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Examining the day-level impact of physical activity on affect during the early months of the COVID-19 pandemic: An ecological momentary assessment study

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A B S T R A C T

Engaging in physical activity (PA) may be a promising approach to mitigate the effects of the COVID-19 pandemic and related restrictions on daily affect. The study used ecological momentary assessment (EMA) to examine the within-subject associations of day-level PA with same-day evening affect. Interactions between daily PA and overall stress related to COVID-19 predicting evening affect were also examined. Adults living in the U.S. (N = 157, Mage = 31.7, 84.1% female) participated in a 28-day smartphone-based EMA study during the early months of the pandemic (April–June 2020). Evening EMA surveys assessed daily PA minutes, momentary positive-activated and deactivated affect, and momentary negative activated and deactivated affect. An online questionnaire assessed demographics. Multi-level linear regression models assessed day-level associations between PA and evening affect, controlling for age, sex, income, body mass index, employment status, and morning affect. There were N = 2499 person-days in the analysis. Baseline COVID-19 stress was not associated with daily PA minutes (p = .09) or positive-activated affect (p = .14), but was associated with lower positive-deactivated affect (p < .001) and greater negative-activated and negative-deactivated affect (ps < .001) in the evenings. On days when individuals reported more PA than usual, they reported greater positive-activated and positive-deactivated affect, and lower negative-activated and negative-deactivated affect in the evening (ps < .001). The interaction of day-level PA and COVID-19 stress predicting evening positive-activated, positive-deactivated, negative-activated, and negative-deactivated affect was not significant (ps > .05). During the early months of the pandemic, adults experienced improved evening affect on days when they engaged in more PA. However, data did not show that PA counteracts detrimental effects of the COVID-19 pandemic on evening affect. Public health efforts should strategically promote and address barriers to PA during the pandemic.

1. Introduction

In early March 2020, COVID-19, the respiratory disease caused by the SARS-CoV-2 virus, was declared a pandemic by the World Health Organization and a national emergency in the United States of America (U.S.). As of May 11, 2021, the date this article was written, there were over 24.8 million COVID-19 cases and 416,010 related deaths in the U.S. (Centers for Disease Control and Prevention, 2020). In order to prevent the spread of COVID-19, state governments in the U.S. issued “Stay-at-home” or “Shelter-in-place” orders, starting between March 19 – April 3, 2020, which generally required “non-essential” businesses to close their physical offices or storefronts and continue operations remotely, discouraging all non-essential travel outside of the home (Abouk & Heydari, 2021; Kates et al., 2020). Most guidelines also included maintaining social distancing of at least six feet and not physically interacting with people outside of one’s own household. In addition, federal, state, and local public parks, trails, and beaches were closed in many jurisdictions starting mid-to-late March with some re-openings occurring in late April or early May, and most others in June.

Social restrictions and closures of businesses and outdoor spaces may disrupt usual routines and significant changes to daily lives due to the COVID-19 pandemic may contribute to widespread emotional distress and increased risk for deteriorating mental health. A systematic review reported relatively high rates of anxiety, depression, and stress during...
the early months of the COVID-19 pandemic among the general population in eight countries (Xiong et al., 2020). Evidence from a study conducted in China at the end of January 2020 found that over half of survey respondents rated the negative psychological impact of COVID-19 as moderate-to-severe (Wang et al., 2020). In addition, a longitudinal study found that the prevalence of clinically significant levels of mental distress increased during April 2020 in the United Kingdom (Pierce et al., 2020). Among a sample of U.S. adults with no prior history of a mental health condition, more than one in four experienced psychological distress in the early phases of the pandemic; the most common symptom experienced for at least three days in the past week was feeling nervous, anxious, or on edge (Holingue et al., 2020). The COVID-19 pandemic may have unfavorable consequences on mental health, which necessitates behavioral strategies to mitigate the burden.

Prior to the COVID-19 pandemic, substantial evidence supported the positive effects of physical activity (PA) on mental health. Previous research suggests that PA can boost emotional well-being, reduce anxiety symptoms, and improve mental health (Physical Activity Guidelines Advisory Committee, 2018; McDowell et al., 2019; Paluska & Schwenk, 2000; Raglin, 1990; Reed & Buck, 2009). PA has also been shown to improve affect; a meta-analysis by Reed and Buck (2009) concluded that aerobic exercise increased self-reported positive affect. PA may also have acute effects on affect, with evidence demonstrating a positive association between PA and momentary positive affect. A systematic review and a meta-analyses revealed engaging in PA predicted higher subsequent positive affect (e.g., 30 min–2 h after finishing PA) (Liao et al., 2015; Reed & Ones, 2006). There is mixed support for the association between PA and subsequent negative affect; some studies reported no association (Liao et al., 2017; Wichers et al., 2012), whereas one study found that children who did more moderate-to-vigorous PA minutes on average reported lower levels of negative affect (Dunton et al., 2014).

Given previous literature on the association between PA and affect, understanding this association in the midst of an unprecedented pandemic may provide further evidence for PA as a potentially promising strategy to alleviate the pandemic’s effects on mental health. Specifically during the COVID-19 pandemic, a cross-sectional study among U.S. adults reported reductions in PA were associated with greater negative mental health consequences (e.g., depressive symptoms, stress) and lower positive mental health (i.e., well-being) (Meyer et al., 2020). A separate study found self-reported moderate-to-vigorous PA to be inversely associated with depressive, anxiety, and co-occurring depressive and anxiety symptoms among self-isolating adults in Brazil during the COVID-19 pandemic (Schuch et al., 2020). Additionally, increased PA during lockdown as compared to before lockdown in Switzerland and France was associated with better perceived physical health, while increased sedentary time was associated with lower physical and mental health (Cheval et al., 2021). Furthermore, PA enhanced positive affect among college students; findings indicated that prospectively assessed changes in PA, from before and during the COVID-19 pandemic, were positively associated with changes in positive affect (Maher et al., 2021). While recent research shows preliminary evidence of cross-sectional and short-term prospective associations between PA and affect or mental health during the COVID-19 pandemic (Cheval et al., 2021), associations at the day-level are unknown.

Examining associations at the person-level can be a form of ecological momentary assessment (EMA), collect information from individuals in their natural environments, making it well-suited to examine within-person (i.e., short-term) variations in PA and affect during a pandemic (Shiffman et al., 2008). Collecting EMA data on smartphones provides benefits such as reductions in biases related to recall and increased ecological validity (Stone et al., 2007). The COVID-19 pandemic is a severe public health crisis that has impacted many lives; thus, recall over long periods of times may be especially subject to biases (e.g., salience bias) which may result in overestimating the frequency or intensity of events and feelings. Employing EMA can be particularly beneficial during the pandemic by gathering data in free-living environments where external contexts are changing as the pandemic continues. By understanding the intra-individual differences in PA on affect, or how individuals vary from day to day (i.e., within-subject effects), future public health programs and interventions can be developed to be tailored to individuals and delivered in real-time.

The first objective of the current study was to examine the within-subject associations of day-level PA with same-day evening affect during the early months of the COVID-19 pandemic. In line with previous literature outside of the pandemic, it was hypothesized that on days when individuals engaged in more PA than usual, they would report greater evening positive-activated and positive-deactivated affect and lower evening negative-activated and negative-deactivated affect. The second study objective was to examine baseline COVID-19 stress as a moderator of the effect of day-level PA on evening affect. It was hypothesized that there would be a significant interaction between day-level PA and COVID-19 stress, such that individuals who reported more COVID-19 stress would report greater evening positive activated and deactivated affect and lower evening negative activated and deactivated affect on days when they report engaging in more PA minutes, compared to days that they reported less PA. Given the potential detrimental effects of the COVID-19 pandemic on mental health and wellbeing among adults, understanding the influential role of health behaviors, such as PA, on daily affect can help guide public health efforts during and after the pandemic (Sallis & Pratt, 2020).

2. Materials and methods

2.1. Study design

An intensive longitudinal study design using a 28-day interval-contingent/fixed time-based EMA study examined the day-level associations between PA and affect. A baseline survey was completed online between April 10 – May 25, 2020. The EMA study was completed between April 11 - June 17, 2020. The current analyses use data from the EMA study and the online baseline survey.

2.2. Recruitment and participants

We used a convenience sampling strategy, focused on recruiting a general population of adults living in the U.S. during the COVID-19 pandemic. Potential participants were electronically invited through various social media platforms (e.g., Facebook, Twitter, Reddit) and university and special interest group email listservs for students, faculty, and staff. Inclusion criteria for the study were: 1) 18 years or older, 2) able to read and speak English, 3) live in the U.S., 4) own and regularly use an Android or iPhone smartphone that is capable of running mobile applications, and 5) willingness to comply with the study protocol and complete app-based surveys. The exclusion criterion was being enrolled in another study related to PA behaviors (including studies monitoring PA, intervening on PA, or examining the effects of wearable fitness trackers). Once eligibility was determined through an online screening questionnaire, individuals agreed to participate through an online anonymous information sheet that described the study procedures, risks, and benefits. The Institutional Review Board of the University of Southern California (HS-20-00304) determined that the study
procedures presented no more than minimal risk and approved the study as exempt from full review. This study was conducted in accordance with the Declaration of Helsinki.

2.3. Procedures

All study procedures took place remotely in order to eliminate in-person interactions. After agreeing to participate in the study, participants completed a baseline survey through an online survey platform, REDCap (Research Electronic Data Capture) (Harris et al., 2009), which took approximately 30 min to complete. Participants were able to complete the survey either on their mobile phone, tablet, or desktop device. Participants were then provided online instructions on how to download a free EMA application and completed up to 28 consecutive days of EMA on their personal smartphone. EMA data were collected through a commercial software mobile phone application for smartphones (RealLifeExp app by LifeData). Participants responded to interval-contingent/fixed time-based survey sampling on their phone. An audible noise and/or vibration notified participants to complete two surveys a day, one in the morning at 8 a.m. and one in the evening at 7 p.m. If no entry was made, participants were sent up to two reminder signals at 45-min intervals (e.g., 8:45 a.m., 9:30 a.m.). Each survey took less than 3 min to complete. Participants were given 2 h to answer each survey; the survey was available from 8 a.m.–10 a.m. and 7 p.m.–9 p.m. Participants were entered into a lottery to win one of ten $50 gift cards after completing the baseline survey; compensation was not given for completing the EMA protocol.

3. Measures

3.1. Self-reported physical activity

During the evening survey, participants indicated whether they had engaged in PA that day. Participants were asked “Did you do physical activity for at least 10 min at least one time today?” Response options included “Yes”, “No”, and “Do not know/Prefers not to answer.” If participants indicated that they had done PA for at least 10 min, they were subsequently asked “During the first time you did physical activity today: How long did it last?” Response options included “10–20 min”, “20–30 min”, “30–40 min”, “40–50 min”, “More than 60 min” and “Do not know/Prefers not to answer.” Participants who reported engaging in one PA bout were subsequently asked if they completed a second PA bout and, if yes, if they completed a third PA bout. The same questions and response options described above were used to assess second and third PA bout duration, respectively. For the analyses, the categorical variable for PA duration was recoded into a continuous variable using the minimum value for each category (e.g., 10 min for “10–20 min”). Total PA minutes per day was used in the final analyses.

3.2. COVID-19 stress

The online baseline survey assessed baseline COVID-19-related stress. Participants were asked to rate their “Overall level of stress related to the COVID-19 outbreak” through a visual analog sliding scale: “Nothing” (left-end) to “Extremely” (right-end). Response values ranged from 0 (“Nothing”) to 100 (“Extreme”), with higher scores indicating more COVID-19 stress. Participant data was centered for the analyses.

3.3. Affect

To reduce participant burden (i.e., each survey can be finished in under 3 min), select items were chosen to represent the two fundamental dimensions of affect suggested by the circumplex model (i.e., valence and arousal) (Russell, 1980; Watson et al., 1999). Positive-activated, positive-deactivated, negative-activated, and negative-deactivated affect were assessed through the morning and evening EMA surveys (Stevens et al., 2020). Participants were asked nine questions in the following format: “How [affect term] were you feeling just before the survey notification?” (Cella et al., 2019). Positive-activated affect (happy, cheerful, energetic or full of pep), positive-deactivated affect (calm or relaxed), negative-activated affect (tense or anxious, stressed, frustrated or angry), and negative-deactivated affect (sad or depressed, fatigued or tired) were assessed. The response options were on a unipolar scale: “Not at all” = 1, “A little” = 2, “Moderately” = 3, “Quite a bit” = 4, “Extremely” = 5, and “Do not know/Prefers not to answer” = 0 (recoded as missing). Scores were averaged to create composite scores for evening and morning positive-activated, positive-deactivated, negative-activated, and negative-deactivated affect, respectively.

3.4. Demographic characteristics

Participants self-reported the following characteristics in the baseline survey: age, biological sex at birth (male, female), race (check all that apply: American Indian/Alaska Native, Asian, Black, Native Hawaiian/Other Pacific Islander, White, Other), ethnicity (Hispanic/Latino, Non-Hispanic/Latino), total combined family income for the past 12 months (later categorized as less than $27,000, $27,000-$59,999, $60,000-$99,999, and $100,000 or more), and employment status (later categorized as working full-time, working part-time, and not working). Body mass index (BMI; kg/m²) was calculated by participant self-reported height and weight. Participants were also asked to indicate if they had any of the following pre-existing conditions: chronic lung disease (asthma/emphysema/COPD), diabetes mellitus, cardiovascular disease, chronic renal disease, liver disease, immunocompromised condition, neurologic/neurodevelopmental/intellectual disability, other chronic diseases, currently pregnant, current smoker, former smoker. Participants were given the option to indicate “Do not know/Prefers not to answer” for each of the demographic questions.

3.4.1. Statistical analyses

The analytic plan was specified prior to analyses. Prior to exploring the study objectives, a series of multi-level linear regressions were run to examine whether baseline COVID-19 stress was associated with daily PA duration, positive activated and deactivated affect, and negative activated and deactivated affect. To test the first study objective of examining the day-level associations between PA and evening affect, multi-level linear regressions models were conducted. The main predictor variable, PA minutes, was disaggregated into between-subject (Level-2, person) and within-subject (Level-1, day) levels to partition the variance (Curran & Bauer, 2011). The between-subject variance represents the individual mean deviation from the grand mean (mean of all observations across all participants), and the within-subject variance represents the deviation from one’s own mean on any given day (Hedeker et al., 2012). The outcomes—positive-activated, positive-deactivated, negative-activated, and negative-deactivated—were examined in separate models. To test the second study objective, cross-level interactions between day-level PA minutes (within-subject, Level-1) and baseline COVID-19 stress (Level-2) were tested predicting evening affect. All models adjusted for the following variables a priori: age, sex, BMI, annual household income, employment status, and morning affect (e.g., morning positive-activated affect when positive-activated affect was the outcome of interest). Multi-level models were conducted in SPSS Version 25 and statistical significance was set at p < .05. Unstandardized regression coefficients, standard errors, and confidence intervals are reported. For observed significant effects, Cohen’s f² was also calculated (PROC MIXED in SAS) to represent effect size (Selya et al., 2012).

4. Results

4.1. Data availability and participant characteristics

A total of 530 individuals expressed interest in the study and...
completed the online screening questions. Of this number, 496 individuals were eligible after completing the screening questions, and 430 individuals agreed to participate in the study. A total of 215 participants had some EMA data (i.e., responded to at least one EMA survey). After matching the morning and evening EMA surveys by date, there were a total of 4765 day-level EMA observations among 215 participants. A total of 2881 (60.46%) day-level observations among 182 participants had responses to both the morning and evening EMA surveys. 245 day-level observations among 4 participants were excluded for having missing data on either morning or evening affect. In addition, 21 participants (227 day-level observations), were excluded for having missing COVID-19 stress or covariate data. The final analytic sample included N = 157 participants (Level-2) and N = 2409 day-level observations (Level-1).

Descriptive statistics for the demographic characteristics of the analytic sample are shown in Table 1. Participants ranged in age from 18 to 79 years with an average age of 31.66 (SD = 10.11) years. The majority of participants reported female for biological sex at birth and did not self-identify as Hispanic/Latino. About 55% of the participants indicated that they were working full-time, whereas 24% of participants indicated that they were not working. About 40% of the sample reported an annual family household income of greater than $100,000. The average BMI was 24.17 kg/m² (categorized as normal weight). About 28% of the participants had a BMI categorized as overweight and 9.6% of participants had a BMI categorized as obese. About 75% of participants reported to have no pre-existing medical conditions and 25% indicated one pre-existing medical condition. Full demographic characteristics are shown in the Appendix Table A1. Descriptive statistics for self-reported PA are also shown in Table I. Participants reported at least one PA bout (lasting ≥ 10 min) on 73.31% of the days during the monitoring period. Intercept only multi-level models were conducted to estimate mean levels of PA minutes, positive activated and deactivated affect, and negative activated and deactivated affect, with the intercept interpreted as the mean. The mean number of daily PA minutes was 30.09, the mean evening positive-activated affect score was 2.54, the mean evening positive-deactivated affect score was 2.75, the mean evening negative-activated affect score was 1.81, and the mean evening negative-deactivated affect score was 2.01. Evening affect scores ranged from 1.0 to 5.0.

4.2. Associations of Baseline COVID-19 stress with daily total PA and evening affect

Separate multi-level linear regressions explored the association between baseline COVID-19 stress with daily PA minutes, evening positive activated and deactivated affect, and evening negative activated and deactivated affect. Univariate associations were examined prior to adjusting for covariates; the results were similar to the findings from complete models (results not shown). Results for each multi-level model are shown in Table 2. Baseline COVID-19 stress was not significantly associated with daily PA minutes (Estimate = −0.15, SE = 0.09, 95% CI = [-0.33, 0.03], \( f^2 < 0.001, p = .09 \)) or positive-activated affect (Estimate = −0.004, SE = 0.002, 95% CI = [-0.01, 0.001], \( f^2 < 0.001, p = .14 \)). COVID-19 stress was associated with positive-deactivated affect (Estimate = −0.01, SE = 0.002, 95% CI = [-0.01, 0.001], \( f^2 < 0.001, p = .01 \), negative-activated affect (Estimate = 0.01, SE = 0.002, 95% CI = [0.007, 0.02], \( f^2 = 0.003, p < .001 \), and negative-deactivated affect (Estimate = 0.01, SE = 0.002, 95% CI = [0.01, 0.02], \( f^2 = 0.002, p < .001 \)). These results indicate that individuals who reported having more stress due to the COVID-19 pandemic reported lower evening positive-deactivated affect and greater evening negative activated and deactivated affect.

4.3. Within-subject associations of day-level PA with evening affect

The first study objective examined the day-level associations between daily PA minutes and evening affect. Univariate associations were examined prior to adjusting for covariates; the results were similar to the findings from complete models (results not shown). Results are shown in Tables 3 and 4. On days when individuals engaged in more PA than usual, they reported greater evening positive-activated affect (Within-subject effect; Estimate = 0.004, SE = 0.001, \( f^2 = 0.03, p < .001 \)) and positive-deactivated affect (Within-subject effect; Estimate = 0.003, SE = 0.001, \( f^2 = 0.01, p < .001 \)). The results indicate that on days when individuals engaged in 10 more minutes of PA than usual, their evening positive-activated affect score increased by a 0.04. Similarly, an increase in 10 min of PA was associated with an increase of 0.03 in positive-
Within-subject effect; Estimate
than usual, they reported lower evening negative-activated affect and deactivated affect. In addition, on days individuals engaged in more PA than usual, they reported lower evening negative-activated affect and deactivated affect. The results suggest that on days when individuals engaged in 10 more minutes of PA a day than usual, their evening negative-activated affect decreased by 0.01 and their negative-deactivated affect decreased by 0.01. There were no between-subject effects of mean daily PA on evening positive-activated (Between-subject effect; Estimate = −0.002, SE = 0.001, \( f^2 = 0.01, p < .001 \)) and negative-deactivated affect (Within-subject effect; Estimate = −0.001, \( SE = 0.001, f^2 = 0.002, p = .01 \)). The results suggest that on days when individuals engaged in 10 more minutes of PA a day than usual, their evening negative-activated affect decreased by 0.02 and their negative-deactivated affect decreased by 0.01. There were no between-subject effects of mean daily PA on evening positive-activated (Between-subject effect; Estimate = 0.001, \( SE = 0.002, p = .72 \)), positive-deactivated (Between-subject effect; Estimate = 0.002, \( SE = 0.002, p = .92 \)), negative-deactivated (Between-subject effect; Estimate = −0.002, \( SE = 0.001, p = .11 \)), or negative-deactivated affect (Between-subject-effect; Estimate = 0.001, \( SE = 0.001, p = .44 \)). To explore whether there were interactions between day-level PA and personal characteristics, post-hoc models tested the moderating effects of age and sex. Post-hoc multi-level models examined the following interactions: Within-subject PA × Age and Within-subject PA × Sex. Each interaction was tested in a separate model. Results indicated null interactions for positive-activated, positive-deactivated, negative-activated, and negative-deactivated affect, suggesting the associations did not differ by age or sex (\( p < .05 \)).

### 4.4. Interaction between day-level PA and COVID-19 stress predicting evening affect

The second study objective explored the interaction between day-level PA and baseline COVID-19 stress predicting evening positive-activated, positive-deactivated, negative-activated, and negative-deactivated affect; the results are shown in Tables 3 and 4. The interaction term Within-subject physical activity × COVID-19 stress was not significant in any model, suggesting that COVID-19 stress did not significantly moderate the effect of Within-subject day-level PA on evening positive-activated (Estimate = −1.21E-5, \( SE = 3.86E-5, p = .75 \)), positive-deactivated (Estimate = −7.05E-5, \( SE = 4.82E-5, p = .14 \)), negative-activated (Estimate = −3.87E-5, \( SE = 3.61E-5, p = .28 \)), or negative-deactivated affect (Estimate = −1.99E-5, \( SE = 3.50E-5, p = .57 \)). Post-hoc analyses examined the interaction between between-subject PA and COVID-19 stress. After controlling for main effects and covariates, the Between-subject physical activity × COVID-19 stress

### Table 2
Multi-level models examining the associations of baseline COVID-19 stress with daily total PA, positive activated and deactivated affect, and negative activated and deactivated affect.

|                          | Main Effects Models | Interaction Models |
|--------------------------|---------------------|--------------------|
|                          | Positive-Activated Affect | Positive-Deactivated Affect | Positive-Activated Affect | Positive-Deactivated Affect |
|                          | Estimate (SE) | 95% CI | \( f^2 \) | Estimate (SE) | 95% CI | \( f^2 \) | Estimate (SE) | 95% CI | \( f^2 \) | Estimate (SE) | 95% CI | \( f^2 \) |
| Intercept                | 1.69 (0.37) | 0.97, 2.42 | *** | 1.86 (0.34) | 1.18, 2.53 | *** | 1.69 (0.37) | 0.97, 2.42 | *** | 1.86 (0.34) | 1.18, 2.53 | *** |
| Level-1 (day)            |                     |               |     |                     |               |     |                     |               |     |                     |               |     |
| Within-subject physical activity | 0.004 | 0.003, 0.03 | 0.003 | 0.002, 0.01 | 0.01 | 0.004 | 0.003, 0.03 | 0.01 | 0.004 | 0.003, 0.03 | 0.01 |
| Morning affect* | 0.22 (0.02) | 0.18, 0.26 | 0.02 | 0.16, 0.24 | 0.02 | 0.22 (0.02) | 0.18, 0.26 | 0.02 | 0.20 (0.02) | 0.16, 0.24 | 0.02 |
| Level-2 (person)         |                     |               |     |                     |               |     |                     |               |     |                     |               |     |
| Between-subject physical activity | −0.003 | −0.003, 0.002 | −0.003 | −0.003, 0.002 | 0.001 | −0.003 | −0.003, 0.002 | 0.001 | −0.003 | −0.003, 0.002 | 0.001 |
| COVID-19 stress          | −0.003 | −0.01, 0.01 | 0.002 | 0.004 | 0.002 | −0.003 | −0.01, 0.01 | <.001 | −0.003 | −0.01, 0.01 | <.001 |
| Within-subject physical activity × COVID-19 stress | −1.2E-5 | (3.9E-5) | 6.4E-5 | (4.8E-5) | 2.4E-7 |

*Corresponding morning affect (e.g., morning positive-activated affect when evening positive-activated affect was the outcome of interest).

### Table 3
Multi-level models examining the association between physical activity, baseline COVID-19 stress, and positive activated and deactivated affect.

|                          | Positive-Activated Affect | Positive-Deactivated Affect |
|--------------------------|--------------------------|-----------------------------|
|                          | Estimate (SE) | 95% CI | \( f^2 \) | Estimate (SE) | 95% CI | \( f^2 \) |
| Intercept                | 30.74 (13.65)* | 2.09 (0.43)*** | 2.27 (0.40)*** | 1.55 (0.31)*** | 1.74 (0.32)*** |
| Baseline COVID-19 stress | −0.15 (0.09) | −0.004 (0.003)*** | −0.01 (0.003)*** | 0.01 (0.002)*** | 0.01 (0.002)*** |
| Age                      | 0.35 (0.21) | 0.01 (0.01) | 0.01 (0.01) | −0.004 (0.005) | −0.01 (0.005) |
| Sex (female)             | 1.43 (4.73) | 0.10 (0.15) | 0.16 (0.14) | −0.17 (0.11) | −0.19 (0.11) |
| Body mass index          | −0.82 (0.43) | 0.02 (0.01) | 0.02 (0.01) | 0.01 (0.01) | 0.02 (0.01) |
| Average household income | < $27,000 | −1.17 (0.65) | −0.32 (0.19) | −0.31 (0.18) | 0.29 (0.14)* | 0.12 (0.14) |
| $27,000-$59,999           | 1.51 (4.62) | 0.02 (0.15) | 0.06 (0.13) | 0.11 (0.11) | −0.11 (0.11) |
| $60,000-$99,999           | 2.52 (5.10) | −0.20 (0.16) | −0.15 (0.15) | 0.002 (0.12) | −0.20 (0.12) |
| Current work status      | 11.72 (5.10)* | −0.27 (0.16) | −0.32 (0.15)* | 0.22 (0.12) | 0.09 (0.12) |
| Working part-time        | 8.21 (5.55) | −0.39 (0.18) | −0.23 (0.16) | 0.15 (0.13) | 0.03 (0.13) |

Note. \( N = 157 \) participants, \( N = 2409 \) day-level observations. Models controlled for age, biological sex (female, male), body mass index, average household income (Less than $27,000, $27,000-$59,999, $60,000-$99,999, More than $100,000), and current work status (working full-time, working part-time, not working).

\( *p < .05 \), \( **p < .01 \), \( ***p < .001 \).
interaction predicting evening negative-activated affect was significant (Estimate = −0.0002, \( f^2 < 0.01, p = .01 \)). The interaction was not significant in the other three models (\( ps > .05 \)). The effect of COVID-19 stress on negative-activated affect may be stronger among those who reported lower overall PA, compared to those who reported greater overall PA.

5. Discussion

The current study is one of the first known studies using EMA to examine the day-level associations between PA and evening affect during the early months of the COVID-19 pandemic. COVID-19 stress was associated with lower evening positive-activated affect and greater evening negative-activated and deactivated affect during April–June 2020. As expected, there were significant within-subject associations of PA with evening positive-activated, positive-deactivated, negative-activated, and negative-deactivated affect; on days when individuals engaged in more PA than usual, they reported greater evening positive activated and deactivated affect and lower evening negative activated and deactivated affect. There were no between-subject associations of PA with evening affect. Additionally, the interaction between daily PA and COVID-19 stress was not significant, indicating that daily PA did not buffer the associations between COVID-19 stress and evening affect.

The significant within-subject findings contribute to the existing literature on the association between affect and PA and provide additional evidence that these relationships withstand a major life-altering event such as a widespread pandemic. The current study’s findings on positive activated and deactivated affect are consistent with prior research outside of the COVID-19 pandemic (Liao et al., 2017), whereas a previous study among children reported null within-subject findings on the association between PA and subsequent negative affect (Dunton et al., 2014). The current study findings contribute to the literature by providing evidence for a significant association between day-level PA and evening negative activated and deactivated affect. Although the causal relationship may still require further temporal resolution, the current study suggests that PA performed during the day had positive outcomes on evening affect during the pandemic even when controlling for baseline COVID-19 stress. These day-level associations highlight the potential importance of PA engagement for improving affect, even during the COVID-19 pandemic. However, the significant results should be interpreted with caution given the small effect sizes (\( f^2 < 0.04 \)). While PA was found to improve evening affect, the effect may not substantially change affect during the pandemic. In addition to PA, other strategies such as reducing screen time or exercising outdoors, may need to be implemented in order to improve affect (Manferdelli et al., 2019; Meyer et al., 2020). Additional research is warranted to elucidate the effect of PA on negative-activated and negative-deactivated affect, both during and outside of a global pandemic. Future studies may benefit by incorporating event-contingent EMA, or participant self-initiated surveys when a certain event occurs (e.g., exercise), to further examine these associations across different, acute periods such as minutes and hours (Burke et al., 2017; Liao et al., 2015). EMA methods can explore the dynamic relationship between PA and time-varying factors, such as affective states and contextual exposures, to improve theoretical models of health behavior and intervention designs (Dunton, 2017).

The second study objective sought to assess whether PA during the pandemic buffered (i.e., lessened) the effect of COVID-19 stress on evening affect. It was hypothesized that individuals who experienced greater COVID-19 stress at baseline would have greater evening positive activated and deactivated affect and lower evening negative activated and deactivated affect than days that they are more physically active, compared to days that they are less physically active. The hypothesis was not supported; the null findings suggest that the daily association between PA and evening affect did not differ among people with higher or lower levels of baseline COVID-19 stress. In addition, baseline COVID-19 stress was not significantly associated with total day PA. Nevertheless, these null results should be interpreted with caution given the associations appear to be small in size. While COVID-19 stress and day-level PA were associated with evening positive-deactivated, negative-activated, and negative-deactivated affect, the results suggest that day-level PA did not diminish the effects of COVID-19 stress on evening affect. Given that COVID-19 stress was associated with consistently lower positive-deactivated affect and greater negative-activated and negative-deactivated affect regardless of PA engagement, the null interactions may be a due to the effects of baseline COVID-19 stress being too large for day-level PA to attenuate. Moreover, the influence of baseline COVID-19-related stress on daily affect may be long-lasting and unaffected by day-to-day PA engagement. Post-hoc analyses indicated between-subject PA buffered the association between baseline COVID-19 stress and negative-activated affect. These findings suggest the effect of COVID-19 stress on negative-activated affect is stronger among

| Table 4 | Multi-level models examining the association between physical activity, baseline COVID-19 stress, and negative activated and deactivated affect. |
|---------|--------------------------------------------------------------------------------------------------------------------------------|
| **Main Effects Models** | **Interaction Models** |
| **Negative-Activated Affect** | **Negative-Deactivated Affect** | **Negative-Activated Affect** | **Negative-Deactivated Affect** |
| Estimate | 95% CI | \( f^2 \) | Estimate | 95% CI | \( f^2 \) | Estimate | 95% CI | \( f^2 \) |
| Intercept | 1.26 (0.25) | 0.77, 1.74 | 1.22 (0.27) | 0.68, 1.75 | 1.26 (0.25) | 0.77, 1.74 | 1.22 (0.27) | 0.68, 1.75 |
| **Level-1 (day)** | **Level-2 (person)** | **Level-2 (person)** | **Level-2 (person)** |
| Within-subject | ** physical activity** | **Morning affect** | **COVID-19 stress** | **Within-subject** | **physical activity** | **COVID-19 stress** | **physical activity** | **COVID-19 stress** |
| Estimate | 0.0001 | 0.06 | 0.01 | 3.9E-5 | \(-3.6E-5\) | \(9.8E-5\) |
| 95% CI | 0.00, 0.01 | 0.00, 0.05 | 0.01 | 0.00, 0.05 | 0.00, 0.05 | 0.00, 0.05 | 0.00, 0.05 | 0.00, 0.05 |
| \( f^2 \) | 0.0003 | 0.004 | 0.0001 | 3.9E-5 | \(-3.6E-5\) | \(9.8E-5\) |

**Note.** \( N = 157 \) participants, \( N = 2409 \) day-level observations. Models controlled for age, biological sex (female, male), body mass index, average household income (Less than $27,000, $27,000-$59,999, $60,000-$99,999, More than $100,000), and current work status (working full-time, working part-time, not working).

* \( p < .05 \). ** \( p < .01 \). *** \( p < .001 \).

*Corresponding morning affect (e.g., morning negative-activated affect when evening negative-activated affect was the outcome of interest).
those who reported lower overall PA, compared to those who reported greater overall PA. Overall PA may attenuate the effects of baseline COVID-19 stress on evening reports of feeling tense or anxious, frustrated or angry, and stressed. However, these results should be interpreted with caution given the association appears to be small in size. In this sample of fairly active adults, day-level PA did not buffer the effects of COVID-19 stress on affect; however, it is possible that PA may buffer the effects of COVID-19 stress in less active populations. Greater changes in PA, from before to during the pandemic, may be needed to produce a “stress-reduction” effect during the pandemic; future research and interventions may seek to produce greater PA engagement in order to buffer the effects of stress. Despite these null findings, the associations between daily PA and evening affect underscore the importance of engaging in PA during the COVID-19 pandemic.

Considering the within-subject findings are consistent with previous studies conducted outside of the context of the pandemic, as well as the absence of moderation by day-level PA on the association between baseline COVID-19 stress and evening affect, these findings may not be specific to the COVID-19 pandemic period. Rather, these findings provide evidence that the effect of daily PA on improving affect remains consistent during and outside of the context of a global public health crisis and periods of stressful life events. This underscores the importance of engaging in PA for same-day affect. Given the recent evidence that PA decreased and sedentary behavior increased during the early months of the pandemic in the U.S. (Duncan et al., 2020; Dunton et al., 2020; Meyer et al., 2020) and worldwide (Ammar et al., 2020; Richardson et al., 2020; Tison et al., 2020), public health efforts are needed to increase PA among adults, particularly to help mitigate the detrimental effects of the pandemic on daily affect. Along with the positive effects of PA on affect and mental health, PA is also thought to have respiratory and immune-protective effects against COVID-19 (Füzéki et al., 2020; Woods et al., 2020). Promoting and implementing programs for home-based and outdoor PA could be advantageous for both mental and physical health and well-being; making use of homes and outdoor spaces can be valuable given that indoor gym facilities may be closed and unable to accommodate social distancing guidelines. Recommendations include affordable online classes, promoting exercises that do not require equipment, activities for different fitness levels and intensities, implementing open street initiatives, and encouraging activity in outdoor spaces (Dwyer et al., 2020; Füzéki et al., 2020; Hammami et al., 2020; Sallis et al., 2020; Sallis & Pratt, 2020).

Strengths of the study included the collection of intensive longitudinal data during the early months of the COVID-19 pandemic (April–June 2020) and the daily assessment of momentary affect through EMA. However, there were some limitations. PA was self-reported by participants, rather than objectively measured, which can introduce reporting biases. However, this approach has been previously validated against accelerometry (Knell et al., 2017) and participants were asked to recall same-day activity engagement, which offers a smaller retrospective time-frame compared to weekly or monthly assessments. Additionally, PA was not defined for participants in the EMA surveys. The current study’s design may not fully capture the within-subject effects that play out over a shorter amount of time (e.g., PA influencing affect over the next hour). Additionally, daily physical activity and current evening affect were both reported during the daily evening EMA survey; evening PA bouts (e.g., those occurring after 7 p.m.) may have been missed. Another limitation to note is that COVID-19-related stress was assessed during the baseline survey and not during daily EMA surveys; therefore, the effects of PA on evening affect were unable to account for daily COVID-19 related stress. Future studies may benefit by incorporating additional daily COVID-19 related EMA questions. In addition, study participants resided in a variety of states and thus were subject to different restrictions and closures; varying guidelines may have influenced the mental health and physical activity of participants differently. The current study is unable to infer causality between PA and affect due to the methodology. It is possible that there were reverse directional associations between PA and affect (Hevel et al., 2021; Liao et al., 2017), which cannot be fully ruled out through measurement temporality and adjustment for morning affect. The study is also limited by the use of a convenience sampling strategy, which may have resulted in selection bias. Lastly, the sample largely consisted of younger adults who were female and from middle-to-higher income households. Given that the study sample is not representative of the entire U.S. population, findings may not be generalizable or fully capture the impact of the COVID-19 pandemic, especially among racial/ethnic minorities or adults from lower income households (Yang & Xiang, 2021). Future research is needed to examine these associations in larger, more representative samples.

6. Conclusions

Results from the study indicate that during the early months of the COVID-19 pandemic, days when adults in engaged in more PA were followed by evenings with improved affect. These findings suggest that PA may be a useful approach for improving affect during the COVID-19 pandemic. However, the null interaction between daily PA and baseline COVID-19 stress suggests that PA may not attenuate the consequences of baseline COVID-19 stress on daily affect. Future research should further investigate the temporality of the association while integrating wearable devices or sensors. Given that higher levels of PA may be needed to have a stress-reducing effect, policies and public health efforts should strategically address the barriers to PA and promote safe opportunities for PA. While complying with all local and national regulations, different PA options and access to recreational spaces should be encouraged in order to improve daily affect during a time marked by uncertainty and stress.

CRediT authorship contribution statement

Bridgette Do: Conceptualization, Writing – original draft, Data curation, Formal analysis, Writing – review & editing. Shirlene D. Wang: Data curation, Writing – review & editing. Jimikaye B. Courtney: Data curation, Writing – review & editing. Genevieve F. Dunton: Conceptualization, Methodology, Supervision, Funding acquisition, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no conflict of interest.

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Appendix

Table A1
Full Demographic Characteristics (N = 157)*

| Demographics | n (%) |
|--------------|-------|
| Age in years | Mean ± SD | 31.7 ± 10.1 |
| Age Category | <40 years | 132 (84.1) |
|              | 40–59 years | 22 (14.0) |
|              | 60+ years | 3 (1.9) |
| Sex | Female | 132 (84.1) |
|      | Male | 25 (15.9) |
| Ethnicity | Hispanic | 36 (22.9) |
|          | Non-Hispanic | 121 (77.1) |
| Race* | American Indian/Alaska Native | 2 |
|       | Asian | 22 |
|       | Black | 6 |
|       | Native Hawaiian/Other Pacific Islander | 3 |
|       | White | 121 |
|       | Other Race | 10 |
|       | Do Not Know/Prefer Not To Answer | 2 |
| Education | 12th Grade or Less | 0 (0.0) |
|          | High School Graduate or Ged | 4 (2.5) |
|          | Some College/Technical School/AA | 4 (2.5) |
|          | Bachelor’s Degree | 60 (38.2) |
|          | Graduate Degree | 89 (56.7) |
| Current School Status | Not in School | 86 (54.8) |
|                      | Community College/Technical School | 4 (2.5) |
|                      | 4-Year University | 6 (3.8) |
|                      | Graduate/Professional School | 61 (38.9) |
| Work Status | Full-Time (>40 h/week) | 87 (55.4) |
|             | Part-Time (20–39 h/week) | 21 (13.8) |
|             | Part-Time (<20 h/week) | 24 (15.3) |
|             | Unemployed – Not looking for work | 13 (8.3) |
|             | Unemployed – Looking for work | 10 (6.4) |
|             | Disabled/Retired/Not looking for work | 1 (0.6) |
| Annual Household Income | < $12,500 | 8 (5.1) |
|                     | $12,500 – $26,999 | 15 (9.6) |
|                     | $27,000 – $44,999 | 30 (19.1) |
|                     | $45,000 – $59,999 | 15 (9.6) |
|                     | $60,000 – $74,999 | 13 (8.3) |
|                     | $75,000 – $99,999 | 12 (7.6) |
|                     | $100,000 – $149,999 | 30 (19.1) |
|                     | ≥ $150,000 | 34 (21.7) |

*Data shown without the collapsed categories used in the final analyses.

**Participants were able to select all that apply.

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