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RESEARCH ARTICLE

Effects of Aerobic Exercise Training on Daily Psychological Processes in Family Caregivers: Secondary Analyses of a Randomized Controlled Trial

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Abstract
The aim of this study was to examine the effects of a 24-week aerobic exercise training program on daily psychological processes and occurrence of stressors in a group of previously physically underactive family caregivers of patients with dementia. As part of the Fitness, Aging, and STress (FAST) randomized controlled trial, 68 participants (F = 55; M = 13) were randomized to either a staff-supported, 24-week aerobic training ($N = 34$) program or waitlist control ($N = 34$) group. Approximately 2 weeks prior to randomization, ecological momentary assessments were completed 6 times per day for 7 days and again in the 24th week of the trial to assess exposure to levels of momentary positive affect, negative affect, rumination, control, and the occurrence of stressors throughout the day. These secondary analyses with data from 56 of the participants revealed that the intervention group showed a significantly larger increase in daily positive affect and perceptions of control compared to control participants over the course of the intervention. A treatment effect was also found for negative affect and rumination, whereby both decreased to a greater extent in the intervention group when compared with participants in the control condition. The 24-week aerobic training program had significant impacts on daily psychological processes in family caregivers, deepening our understanding of the robust effects of exercise on mental health.

Keywords Aerobic exercise · Affective states · Rumination · Perceived control · Ecological momentary assessments · Randomized controlled trial

Introduction

Engaging in aerobic exercise (i.e., planned structured bouts of physical activity for health benefits; Caspersen et al., 1985) confers reduced risk for physical morbidities (Pedersen & Saltin, 2015). The benefits of aerobic exercise are psychological as well, with meta-analyses reporting that randomized controlled trials of exercise interventions have consistent and robust antidepressant and anxiolytic effects in clinical and non-clinical populations (Rethorst et al., 2009; Schuch et al., 2016; Stubbs et al., 2017; Wipfli et al., 2008).

A growing body of evidence suggests that exercise improves trait positive and negative affect (e.g., McIntyre et al., 2020; Reed & Buck, 2009). However, the effects of increasing aerobic exercise levels on daily or state affect remain largely unknown. To date, only one study (Williams et al., 2016) has examined the effects of aerobic exercise on affect in previously physically underactive adults using daily assessments in naturalistic settings within the context of a

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randomized controlled design. In their study, Williams et al. (2016) demonstrated that previously underactive participants randomized to engage in exercise at a self-selected pace were more likely to report greater positively valenced *integral* affect—affect reported during or in response to a specific behavior—compared to those asked to engage in prescribed moderate levels of aerobic activity. Importantly, Williams and colleagues demonstrated that these differences in integral affect corresponded with increased likelihood of engaging in exercise at a future assessment point.

In the current study, we examined whether naturalistically occurring incidental positive and negative affect—affect not specifically associated with a behavior—were modified by a 24-week aerobic exercise program in a sample of previously physically underactive family caregivers. We further examined whether daily cognitive processes, including rumination and perceived control throughout the day, were changed in response to the exercise program in our sample of caregivers randomized to an exercise arm compared to those randomized to the waitlist control group. We chose to study family caregivers because they are prone to mental and physical health conditions (Glaser et al., 2001; Schulz & Beach, 1999; Schulz & Martire, 2004; Vitaliano et al., 2003), in part due to increased exposure to daily stressors (Gouin et al., 2012; Smith et al., 2010).

Daily Psychological Processes

Four decades of research have established that increased exposure to daily stressors is as important as major stressful life events in shaping health and wellbeing (Almeida et al., 2011). DeLongis and colleagues were the first to report that a greater number of stressful events that occur on a daily basis are associated with global (DeLongis et al., 1982) and daily (DeLongis et al., 1988) physical health.

In addition to daily stressors, daily affective states and cognitive processes are also proposed and evidenced to impact health and wellbeing (Almeida et al., 2011; Brosschot et al., 2006). For example, daily positive affect, measured nightly for 8 days and averaged, has been prospectively found to be associated with better self-reported health, lower number of chronic conditions, and reduced risk of earlier mortality 9 years later, while the reverse associations were evident for averaged daily negative affect (Willroth et al., 2020). Relatedly, the greater the decrease in positive affect on days with stressful events compared to days without such events is prospectively associated with increased likelihood of mortality 10 years later (Mroczek et al., 2015). Others have similarly found that increases in negative affect on days people experience stressful events compared with days without stressors have been shown to prospectively predict psychological (Charles et al., 2013) and physical (Piazza et al., 2013) health a decade later, and mortality 20 years later (Chiang et al., 2018).

In contrast to the emerging literature examining the prospective effects of daily affective states on long-term health and wellbeing, the majority of studies that have investigated the role of daily cognitive processes in health and wellbeing have focused on daily fluctuations in these outcomes. Elevations within individuals' daily perseverative cognitions, such as rumination or worry, from one day to another have been shown to predict poorer daily negative affect (Moberly & Watkins, 2008; Puterman et al., 2010), health complaints (Verkuil et al., 2012), and nightly sleep disturbances (Sladek et al., 2020). Although daily perseverative cognitions, such as rumination or worry, might predict worsening daily mood or health problems, reporting a greater sense of control during the day predicts lower negative affect (Diehl & Hay, 2010).

To summarize, daily affective states and cognitive processes, independent of and in response to daily stressors, shape daily and long-term health and wellbeing, for good or bad. In the current investigation, we examine whether an aerobic exercise intervention program can alter daily affective or cognitive processes reported throughout the day, though not in response to the occurrence of stressful events.

Physical Activity and Daily Psychological Processes

The majority of naturalistic studies in psychological research measuring physical activity (i.e., any movement of the body resulting in energy expenditure; Caspersen et al., 1985) and exercise on a daily basis have examined their associations with daily affective states. Poole et al. (2011) showed that greater amounts of physical activity measured over 2 weeks with accelerometers were associated with higher average positive affect measured nightly over the same time period but not with average negative affect. In contrast, Bernstein et al. (2019) demonstrated that greater amounts of exercise reported over a 15-day period are associated with reduced persistence of anxiety over the same period. Other studies using naturalistic designs have examined the relationship between physical activity and exercise with affect *at the daily level*. Wichers et al. (2012) showed that self-reported exercise bouts are associated with subsequent rises in positive affect following the bout lasting for as long as 3 h, but not associated with subsequent changes in negative affect. In contrast, a recent daily experience sampling study among 2,022 individuals over 8 consecutive days provided evidence that daily negative affect and the change in daily negative affect on days with stressors compared with days without stressors (i.e., negative affective reactivity) were lower among active compared with low active individuals (Puterman et al., 2017). These findings, in addition to others (e.g., Emerson et al., 2018; Hyde et al., 2011; Liao et al., 2017; Mata et al., 2012), provide indications that regular physical activity and exercise may be related to either higher positive affect or lower negative affect on a daily basis.

To our knowledge, no observational or intervention studies have investigated relationships between daily physical activity and exercise and daily cognitive processes, such as rumination and perceived control. However, in light of previous studies demonstrating that rumination and perceived control are associated with changes in affect, health, and sleep (Moberly & Watkins, 2008; Puterman et al., 2010; Sladek et al., 2020; Verkuil et al., 2012) on a daily basis, and studies linking physical activity to positive (Mata et al., 2012; Wichers et al., 2012) and negative (Bernstein et al., 2019; Puterman et al., 2017) affect, it is plausible that physical activity may also be related to reduced daily rumination and increased daily perceptions of control. In the current study, we investigate whether an aerobic exercise intervention trial can lead to changes in daily positive affect, negative affect, rumination, and perceived control over the course of the 24-week trial in caregivers randomized to exercise compared to waitlist control participants.

The Current Study

The aim of this study was to examine the effects of a 24-week individualized aerobic exercise program on daily reports of psychological processes. The study represents a secondary analysis of data derived from a randomized controlled trial (RCT), which involved a highly stressed, inactive group of family caregivers of patients with Alzheimer's disease or dementia-related disorders (ADRD). Family caregivers report significantly less physical activity and exercise than their non-caregiver counterparts (Burton et al., 1997; King & Brassington, 1997), and caregivers of patients with ADRD typically experience higher levels of stress and depression, lower subjective wellbeing, and poorer physical health than caregivers of patients with other disorders and non-caregivers (Pinquart & Sörensen, 2003). Family caregivers are also at ~ 60% higher risk of cardiovascular disease (Lee et al., 2003) and early mortality than non-caregiving adults (Schulz & Beach, 1999), partly accounted for by the emotional strain of caregiving (Schulz & Martire, 2004) and partly through reduced engagement in healthy behaviors (Schulz et al., 1997). The AARP (2015) reported that approximately 17% (39.8 million) of Americans provided informal care to an adult with a disability or illness over the past 12 months. ADRD accounted for 22% of the conditions for which these individuals provided care. Caregiving is time-intensive, with caregivers providing an average of 45 h of care to a spouse or partner per week, or an average of 24 h to another family member or friend (AARP, 2015). The US Congressional Budget Office estimated that the unpaid labor provided by informal family caregivers was worth $234 billion in 2013 (Congressional Budget Office, 2013).

Data for the current study comes from the Fitness, Aging, and STress (FAST) study, in which greater than 80% of previously inactive participants randomized to an aerobic exercise program increased their moderate-to-vigorous physical activity levels to at least 120 min per week over the course of a 24-week trial compared to participants randomized to a waitlist control group who remained low in activity at the completion of the study (see Puterman et al., 2018 for more details). In this current study, daily stressors and psychological processes were measured randomly 6 times per day for 7 consecutive days prior to condition randomization to either the aerobic exercise program or waitlist control arm and in the final week of the intervention (Puterman et al., 2018).

In the current set of secondary analyses, we hypothesized that caregivers who were randomized to the exercise arm of the study would have significant reductions from baseline to trial completion in negative affect and rumination measured repeatedly and randomly throughout the day for 7 days compared with caregivers randomized to the waitlist control group. We further hypothesized that caregivers randomized to the exercise arm would display significant increases in reported daily positive affect and perceptions of control when compared with caregivers randomized to the waitlist control group. Finally, in light of previous observational (i.e., non-experimental) research demonstrating that there were no differences between number of days with or without stressors between active and low active participants (Puterman et al., 2017), we did not expect that number of stressors reported during the week would differ between the caregivers assigned to aerobic exercise and those assigned to the waitlist control. As such, no a priori hypotheses were advanced for the effects of the aerobic exercise intervention in relation to number of stressors reported; however, we examined this as an exploratory research question in the current study.

Methods

Data presented in this manuscript were collected as part of the FAST study, which examined the effects of a 24-week aerobic exercise training program on cellular and psychological markers of health in high-stressed, inactive caregivers. The randomized trial's recruitment, intervention, and data collection were conducted at the University of California San Francisco (UCSF) with approval from UCSF's institutional review board and have been reported previously (Puterman et al., 2018). Data analyses were completed at the University of British Columbia with approval from the ethics boards of both institutions. The trial was registered at clinicaltrials.gov (#NCT01993082) and received funding from the National Heart, Lung, and Blood Institute (R00HL109247) and the Alzheimer's Association (014-NIRG-302742).

Participants

All interested 50- to 75-year-old adults were required to be English speaking and provide a minimum of 10 h/week of unpaid care to a family member with ADRD (life expectancy > 1 year). All interested adults were required to have a body mass index between 20 and 35 kg/m^2, have access to a computer, and if female, be post-menopausal. Interested adults were only included if they reported Perceived Stress Scale (PSS; Cohen et al., 1983) scores ≥ 0.5 standard deviations (3.5 PSS units) above the most updated reported norms in the USA (Cohen & Janicki-Deverts, 2012) at the time of study recruitment (PSS ≥ 15 for adults 65 and older; PSS ≥ 18 for adults aged 50–64). Lastly, interested adults were required to report lower physical activity levels than those recommended by the Centers for Disease Control and Prevention, measured using the Stanford Leisure Time Activity Categorical Item (L-CAT; Kiernan et al., 2013). Exclusion criteria included major chronic conditions (e.g., cardiovascular, liver, or autoimmune), cancer outside of remission (i.e., current diagnosis or having received chemotherapy or radiation within the past 10 years), heart attack in the past 6 months or repeated chest pain, pressure and/or arrhythmia, eating disorders (e.g., bulimia, anorexia nervosa), endocrine disorders (e.g., Cushing's syndrome), current substance dependence or addiction, current smoking, steroid medication use, or contraindication(s) to exercise, including major physical injuries, physical impairment preventing moderate-intensity activity, and inability to walk for extended lengths without experiencing chest pain, loss of breath, or dizziness.

Procedures

Participant recruitment took place in the San Francisco Bay Area through local caregiver organizations, hospitals, and day centers. Individuals interested in participating were screened for eligibility via telephone and internet-based interviews and attended an in-person orientation seminar. Upon consent, participants were invited to complete the optional daily sub-study portion of the study, which included 6 ecological momentary assessments (EMAs) per day for 7 consecutive days prior to their visit to the clinic for health assessments and randomization. EMAs are a repeated sampling procedure that, in comparison to retrospective self-reports, minimizes recall bias and maximizes ecological validity for dynamic processes that occur in real time (Shiffman et al., 2008). Prior to completing the EMAs, participants were asked at the start of the week what time they woke up and went to sleep typically on each day of the week. Each morning's assessment was delivered 30 min after their reported wakeup time. The remaining 5 EMAs were signal contingent and variable time based, with the first sent a minimum of 2 h from their morning signal in five equal blocks until 30 min before bedtime, requiring a minimum of 30 min to pass between signals.

Assessments were sent to participants' mobile devices with links to a Qualtrics online survey questionnaire, accompanied by an auditory and visual prompt. If participants were not in possession of a cellular device, iPhone 5s were provided to them to complete the EMAs. Participants were instructed to complete each assessment as soon as they received the assessment prompt. If participants did not complete their assessment within 1 h of the signal, their data for that time point were excluded from the analysis.

Within 2 weeks of completion of the baseline pre-trial EMA week, participants arrived at the university hospital to complete health assessments (e.g., anthropometrics, cardiopulmonary exercise test (CPET)). Once approved to exercise by the study's physician (co-author KLJ) and the university-appointed physician, participants were then randomized to either the 24-week aerobic exercise arm or the waitlist control and asked to remain as physically active as before study entry. In the final week of the 24 weeks, participants were asked to repeat the 7 consecutive days of EMAs.

Randomization

SPSS v21 was used to generate a permuted block randomization, assigning participants in blocks of 4 to the exercise or waitlist group.

Aerobic Training Intervention

The 24-week aerobic training intervention aimed to increase participant physical activity to levels that met the Center for Disease Control and Prevention recommendations of 150 min of moderate-intensity activity per week. All participants received free gym memberships for 6 months, wore wGT3X-BT Monitor Actigraph™ accelerometers during their planned exercise, and were provided heart rate monitors (Polar T31) and watches (Polar FT1) to monitor and remain within their target heart rate goals based on their individualized programs. Heart rate reserve data from each participant's CPET were used to create individualized exercise plans that gradually increased participants' exercise intensity from 40% of heart rate reserve in week 1 to 59% in week 9, duration from 20 to 30 min, and frequency from 3 to 5 sessions per week. The latter values were then maintained for the remaining 15 weeks. A study-appointed support coach met each participant at their nearest YMCA to set goals and action for an individualized program. All participants randomized to the exercise arm received weekly progress reports by email based on their accelerometry data uploaded to the ActiLife™ cloud. Participants who did not meet weekly goals received a phone call from their study-appointed coach to discuss facilitators and barriers to their exercising plans, based on motivational interviewing techniques (Miller & Rollnick, 2013). Coaches also sent 5 weekly text messages containing personalized motivational content and exercise reminders.

Waitlist Control Group

Participants in the waitlist control group were asked not to change their levels of physical activity over the course of the intervention and received a monthly email questionnaire assessing physical activity levels. Following the intervention, waitlisted participants received free gym memberships and an individualized aerobic workout program.

Measures

EMAs were used to randomly capture daily outcome measures in our caregiver sample.

Positive and Negative Affect At each assessment from morning until night time, participants were asked: “Please rate the extent to which you were feeling each of the following emotions at the time of the prompt.” Aggregate ratings for “happy,” “content,” “energetic,” “compassionate,” and “relaxed” were used for values of positive affect. Negative affect was an aggregate of “lonely,” “anxious,” “angry,” “frustrated,” “sad,” “embarrassed,” and “fatigued.” All ratings were provided using visual analog scales ranging from 0 to 100. Within- and between-person positive affect reliability estimates were calculated using suggested methods for nested data (code provided by Scott et al., 2018) and were 0.74 and 1.00 for pre-trial, respectively, and 0.71 and 1.00 for the follow-up, respectively. Within- and between-person negative affect reliability estimates were 0.71 and 0.99 for pre-trial, respectively, and 0.71 and 0.99 for the follow-up, respectively.

Sense of Control At each post-morning assessment, participants were asked whether they were feeling that they could “control important things in (your) life today,” at the time of the prompt. All ratings were provided using a visual analog scale ranging from 0 to 100.

Rumination At each post-morning assessment, participants were asked whether they were “dwelling on personal problems and concerns.” All ratings were provided using a visual analog scale ranging from 0 to 100.

Self-Reported Stressor At each assessment, except for the morning one, participants were asked whether anything stressful occurred since their previous time-stamped prompt on that day. Each prompt was collapsed as “stressor-free,” scored “0” or “with stressor,” scored “1.”

Statistical Approach

All participants who were randomized in the study were included in the intent-to-treat analysis plan. We used mixed models (MIXED command in SPSS v23) with maximum likelihood estimation for the continuous unstandardized outcome measures, with 3-level models with random intercepts and fixed slopes estimated to account for nested EMAs within days within persons. A 3-level structure was modeled since EMAs were nested within days within participants. Coded factors included (1) time (0 = baseline, 1 = end of trial) and (2) treatment group (0 = waitlist, 1 = aerobic training). The interaction between the two factors was used to assess the unstandardized treatment effect—whether changes in any outcome over the course of the intervention were significantly different between groups. The mixed model approach estimates four intercepts based on the coding of these two factors: (1) $B_{0(\mathrm{w0})}$—the estimated mean value of the outcome for the waitlist (w) group at baseline, (2) $B_{1(\mathrm{w1\text{-}w0})}$—the estimated mean difference for the waitlist group from baseline to post-treatment, (3) $B_{2(\mathrm{e0\text{-}w0})}$—the estimated mean difference between the waitlist and exercise (e) training group at baseline, and (4) $B_{3(\mathrm{t.e.})}$—an estimated slope for the group*time interaction, indicating whether changes over time differed significantly between groups (i.e., the treatment effect; t.e.). Following a significant treatment effect, we then reversed coded groups (0 = aerobic training and 1 = waitlist), with new estimates for $B_{0(\mathrm{e0})}$ and $B_{1(\mathrm{e1\text{-}e0})}$, indicating the estimated mean value for the intervention group at baseline and over time, respectively. Effect sizes (ES) for each outcome were calculated by dividing the estimated treatment effect, $B_{3(\mathrm{t.e.})}$, by the raw standard deviation for all participants at baseline (Feingold, 2009). For stressor occurrence, multilevel logistic regressions were employed using GENLINMIXED command in SPSS v23. All data in these analyses are available upon request.

Results

Sample Size and Baseline Characteristics Of the 290 interested caregivers, 102 were eligible. Eighty-nine participants attended the study orientation meeting and 78 consented to participate. Eight participants withdrew prior to attending the clinic for their CPET examinations, and the CPET examination disqualified a final two participants for medical reasons. Sixty-eight participants were randomized to either the exercise group or waitlist control, of which 67 (98%) had participated in the optional, pre-randomization EMA sub-study of the project. Sixty-one (90%) of the 67 participants completed a minimum 3 days of EMAs. Of these 61, four participants dropped out of the study during the intervention for medical ($N = 1$), relocation ($N = 1$), or personal ($N = 2$) reasons. One participant completed the intervention but declined the invitation to complete the EMA sub-study at the end of the trial. Thus, a total of

56 participants completed the final week of EMAs. Of the 42 (i.e., 6/day for 7 days) EMAs delivered per week to participants, an average of 37.2 (SD = 4.2; range 18 to 42) were completed, representing 89% of completed surveys. Mean age of the 56 participants was 61.44 (SD = 6.34), and the majority were women (80.3%).

Change in Daily Positive Affect There were no significant differences at baseline between treatment groups in daily positive affect ($B_{2(e0\text{-}w0)} = -5.42$; SE = 3.83; 0.95 CI = −13.09, 2.25; $p = 0.16$). Estimated treatment effects and estimated within-group baseline measures and changes are presented in Table 1. The 24-week change in daily positive affect differed significantly between groups (ES = 0.26; $p < 0.001$), with increases in the intervention group (6.52 unit increase, $p < 0.001$) exceeding the increases of those of the waitlist control group (1.51 unit increase, $p = 0.006$).

Change in Daily Negative Affect There were no significant differences at baseline between groups in negative affect ($B_{2(e0\text{-}w0)} = -1.85$; SE = 2.91; 0.95 CI = −7.68, 3.96; $p = 0.53$). Table 1 shows estimated treatment effects and estimated within-group baseline measures and changes. The 24-week change in daily negative affect differed significantly between groups (ES = 0.41; $p < 0.001$). Whereas the intervention group significantly decreased (4.52 unit decrease, $p < 0.001$) estimated negative affect reported on a daily basis following the intervention, the waitlist control group increased significantly over time (2.47 unit increase, $p < 0.001$).

Change in Daily Sense of Control There were no significant differences at baseline between treatment groups in daily sense of control ($B_{2(e0\text{-}w0)} = -1.13$; SE = 4.89; 0.95 CI = −10.92, 8.65; $p = 0.82$; Table 1). The 24-week change in daily sense of control differed significantly between groups (ES = 0.43, $p < 0.001$). Whereas the intervention group significantly increased estimated daily sense of control following the 24-week exercise program (10.03 unit increase, $p < 0.001$), the waitlist control group did not change significantly over time (0.94 unit decrease, $p = 0.19$).

Change in Daily Rumination There were no significant differences in estimated rumination at baseline between conditions ($B_{2(e0\text{-}w0)} = -1.07$; SE = 3.99; 0.95 CI = −9.05, 6.91; $p = 0.79$; Table 1). The 24-week change in daily rumination differed significantly between groups (ES = 0.25, $p < 0.001$). Whereas the intervention group significantly decreased estimated rumination reported on a daily basis following the intervention (8.52 unit decrease, $p < 0.001$), there were no significant changes in the waitlist control group over time (1.46 unit decrease, $p = 0.20$).

Changes in the Occurrence of Stressors Eight hundred three days of data were collected across both time points, and

Table 1 Treatment effects and within-group changes from pre-trial to post-assessment in daily affective and cognitive processes

Outcomes	Waitlist control						Aerobic training						Treatment effect		
	Intercept			Time			Intercept			Time			Interaction		
	$B_{0(w0)}$	SE	CI	$B_{1(w1\text{-}w0)}$	SE	CI	$B_{0(e0)}$	SE	CI	$B_{1(e1\text{-}e0)}$	SE	CI	$B_{3(t.e.)}$	SE	CI
Positive affect	56.80	2.56	51.67, 61.92	1.51	0.54	0.44, 2.58	51.38	2.85	45.68, 57.09	6.52	0.61	5.33, 7.71	5.01	0.82	3.41, 6.61
Negative affect	21.83	1.94	17.96, 25.71	2.47	0.52	1.44, 3.49	19.98	2.16	15.65, 24.30	−4.52	0.58	− 5.66, − 3.38	−6.99	0.78	− 8.52, − 5.45
Sense of control	58.16	3.27	51.62, 64.70	−0.94	0.72	− 2.36, 0.48	57.03	3.64	49.75, 64.31	10.03	0.81	8.45, 11.61	10.97	1.08	8.85, 13.10
Rumination	30.69	2.67	25.36, 36.03	−1.46	1.15	− 3.73, 0.80	29.63	2.97	23.69, 35.56	−8.52	1.29	− 11.04, − 6.00	−7.06	1.73	− 10.44, − 3.67

Baseline scores (intercept) and change scores (time) for all factors were calculated for each treatment arm. The treatment effect (interaction) is the estimated mean difference between changes of each group over the course of the intervention

B, estimated unstandardized coefficient; *SE*, standard error; *CI*, confidence interval participants reported that 43.8% of these days were stressor-free. Four hundred nineteen stressors were reported at pre-trial and 384 at 24 weeks. Twenty-eight percent of days had only one stressor reported, 16.9% of days had 2 stressors, 7.3% 3 stressors, 2.9% 4 stressors, and 0.5% 5 stressors. We observed no difference in likelihood of the reported occurrence of stressors throughout the day in those in the intervention arm of the study compared with the waitlist control arm (estimate = 0.02; SE = 0.25; 0.95 CI = − 0.47, 0.51; $p = 0.93$). There were, however, significant effects of time, whereby the likelihood that participants reported stressors at any EMA decreased from pre- to post-assessment (estimate = − 0.54; SE = 0.16; 0.95 CI = − 0.86, − 0.22; OR = 0.58, $p < 0.001$).

Discussion

The current study aimed to explore the effects of an aerobic exercise program on momentary affective and cognitive processes and occurrence of stressors reported on a daily basis. The sample included physically inactive, highly stressed family caregivers, which represent a population of adults who are at elevated risk for depression, disease, and earlier mortality (Bookwala et al., 2002; Pinquart & Sörensen, 2003; Vitaliano et al., 2003). The current RCT demonstrated that inactive family caregivers randomized to exercise for 24 weeks had consistent effects across all psychological processes measured, including significant increases in their daily positive affect and sense of control and decreases in their daily negative affect and rumination compared with caregivers in the waitlist control group. No significant treatment effects were demonstrated for occurrence of stressful events throughout the days.

Previous work that has explored the physical activity–daily affect relationship has primarily used observational designs. Our study extends this research by testing the effects of an aerobic exercise intervention on daily affect in those experiencing high levels of chronic psychological stress who were initially inactive. Participants randomized to exercise in our intervention significantly increased their daily positive affect to a greater extent than waitlist control caregivers, corroborating the findings from several other exercise interventions that used more trait-like measures to determine affect (Reed & Buck, 2009). Whereas past research has been inconsistent in whether physical activity and exercise on a daily basis are associated with daily negative affect in healthy individuals (Mata et al., 2012; Poole et al., 2011; Puterman et al., 2017; Wichers et al., 2012), the current investigation suggests that *becoming* a regular exerciser can significantly reduce daily negative affect, at least among physically underactive adults experiencing high chronic stress. Our investigation further demonstrated significant treatment effects in daily cognitive processes, including rumination and perceived control, whereby caregivers who exercised significantly improved in these outcomes, and caregivers in the waitlist control remained similar to their baseline levels at the completion of the study.

While the current study demonstrated changes in daily affective and cognitive processes throughout the day that resulted from the exercise program, these processes were measured independent of stressor occurrence. Exposure to daily stressors and their resultant affective and cognitive responses are important factors to study as well. Stressor *reactivity* (i.e., how one affectively, cognitively, or physiologically responds to a *particular* stressor), *stressor recovery* (i.e., how long the initial response to the stressor takes to dissipate), and *pile-up* (i.e., the accumulation of daily stressors and their resultant changes in emotions, cognitions, or physiology) have been conceptualized and shown to be important components of how stress unfolds on a daily basis and their resultant impact on health behavior engagement (Almeida et al., 2020; Smyth et al., 2018) and long-term health and wellbeing (Almeida et al., 2011; Charles et al., 2013; Piazza et al., 2013).

Previous observational research suggests that physical activity perhaps impacts stressor reactivity. For example, Puterman et al. (2017) demonstrated that the negative affect increase observed on days with stressors compared with days without stressors is 14% lower in adults who are physically active compared with adults reporting low levels of activity. Laboratory studies further demonstrate that although adults typically respond to a standardized laboratory psychological stressor with increases in anxiety and reductions in calmness, these changes are mitigated in athletes and physically active non-athletes compared with adults who display low levels of physical activity (Rimmele et al., 2007, 2009). Furthermore, laboratory-based studies suggest that exercising immediately at moderate-to-vigorous levels prior to experiencing a standardized stressor reduces the extent to which ruminating in response to the stressor is associated with increases in negative affect (Bernstein & McNally, 2017). These observational and laboratory studies suggest that becoming a more regular exerciser might improve immediate affective or cognitive responses (e.g., reduced rumination, increased sense of control) directly in response to daily stressors. To date, no intervention study has examined whether an exercise program can alter stressor reactivity, recovery, or pile-up in naturalistic settings, providing an exciting future area of study.

Although the exercise intervention in the current study altered affective and cognitive processes in a group of caregivers reporting high levels of chronic psychological stress, the relative contributions of each component of this multifaceted treatment remain less clear. Although engagement in exercise likely contributed to changes in these processes via neurophysiological adaptations (Heijnen et al., 2016), the goal setting completed in the first meeting (McEwan et al., 2016) and the coaching and motivational messaging elements (O'Halloran et al., 2014) that occurred throughout the program are known to be effective intervention components and may have contributed to the demonstrated changes in affect and cognitions in the current study, through changes in perceptions of self-mastery. Accordingly, when implementing large-scale aerobic exercise trials, future studies should identify the relative contributions of (1) neurophysiological mechanisms through which exercise improves affect and (2) motivational tools that help facilitate exercise participation and engagement.

The current investigation has several strengths. As noted elsewhere (Puterman et al., 2018), participants in the study had high levels of adherence, which was confirmed with accelerometers. The current investigation implemented a program that was tailored to each participant, using techniques evidenced to maximize adherence (Puterman et al., 2018). The design considered and directly attended to potential barriers, with each participating caregiver having received (1) a free membership to any nearby YMCA to lessen possible financial and environmental barriers, (2) individualized exercise programs that included goal setting (McEwan et al., 2016) conversations with our study-appointed coach, (3) weekly one-on-one conversations to develop solutions to motivational barriers (McEwan et al., 2016; Miller & Rollnick, 2013), and (4) near-daily supportive text message (Heron & Smyth, 2010; Patrick et al., 2009) reminders from our team. How these methods impacted adherence, however, is unknown as we did not include a comparison group of caregivers who were randomized to the exercise arm of the trial without these supportive techniques. The current investigation is strengthened further by the inclusion of reports of daily stressors and affective and cognitive processes throughout the day, reducing risk of recall bias or trait ascription bias. However, the study is limited in its generalizability, since the study primarily included Caucasian women and individuals who were caregivers. Further replication in a more diverse gendered and ethnoracial cohort is warranted, as is a cohort of participants who are physically inactive and non-exercisers but not chronically stressed.

Conclusion

Considering the effects of chronic and daily stressor exposure and reactivity on health, it is imperative to develop strategies to reduce the occurrence of and reactivity to stressors. In the current study, we provided a free and accessible aerobic exercise program to family caregivers and demonstrated robust changes in cognitive and emotional processes on a daily basis without changes in exposure to stressors. These treatment effects were in addition to those previously reported with this sample of participants, whereby the intervention improved cardiorespiratory fitness, body mass index, perceptions of chronic stress, and lengthened average telomere lengths in immune cells (Puterman et al., 2018). Although the various features of the intervention require further exploration, this secondary analysis of a RCT demonstrates that individuals who are inactive and highly stressed can benefit psychologically from initiating and maintaining an exercise regimen.

Authors' Contribution Statements AC processed and analyzed data and prepared the first draft. MB reviewed and edited the draft. JW and SS managed the project and edited the draft. BH processed the data and edited the draft. KLJ was the study physician, helped design the project, and edited the draft. EE helped design the project and edited the draft. EP secured funding for the project, designed and implemented the project, and edited the draft.

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Data Availability Data are publicly available at https://osf.io/gc9qa/.

Conflict of Interest The authors declare that they have no conflict of interest.

IRB and Preregistration The study was approved by UCSF's Human Research Protection Program Committee on Human Research (IRB# 13-11322) and was preregistered on clinicaltrials.gov (#NCT0s993082).

Ethical Approval The study was approved by UCSF's Human Research Protection Program Committee on Human Research (IRB# 13-11322) as well as the UBC Clinical Research Ethics Board (CREB # H16-01094) and was preregistered on clinicaltrials.gov (#NCT01993082).

Informed consent All study participants gave informed consent prior to beginning the study.

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