.16</td>
<td>.748</td>
<td>2.24</td>
<td>1.77</td>
<td>.209</td>
<td>-0.70</td>
<td>1.23</td>
</tr>
<tr>
<td>Day in Study</td>
<td>122.14</td>
<td>47.34</td>
<td>&lt;.001***</td>
<td>0.83</td>
<td>0.43</td>
<td>.055</td>
<td>-0.69</td>
<td>0.21</td>
</tr>
<tr>
<td><strong>Within-person results</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Loneliness</td>
<td>-16.52</td>
<td>8.29</td>
<td>.052</td>
<td>-0.23</td>
<td>0.09</td>
<td>.015*</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Pain</td>
<td>-5.84</td>
<td>10.89</td>
<td>.592</td>
<td>-0.10</td>
<td>1.12</td>
<td>.438</td>
<td>0.17</td>
<td>0.05</td>
</tr>
<tr>
<td><strong>Between-person results</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Loneliness</td>
<td>-32.55</td>
<td>17.52</td>
<td>.066</td>
<td>0.06</td>
<td>0.12</td>
<td>0.594</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Pain</td>
<td>1.78</td>
<td>21.15</td>
<td>.933</td>
<td>0.07</td>
<td>0.14</td>
<td>.633</td>
<td>0.28</td>
<td>0.10</td>
</tr>
</tbody>
</table>

Note. SE = standard error, MVPA = moderate-to-vigorous physical activity. Sex was coded as 0 = male, 1 = female. * p < .05, ** p < .01
Table 3

*Results from Multilevel Models Examining Age as a Moderator for Main Outcome Variables*

<table>
<thead>
<tr>
<th>Cross-Level Interactions Predicting Daily Steps</th>
<th>Coefficient</th>
<th>Standard Error</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age x Pain</td>
<td>-0.33</td>
<td>1.03</td>
<td>.748</td>
</tr>
<tr>
<td>Age x Loneliness</td>
<td>-0.57</td>
<td>0.98</td>
<td>.558</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cross-level Interactions Predicting Daily MVPA</th>
<th>Coefficient</th>
<th>Standard Error</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age x Pain</td>
<td>-0.004</td>
<td>0.007</td>
<td>.585</td>
</tr>
<tr>
<td>Age x Loneliness</td>
<td>0.003</td>
<td>0.007</td>
<td>.687</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cross-Level Interactions Predicting Daily Pain</th>
<th>Coefficient</th>
<th>Standard Error</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age x Loneliness</td>
<td>-0.005</td>
<td>0.005</td>
<td>.256</td>
</tr>
</tbody>
</table>

*Note. MVPA = moderate-to-vigorous physical activity*
7 Figures

Figure 1

*Representation of Within- and Between-Person Variability in Number of Steps*

![Pie chart showing 64% Within-Person Variability and 36% Between-Person Variability]

*Note. ICC = 0.64*

Figure 2

*Representation of Within- and Between-Person Variability in MVPA*

![Pie chart showing 63% Within-Person Variability and 37% Between-Person Variability]

*Note. ICC = 0.37; MVPA = moderate-to-vigorous physical activity*
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