Emotion

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Exercise and Emotion Dynamics: An Experience Sampling Study

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Though it has been widely demonstrated that regular exercise is associated with better emotional wellbeing, the nature of this association remains unclear. The present study explored the relationship between voluntary exercise and the temporal dynamics of daily emotions, and thus how voluntary exercise could be impacting emotional reactivity and recovery in naturalistic contexts. Seventy-six young adults participated simultaneously in this ecological momentary assessment study, and received 75 prompts over the course of 15 days. Emotional inertia (persistence of emotional states), emotional variability (intensity of emotional fluctuations), and emotional instability (tendency for emotional fluctuations) were considered. Past research has shown that low wellbeing tends to be associated with high inertia, variability, and instability. Each prompt included ratings of present emotions (anxiety, sadness, cheerfulness, contentment) and any recent physical activity. Greater average exercise time was significantly associated with less inertia (reduced autocorrelation) of anxiety. Exercise was not significantly associated with inertia of the other emotions, although results were in the same direction. Exercise habits were unrelated to emotional variability and instability. Results suggest that exercise may buffer against prolonged or persistent negative affective states and consequently could benefit a person's ability to self-regulate or recover from changes in the environment and internal emotional experiences, rather than simply reducing the frequency or intensity of anxious emotions.

Keywords: exercise, anxiety, emotion dynamics, emotional inertia, emotion regulation

It is widely accepted that exercise is good for us, both physically and mentally. And there are now decades of research showing positive associations between exercise and numerous mental health outcomes (Lee & Russell, 2003; Penedo & Dahn, 2005; Stephens, 1988). Cross-sectional and prospective studies show that regular exercise is associated with fewer anxious and depressive symptoms, lower rates of psychiatric disorders, higher levels of reported positive affect, lower levels of reported negative affect, greater emotional wellbeing, and less stress (De Moor, Beem, Stubbe, Boomsma, & De Geus, 2006; Garcia, Archer, Moradi, & Andersson-Arntén, 2012; Goodwin, 2003; Hassmén, Koivula, & Uutela, 2000; Paffenbarger, Lee, & Leung, 1994; Ströhle et al., 2007). Longitudinal studies have demonstrated similar benefits for emotional health (DiLorenzo et al., 1999; Kanning & Schlicht, 2010; Petruzzello, Landers, Hatfield, Kubitz, & Salazar, 1991). Also, people report feeling better on days when they exercise (Giacobbi, Hausenblas, & Frye, 2005; Hyde, Conroy, Pincus, & Ram, 2011). Moreover, among individuals diagnosed with psychiatric disorders, engaging in exercise interventions appears beneficial as well (Szuhany, Smits, Asmundson, & Otto, 2014). Results for exercise alleviating anxiety and depression have been especially robust (Asmundson et al., 2013; Blumenthal et al., 1999; Harris, Cronkite, & Moos, 2006; Schuch et al., 2016; Tordeurs, Janne, Appart, Zdanowicz, & Reynaert, 2011; Wipfli, Rethorst, & Landers, 2008).

The question remains: *how* does exercise benefit emotional wellbeing? Research addressing this question tends to assess emotion from a static perspective. Whether the variable of interest is positive affect, negative affect, anxiety, or another index of emotional wellbeing, it has typically been measured either at a single time point, measured before and after an intervention period, or consolidated as an average rating across multiple time points. These measures do not disclose the temporal dynamics of exercise's effects on mood. Given the ostensible benefit of exercise for mental health, more research is needed to clarify the nature of these effects. Improved understanding could promote more targeted, efficacious use of exercise as a primary and adjunctive intervention as well as increase motivation to initiate and maintain exercise regimens by identifying specific, immediate, experiential benefits.

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Experimental data suggest that exercise may enhance emotional flexibility, or a person's ability to adaptively respond to and recover from emotional stressors. In particular, exercise may help mitigate prolonged or excessive emotional reactions, typically conceptualized as risk and maintenance factors for emotional disorders (Flueckiger, Lieb, Meyer, Witthauer, & Mata, 2016; Kishida & Elavsky, 2015; Ströhle, 2009). Physiologically, physically fit individuals show faster heart rate recovery following a stressor, and acute exercise prior to a stressor may attenuate heart rate and blood pressure reactivity (Blumenthal et al., 1988; Forcier et al., 2006; Jackson & Dishman, 2006; Rejeski, Thompson, Brubaker, & Miller, 1992). Furthermore, prior exercise appears to hasten self-reported emotional recovery following a psychosocial stressor as well; acute exercise did not alter the strength of initial emotional responses, but did foster a swifter return to baseline among those otherwise struggling with emotion regulation (Bernstein & McNally, 2017a, 2017b).

Thus, the enhanced emotional health of regular exercisers may reflect the ability to self-regulate emotions in response to environmental challenges rather than prevent the occurrence of negative emotions. This is consistent with a push in recent years to examine emotion dynamics—or how emotions change and fluctuate across time and how people regulate their emotions—above and beyond reports of typical or average experiences (Houben, Van Den Noortgate, & Kuppens, 2015; Kuppens, 2015). In fact, averages and generic measures may mask important effects. In this vein, the present study explored whether the link between exercise and emotion regulation would hold outside of the laboratory. To examine the effects of voluntary physical activity on daily emotional experiences, we collected three weeks of ecological momentary assessment data (i.e., repeated sampling of participants' experiences in their daily lives) from young adults with a range of exercise habits and examined three patterns of short-term emotion dynamics: inertia, variability, and instability.

First, emotional inertia reflects the degree to which a person's emotional states are persistent and resistant to change. Operationally, this refers to how much affect carries over into subsequent time points, or how predictive prior affect is of current affect. A person high on this inertia index would show prolonged emotional responses and slow recovery, whereas a person low on this index would show quicker recoveries and a greater propensity to return to homeostasis or baseline levels (Kuppens, Allen, & Sheeber, 2010; Suls, Green, & Hillis, 1998). Increased emotional inertia—both positive and negative affect—is associated with decreased psychological wellbeing, low self-esteem, negative perseverative thinking, and depression (Brose, Schmiedek, Koval, & Kuppens, 2015; Houben et al., 2015; Koval, Kuppens, Allen, & Sheeber, 2012; Kuppens et al., 2010). Though not a direct measure of emotional recovery, there is evidence that heightened emotional inertia for negative affect is strongly related to impaired recovery (Koval et al., 2015).

Second, emotional variability captures the intensity of affective fluctuations or how much a person's emotional experience tends to deviate from his or her average or daily level. A person high on this index tends to have intense emotional reactions. This index is intuitively related to mental health as numerous psychiatric disorders are defined in terms of intense, distressing emotional responses (e.g., mania, panic). And supporting research shows that high emotional variability is associated with indicators of poor psychological health such as low self-esteem, neuroticism, and depression (Eid & Diener, 1999; Houben et al., 2015; Kuppens, Van Mechelen, Nezlek, Dossche, & Timmermans, 2007).

Third, emotional instability describes how much a person's emotions shift from one moment to the next. A person high on this index has a high propensity for emotional fluctuations. Although most evident in disorders characterized by instability, such as borderline personality disorder or bipolar disorder, data show that emotional instability is associated with a broad range of pathology including depression and general psychological wellbeing (Houben et al., 2015; Thompson et al., 2012; Trull et al., 2008).

In sum, poor emotional outcomes are characterized by highly persistent, variable, and unstable emotional experiences (Houben et al., 2015). Measures of emotional inertia, variability, and instability are mathematically related, with instability reflecting high variability and to a lesser extent low inertia (Jahng, Wood, & Trull, 2008; Koval, Pe, Meers, & Kuppens, 2013; Wang, Hamaker, & Bergeman, 2012). These constructs are thus related and in some ways overlapping. Accordingly, it is unsurprising that instability is often positively associated with variability and negatively associated with inertia. However, because there are still important differences in how each measure is calculated, it is valuable to include all three and thus examine emotional dynamics from these three perspectives. We hypothesized that more regular physical activity would be associated with indicators of better emotional health, including lower emotional inertia, lower emotional variability, and lower emotional instability. Given experimental evidence that acute exercise benefited self-reported emotional recovery in particular, we expected the relationship between voluntary activity and emotional inertia to be especially strong (Bernstein & McNally, 2017a, 2017b).

Method

Participants

Seventy-six participants (53 women, M_{age} = 19.80 years, SD = 1.24, age range: 18–22) completed the study in 2016. The ethnic/racial composition of the final sample was 42.11% Caucasian, 7.89% African American, 34.21% Asian or Asian American, 2.63% Native American or American Indian, 11.84% multiracial, and 5.26% of participants identified as Hispanic or Latino. Eligible participants were current undergraduates enrolled in introductory level psychology courses, at least 18 years of age, and fluent in English. Participants were excluded if they reported no regular exercise (defined as less than one hour per week of at least moderate activity, e.g., walking, weightlifting, or bowling) and denied any interest in being physically active. The Committee on the Use of Human Subjects approved the study protocol, and participants provided informed consent prior to initiation of any study procedure. Participants were compensated with academic credits for their course(s); they received the maximum number credits if they responded to at least 75% of prompts. They received a corresponding fraction of these possible credits if they responded to fewer than 75%. We aimed to recruit a sample whose size (N = 76) and number of data points per person (up to 75) were both feasible for the present project and similar to prior research examining similar constructs (Kuppens et al., 2007; Suls et al., 1998; Trull et al., 2008).

Procedure

We used the LifeData (https://www.lifedatacorp.com/) company's RealLife Exp smartphone app for ecological momentary assessment (Runyan et al., 2013). Participants completed the study during a single academic semester. At baseline, participants completed a brief questionnaire surveying demographics (age, sex, ethnicity, race, height, weight, and class year), depressive and anxious symptoms, and physical fitness. The Depression Anxiety Stress Scales (DASS-21; Lovibond & Lovibond, 1995) captures depressive, physical, and psychological arousal or tension, and agitation, and shows internal consistency and concurrent validity (Antony, Bieling, Cox, Enns, & Swinson, 1998). It yields three subscales: depression, anxiety, and stress. Lastly, we used the habitual physical activity item from the George Non-Exercise Test (GNET) to quantify exercise habits (George, Stone, & Burkett, 1997). Ratings range from 0 (avoid walking or exertion) to 10 (over 8 hr per week of vigorous activity).

Upon submission of the questionnaire, participants could begin receiving question prompts and messages from the app. Questions were identical in terms of content and schedule for all participants. Question prompts were delivered at three separate time intervals, approximately 4 weeks apart. Each interval consisted of 5 days, with participants receiving 5 question prompts each day, for a total of 75 question prompts per participant. Participants were sent questions in a randomized order with each prompt. They were asked to rate on a sliding scale (0- not at all, 100- extremely) how much they felt four emotions: cheerful, content, sad, anxious/worried. Second, they were asked whether or not they had exercised since the last time they responded to a prompt (NB: This did not include walking to class, work, social events, or errands). If they indicated *yes*, follow up questions included duration (i.e., time spent exercising) and intensity (vigorous [e.g., be out of breath], moderate [e.g., experience heavy breathing], light [e.g., able to speak comfortably throughout]). After the final 5-day data collection period, participants repeated the DASS-21 and GNET.

At baseline, participants were automatically randomized to one of two groups (basic or augmented). Participants in the augmented group received additional messages throughout the study period. In addition to the self-monitoring protocol described above, participants in this condition also received text messages explicitly reminding and encouraging them to exercise every other day throughout the study period.

Statistical Analyses

Descriptive data for the enrolled sample are presented as means with standard deviations (*SD*) for continuous variables and counts with proportions for categorical variables. We conducted independent sample *t* tests to assess group differences in age, depressive, anxious, and stress-related symptoms, and baseline exercise habits and chi-square tests to assess whether gender, race, ethnicity, or class level differed by group assignment. Overall changes in exercise, mood, and anxiety from baseline to close of study were tested with repeated measures *t* tests. One-way ANCOVAs were conducted to examine group differences in these changes; the outcome variables were included as dependent variables, group assignment as the independent variable, and the appropriate baseline measure as a covariate.

In accordance with our hypotheses, we first examined whether levels of emotion across time were associated with physical activity. Second, to examine the effects of voluntary physical activity on daily emotional experiences, we examined patterns of short-term emotion dynamics. This included (a) emotional variability, operationalized as within-person standard deviations or variance of emotions across time; (b) emotional instability, operationalized as the mean squared successive difference between consecutive emotion scores; and (c) emotional inertia, operationalized as the autocorrelation of emotions across time (Houben et al., 2015). Specifically, we used a multilevel model approach to estimate autocorrelation coefficients of affect, as well as the interaction effect between emotional inertia and physical activity. Multilevel models permit decomposition of within- and between-person effects (Krull & MacKinnon, 2001), whereby fixed effect and random effect components may be estimated. The following models were specified for each affect domain:

$$\text{Level 1: Affect(t)}_{ij} = \beta_{0j} + \beta_{1j}(\text{Affect(t-1)}) + r_{ij}$$
$$\text{Level 2: } \beta_{0j} = \gamma_{00} + \gamma_{01}(\text{Average exercise time}) + u_{0j}$$
$$\beta_{1j} = \gamma_{10} + \gamma_{11}(\text{Average exercise time}) + u_{1j}$$

In these models, Affect(t) and Affect(t-1) are level 1 variables, whereas average exercise time is a level 2 variable. Affect(t)_{ij} reflects an emotion score of participant $_j$ at time $_i$. Estimates of physical activity were derived by computing the average daily exercise time for each subject across all time points. The following coefficients were specified: β_{0j} denotes the within-person mean affect, β_{1j} denotes the autocorrelation coefficient for emotional inertia, r_{ij} denotes the random effect component for level 1. For the intercept, γ_{00} denotes the average affect level when the exercise time and Affect(t-1) is 0, γ_{01} denotes the effect of exercise time on affect, and u_{0j} denotes the random effect component for level 2. For the emotional inertia coefficient, γ_{10} denotes the effect of Affect(t-1) on Affect(t) when the exercise time is 0, γ_{11} denotes the cross-level interaction effect of exercise time and Affect(t-1), and u_{1j} denotes a random effect component for level 2. The lagged predictor (Affect(t-1)) was not person-mean centered, and it excluded the last observations from the first and second sampling phases. Excluding these data points avoids biasing the autoregressive parameter with interobservation intervals that are far longer than the rest. Third, because exercise effects may vary by the intensity of the physical activity, we computed multilevel models that included average exercise intensity as well as the interaction between duration and intensity. Finally, because baseline exercise habits could influence the effects of acute physical during the study period, we repeated the above analyses while including baseline fitness as a covariate. All analyses were conducted in R, and the *lme4* package was used for all multilevel models.

Results

The basic and augmented groups did not differ in age, BMI, exercise habits, gender, race, ethnicity, class level, mood symptoms, or compliance ($ps > .05$). See Table 1 for a summary. Overall, participants experienced no significant changes in depressive symptoms, $t(41) = .70$, p .49; $M_{pre} = 5.86$, $SD = 5.65$; $M_{post} = 6.51$, $SD = 6.73$, anxious symptoms, $t(41) = 1.28$, $p = .21$; $M_{pre} = 4.57$, $SD = 4.49$; $M_{post} = 5.49$, $SD = 5.66$, and stress, $t(41) = 1.68$, $p = .10$; $M_{pre} = 8.81$, $SD = 7.11$; $M_{post} = 10.51$,

Table 1
Characteristics of the Sample

Measure	Whole sample *N* (%)	Basic group *N* (%)	Augmented group *N* (%)	*p*
Gender				.63
Female	53 (69.74)	29 (74.36)	24 (64.86)	
Male	22 (28.95)	10 (25.64)	12 (32.43)	
Unreported	1 (1.32)	0 (.00)	1 (2.70)	
Race				
Caucasian	32 (42.11)	22 (56.41)	10 (27.03)	.05
Black/African American	6 (7.89)	4 (10.26)	2 (5.41)	
Asian/Asian American	26 (34.21)	9 (23.08)	17 (45.95)	
Native American/American Indian	2 (2.63)	0 (.00)	2 (5.41)	
Multiracial	9 (11.84)	4 (10.26)	5 (13.51)	
Ethnicity				.36
Hispanic/Latino	4 (5.26)	3 (7.69)	1 (2.70)	
Not Hispanic/Latino	67 (88.16)	35 (89.74)	32 (86.49)	
Unreported	5 (6.58)	1 (2.56)	3 (8.11)	
Class				.19
Freshman	27 (35.53)	12 (30.77)	15 (40.54)	
Sophomore	19 (25.00)	14 (35.90)	5 (13.51)	
Junior	13 (17.11)	6 (15.38)	7 (18.92)	
Senior	16 (21.05)	7 (17.95)	9 (24.32)	
Emotion	Mean ± *SD*	Mean ± *SD*	Mean ± *SD*	*p*
Age	19.80 ± 1.24	19.67 ± 1.18	19.94 ± 1.31	.34
DASS-Depression	6.35 ± 6.66	5.44 ± 5.66	7.11 ± 7.60	.29
DASS-Anxiety	5.25 ± 5.20	4.26 ± 4.79	5.94 ± 5.48	.16
DASS-Stress	10.08 ± 7.67	8.51 ± 6.56	11.00 ± 8.04	.15
BMI	22.89 ± 3.07	22.85 ± 2.94	22.94 ± 3.25	.90
GNET	5.83 ± 3.03	6.36 ± 3.28	5.25 ± 2.66	.11
Compliance	56.61 ± 27.64	54.91 ± 28.13	58.41 ± 27.38	.58

Note. *p* values were derived from one-way ANOVAs for categorical variables and bivariate regressions for continuous variables. DASS = Depression Anxiety Stress Scales (Depression, Anxiety, and Stress subscales); BMI = Body mass index (kg/m^2); GNET = exercise habits as measured with item 3 on the George Non-Exercise Test; Compliance = percentage of EMA surveys completed.

SD = 7.12. Participants, on average, reported being less active at the end of the study (M_{post} = 4.03, *SD* = 2.73) than at the beginning (M_{pre} = 5.57, *SD* = 2.98), t (30) = 3.77, p = .001. Prepost changes did not differ by group, *p*s > .05. Given the lack of group differences, we collapsed across both groups for the main analyses. Means and SDs (within- and between-persons) and intraclass correlation coefficients (ICCs) for the 4 emotions assessed were as follows: sadness (*M* = 28.58, within-subject *SD* = 18.64, between-subjects *SD* = 9.65, ICC = .21), cheerfulness (*M* = 57.99, within-subject *SD* = 18.24, between-subjects *SD* = 7.41, ICC = .14), anxiety (*M* = 37.73, within-subject *SD* = 21.25, between-subjects *SD* = 10.03, ICC = .18), contentment (*M* = 61.76, within-subject *SD* = 17.64, between-subjects *SD* = 7.41, ICC = .15).

We then examined the relationship between average exercise time and emotional inertia (autocorrelations), variability (within-person standard deviations), and instability (mean squared successive difference) for anxiety, sadness, contentment, and cheerfulness across the 15 days of data collection. Overall means and standard deviations of dynamic measures for each emotion appear in Table 2. Average exercise time was not significantly associated with average estimates of reported sadness, $r = -.16$, $p = .48$, anxiety, $r = -.18$, $p = .17$, cheer, $r = .01$, $p = .97$, or contentment, $r = .06$, $p = .65$. However, a significant interaction emerged between average exercise time and the inertia coefficient for anxiety, such that more exercise was associated with reduced autocorrelation ($\gamma_{11} = -0.01$, $p = .02$, 95% CI [−.02, −.001]). The results of the other multilevel models revealed no other significant interaction effects (see Table 3). Additionally, there was no relationship between average exercise time and emotional variability or instability for each affect domain (*p*s > .05) (see Table 4). Correlations between emotional variability, instability, inertia, and exercise time are included in Table 4. Models of emotion dynamics with exercise intensity and the interaction of exercise intensity and time yielded no significant results (*p*s >

Table 2
Means and Standard Deviations of Dynamic Measures

	Inertia		Variability		Instability	
Emotion	Mean	*SD*	Mean	*SD*	Mean	*SD*
Sad	.19	.19	17.20	5.07	39.54	22.00
Cheer	.12	.17	16.93	4.63	38.64	21.52
Anxiety	.17	.20	19.72	5.78	38.26	22.27
Content	.16	.23	16.17	4.80	39.02	22.14

Note. *SD* = Standard deviation.

Table 3
Multilevel Models of Inertia and Exercise Time

Parameter	Model 1			Model 2			Model 3			Model 4		
Fixed effects	Estimate	*SE*	95% CI	Estimate	*SE*	95% CI	Estimate	*SE*	95% CI	Estimate	*SE*	95% CI
Intercept (γ_{00})	23.01^{***}	2.00	19.39; 27.55	48.57^{***}	3.28	42.41; 55.27	29.02^{***}	2.39	24.97; 34.61	47.39^{***}	4.01	39.75; 55.48
Affect *t*-1 (γ_{10})	$.22^{***}$	.06	.09; .33	$.15^{**}$	.06	.04; .25	$.27^{***}$	.06	.14; .37	$.23^{***}$	.06	.10; .34
Exercise Time (γ_{01})	−.09	.18	−.47; .24	.36	.31	−.24; .97	.07	.19	−.34; .44	.65	.37	−.07; 1.34
Affect *t*-1 × Exercise Time (γ_{11})	−.004	.005	−.01; .006	−.005	.005	−.01; .0052	$-.01^{*}$	.01	−.02; −.001	−.01	.01	−.02; .002

Note. Model 1 = Sad; Model 2 = Cheer; Model 3 = Anxiety; Model 4 = Content. *SE* = standard error. Random effect components are omitted for ease of presentation.
$^{*}p < .05$. $^{**}p < .01$. $^{***}p < .001$.

.05). The results did not significantly change when we included baseline fitness as a covariate in the above analyses.

Discussion

Ecological momentary assessment data showed that individuals who exercised more in their daily lives experienced less persistent states of anxiety or stress. In other words, more physically active individuals more quickly returned to baseline from bouts of anxiety, whereas less physically active individuals experienced more prolonged negative emotion (i.e., more emotional inertia). These results suggest that habitual exercise can enhance emotion regulation (Kuppens et al., 2010). Importantly, there was no relationship between reports of physical activity and the intensity of emotions (variability) or the tendency to experience large emotional fluctuations (instability). This finding is consistent with experimental work demonstrating that acute exercise prior to a stressor facilitated quicker emotional recovery, rather than blunting the initial response to the stressor (Bernstein & McNally, 2017a, 2017b). Thus, it seems oversimplified to conclude that exercise reduces negative affect and thereby benefits global emotional wellbeing; and in fact, we did not find an association between exercise habits and average levels of negative or positive affect. Instead, in a more nuanced way, exercise was associated with less persistent negative emotional states; it is thus plausible that exercise could be promoting emotional flexibility, or a person's ability to bounce back from stressful experiences. Importantly, measures of emotional inertia, variability, and instability are related to, but indirect indices of, emotional reactivity, recovery, and regulation. To test this interpretation directly, researchers need to examine responses to discrete emotional events.

Temporal patterns of emotion dynamics such as this, and negative emotions in particular, strongly and prospectively predict changes in mental health status (Houben et al., 2015). Thus, although it may be surprising that exercise was unrelated to positive emotion dynamics given the colloquial understanding of exercise's positive effect on mood, the finding for negative affect suggests that exercise fosters resilience. Past studies showed that individuals with high inertia of negative affect did not experience more or different types of stressful events than did peers with low inertia, nor did their initial affective responses differ; in both experimental and experience sampling assessments, individuals with high inertia struggled more with recovery from events (Koval et al., 2015). Lower emotional inertia reflects enhanced adaptability to fluctuating environmental demands and hence may foster more successful automatic or conscious attempts at affective repair (Kuppens et al., 2010). In contrast, emotional disorders, and to a lesser extent other types of psychopathology, are characterized by poor emotion regulation skills and consequently more prolonged mood states (Aldao, Nolen-Hoeksema, & Schweizer, 2010; Gross

Table 4
Correlations Between Emotional Variability, Emotion Instability, Emotion Inertia, and Exercise Time

Measure	Variability				Instability				Inertia			
	Sad	Cheer	Anxiety	Content	Sad	Cheer	Anxiety	Content	Sad	Cheer	Anxiety	Content
Cheer Var	$.69^{***}$											
Anx Var	$.73^{***}$	$.64^{***}$										
Content Var	$.78^{***}$	$.86^{***}$	$.70^{***}$									
Sad Inst	−.05	$-.28^{*}$	−.04	−.18								
Cheer Inst	.15	$.32^{*}$	.19	.21	.23							
Anx Inst	$.26^{*}$	.17	$.50^{***}$	.24	$.35^{**}$	$.41^{**}$						
Content Inst	.02	.07	.06	.14	$.38^{**}$	$.43^{***}$	$.34^{**}$					
Sad Iner	$-.31^{*}$	−.2	$-.47^{***}$	−.16	−.19	$-.27^{*}$	$-.48^{***}$	−.21				
Cheer Iner	$-.35^{**}$	$-.29^{*}$	$-.32^{*}$	−.22	−.06	$-.32^{*}$	$-.33^{*}$	−.14	$.69^{***}$			
Anx Iner	$-.33^{**}$	−.14	$-.36^{**}$	−.13	−.17	−.2	$-.45^{***}$	−.14	$.81^{***}$	$.67^{***}$		
Content Iner	$-.43^{***}$	−.23	$-.49^{***}$	$-.28^{*}$	−.19	−.14	$-.43^{***}$	−.22	$.73^{***}$	$.77^{***}$	$.72^{***}$	
Average Exercise	.18	.01	.19	.00	.06	.18	−.08	−.09	−.09	−.06	−.18	−.12

Note. Anx = anxiety; Var = variability; Inst = instability; Iner = Inertia.
$^{*}p < .05$. $^{**}p < .01$. $^{***}p < .001$.

& Muñoz, 1995; Peeters, Nicolson, Berkhof, Delespaul, & deVries, 2003).

Though greater flexibility may be a pathway through which exercise buffers against the onset of emotional disorders or promotes general wellbeing, the present findings could also provide insight into why regular exercise does not protect *all* people from such psychopathology. From the emotion dynamics perspective, poor emotional health is characterized by large and frequent changes in emotional state without homeostatic tendencies that promote regaining balance. Thus, even with strengthened homeostatic tendencies (i.e., lower inertia) and quick recoveries, a person accumulating sufficiently frequent and intense negative emotional experiences could still be at risk for affective disorders (Houben et al., 2015; Wichers, 2014). For this type of person, regular exercise may raise the threshold for vulnerability, but not emotionally immunize the person entirely. This is evinced by our lack of findings for measures of variability and instability; though the three constructs are mathematically and conceptually related, this divergence highlights important differences.

Results should be interpreted in the context of study limitations. First, analyses were unable to account for context. For example, we could not examine the severity or even occurrence of stressors that triggered or maintained changes in participants' emotional ratings. Additionally, there could be third variables that suppress physical activity and increase emotional inertia, such as lack of sleep. Second, differences between types of exercise, intensity, schedules (e.g., exercising in the morning vs. evening, exercising briefly each day or for longer durations three days each week), and contexts (e.g., alone or with friends) could not be explored. Though this type of examination was outside the scope of the present project, it merits attention in follow-up work. For example, it may provide more specific, targeted recommendations for using exercise as a tool for emotion regulation. Additionally, it would provide more information critical for understanding the effects of exercise on emotion regulation. Though the present study converges with other research suggesting that exercise—broadly defined—is emotionally beneficial, it remains unclear whether aerobic versus anaerobic, solitary versus group, and recreational versus competitive exercise, for instance, influence emotional responding and regulation in the same ways. Similarly, the extent to which level of enjoyment, feelings of purpose or accomplishment, or simple behavioral activation might account for the observed effects remains underexplored. Third, the sample was limited to young, relatively healthy adults; it is unclear how results would generalize to other age groups or to clinical samples. With greater variance in emotion ratings or the inclusion of additional emotions in our measurements, for example, it is possible that additional effects would emerge. Finally, data were exclusively self-report. While informative, future iterations of the study would benefit from including additional accelerometer, physiological or other biological data. This would be important both for measuring baseline levels of physical fitness (e.g., VO_2max or maximal oxygen consumption) and exercise behavior prior to and during the study period. There are likely inaccuracies in subjective reporting of these variables as well as individual differences in perceptions of intensity, for example. Thus, it is possible that repeating this study with such measures could yield different results. For these reasons, although results are suggestive of an important link between exercise and emotional dynamics, the absence of more objective complementary data precludes a definitive conclusion about this link.

Overall, results suggest that regular exercise can support mental health through enhanced emotion regulation or recovery, rather than generally lowering levels of negative affect. The present study provides important naturalistic data that complement similar experimental findings. Understanding this pathway could better help clinicians integrate exercise into interventions. For example, clinicians may recommend exercise for clients' struggling with rumination or other emotion regulation deficits that are associated with prolonged, or inert, emotions. As an adjunctive measure, exercise may enhance other treatment effects. For example, many recent evidence-based treatments cohere in their message that the experience of negative emotions per se is not inherently problematic, rather people's secondary reactions to those experiences promote pathology and merit intervention (Barlow, Allen, & Choate, 2004; Curtiss, Klemanski, Andrews, Ito, & Hofmann, 2017; Ellard, Fairholme, Boisseau, Farchione, & Barlow, 2010; Gratz & Tull, 2010; Klemanski & Curtiss, 2016). Exercise may help people better tolerate uncomfortable emotional fluctuations. Furthermore, merely educating clients about the specific and immediate emotional benefits they could garner from regular exercise may enhance motivation to be physically active. This benefit could extend further to at-risk or healthy individuals in a preventive way. Although exercise may not necessarily increase positive affect, decrease the intensity of negative affect, or even lower the likelihood of experiencing negative affect, it may provide a significant emotional buffer for individuals who would otherwise suffer in prolonged negative states by improving emotion regulation or raising the threshold for the level of stress required to precipitate clinical dysregulation.

References

Aldao, A., Nolen-Hoeksema, S., & Schweizer, S. (2010). Emotion-regulation strategies across psychopathology: A meta-analytic review. *Clinical Psychology Review, 30,* 217–237. http://dx.doi.org/10.1016/j.cpr.2009.11.004

Antony, M. M., Bieling, P. J., Cox, B. J., Enns, M. W., & Swinson, R. P. (1998). Psychometric properties of the 42-item and 21-item versions of the Depression Anxiety Stress Scales in clinical groups and a community sample. *Psychological Assessment, 10,* 176–181. http://dx.doi.org/10.1037/1040-3590.10.2.176

Asmundson, G. J. G., Fetzner, M. G., Deboer, L. B., Powers, M. B., Otto, M. W., & Smits, J. A. J. (2013). Let's get physical: A contemporary review of the anxiolytic effects of exercise for anxiety and its disorders. *Depression and Anxiety, 30,* 362–373. http://dx.doi.org/10.1002/da.22043

Barlow, D., Allen, L., & Choate, M. (2004). Toward a unified treatment for emotional disorders. *Behavior Therapy, 35,* 205–230. http://dx.doi.org/10.1016/S0005-7894(04)80036-4

Bernstein, E. E., & McNally, R. J. (2017a). Acute aerobic exercise helps overcome emotion regulation deficits. *Cognition and Emotion, 31,* 834–843. http://dx.doi.org/10.1080/02699931.2016.1168284

Bernstein, E. E., & McNally, R. J. (2017b). Acute aerobic exercise hastens emotional recovery from a subsequent stressor. *Health Psychology, 36,* 560–567. http://dx.doi.org/10.1037/hea0000482

Blumenthal, J. A., Babyak, M. A., Moore, K. A., Craighead, W. E., Herman, S., Khatri, P., . . . Krishnan, K. R. (1999). Effects of exercise training on older patients with major depression. *Archives of Internal Medicine, 159,* 2349–2356. http://dx.doi.org/10.1001/archinte.159.19.2349

Blumenthal, J. A., Emery, C. F., Walsh, M. A., Cox, D. R., Kuhn, C. M., Williams, R. B., & Williams, R. S. (1988). Exercise training in healthy type A middle-aged men: Effects on behavioral and cardiovascular responses. *Psychosomatic Medicine, 50,* 418–433. http://dx.doi.org/10.1097/00006842-198807000-00009

Brose, A., Schmiedek, F., Koval, P., & Kuppens, P. (2015). Emotional inertia contributes to depressive symptoms beyond perseverative thinking. *Cognition and Emotion, 29,* 527–538. http://dx.doi.org/10.1080/02699931.2014.916252

Curtiss, J., Klemanski, D. H., Andrews, L., Ito, M., & Hofmann, S. G. (2017). The conditional process model of mindfulness and emotion regulation: An empirical test. *Journal of Affective Disorders, 212,* 93–100. http://dx.doi.org/10.1016/j.jad.2017.01.027

De Moor, M. H., Beem, A. L., Stubbe, J. H., Boomsma, D. I., & De Geus, E. J. (2006). Regular exercise, anxiety, depression and personality: A population-based study. *Preventive Medicine, 42,* 273–279. http://dx.doi.org/10.1016/j.ypmed.2005.12.002

DiLorenzo, T. M., Bargman, E. P., Stucky-Ropp, R., Brassington, G. S., Frensch, P. A., & LaFontaine, T. (1999). Long-term effects of aerobic exercise on psychological outcomes. *Preventive Medicine, 28,* 75–85. http://dx.doi.org/10.1006/pmed.1998.0385

Eid, M., & Diener, E. (1999). Intraindividual variability in affect: Reliability, validity, and personality correlates. *Journal of Personality and Social Psychology, 76,* 662–676. http://dx.doi.org/10.1037/0022-3514.76.4.662

Ellard, K. K., Fairholme, C. P., Boisseau, C. L., Farchione, T. J., & Barlow, D. H. (2010). Unified protocol for the transdiagnostic treatment of emotional disorders: Protocol development and initial outcome data. *Cognitive and Behavioral Practice, 17,* 88–101. http://dx.doi.org/10.1016/j.cbpra.2009.06.002

Flueckiger, L., Lieb, R., Meyer, A. H., Witthauer, C., & Mata, J. (2016). The importance of physical activity and sleep for affect on stressful days: Two intensive longitudinal studies. *Emotion, 16,* 488–497. http://dx.doi.org/10.1037/emo0000143

Forcier, K., Stroud, L. R., Papandonatos, G. D., Hitsman, B., Reiches, M., Krishnamoorthy, J., & Niaura, R. (2006). Links between physical fitness and cardiovascular reactivity and recovery to psychological stressors: A meta-analysis. *Health Psychology, 25,* 723–739. http://dx.doi.org/10.1037/0278-6133.25.6.723

Garcia, D., Archer, T., Moradi, S., & Andersson-Arntén, A.-C. (2012). Exercise Frequency, High Activation Positive Affect, and Psychological Well-Being: Beyond Age, Gender, and Occupation. *Psychology, 3,* 328–336. http://dx.doi.org/10.4236/psych.2012.34047

George, J. D., Stone, W. J., & Burkett, L. N. (1997). Non-exercise VO2max estimation for physically active college students. *Medicine and Science in Sports and Exercise, 29,* 415–423. http://dx.doi.org/10.1097/00005768-199703000-00019

Giacobbi, P. R., Hausenblas, H. A., & Frye, N. (2005). A naturalistic assessment of the relationship between personality, daily life events, leisure-time exercise, and mood. *Psychology of Sport and Exercise, 6,* 67–81. http://dx.doi.org/10.1016/j.psychsport.2003.10.009

Goodwin, R. D. (2003). Association between physical activity and mental disorders among adults in the United States. *Preventive Medicine, 36,* 698–703. http://dx.doi.org/10.1016/S0091-7435(03)00042-2

Gratz, K. L., & Tull, M. T. (2010). Emotion regulation as a mechanism of change in acceptance- and mindfulness-based treatments. In R. A. Baer (Ed.), *Assessing mindfulness and acceptance processes in clients: Illuminating the theory and practice of change* (pp. 107–134). Oakland, CA: New Harbinger Publications, Inc.

Gross, J., & Muñoz, R. (1995). Emotion regulation and mental health. *Clinical Psychology: Science and Practice, 2,* 151–164. http://dx.doi.org/10.1111/j.1468-2850.1995.tb00036.x

Harris, A. H. S., Cronkite, R., & Moos, R. (2006). Physical activity, exercise coping, and depression in a 10-year cohort study of depressed patients. *Journal of Affective Disorders, 93,* 79–85. http://dx.doi.org/10.1016/j.jad.2006.02.013

Hassmén, P., Koivula, N., & Uutela, A. (2000). Physical exercise and psychological well-being: A population study in Finland. *Preventive Medicine, 30,* 17–25. http://dx.doi.org/10.1006/pmed.1999.0597

Houben, M., Van Den Noortgate, W., & Kuppens, P. (2015). The relation between short-term emotion dynamics and psychological well-being: A meta-analysis. *Psychological Bulletin, 141,* 901–930. http://dx.doi.org/10.1037/a0038822

Hyde, A. L., Conroy, D. E., Pincus, A. L., & Ram, N. (2011). Unpacking the feel-good effect of free-time physical activity: Between- and within-person associations with pleasant-activated feeling states. *Journal of Sport & Exercise Psychology, 33,* 884–902. http://dx.doi.org/10.1123/jsep.33.6.884

Jackson, E. M., & Dishman, R. K.. (2006). Cardiorespiratory fitness and laboratory stress: A meta-regression analysis. *Psychophysiology, 43,* 57–72. http://dx.doi.org/10.1111/j.1469-8986.2006.00373.x

Jahng, S., Wood, P. K., & Trull, T. J. (2008). Analysis of affective instability in ecological momentary assessment: Indices using successive difference and group comparison via multilevel modeling. *Psychological Methods, 13,* 354.

Kanning, M., & Schlicht, W. (2010). Be active and become happy: An ecological momentary assessment of physical activity and mood. *Journal of Sport & Exercise Psychology, 32,* 253–261. http://dx.doi.org/10.1123/jsep.32.2.253

Kishida, M., & Elavsky, S. (2015). Daily physical activity enhances resilient resources for symptom management in middle-aged women. *Health Psychology, 34,* 756–764. http://dx.doi.org/10.1037/hea0000190

Klemanski, D. H., & Curtiss, J. E. (2016). *Don't let your anxiety run your life: Using the science of emotion regulation and mindfulness to overcome fear and worry*. Oakland, CA: New Harbinger Publications.

Koval, P., Brose, A., Pe, M. L., Houben, M., Erbas, Y., Champagne, D., & Kuppens, P. (2015). Emotional inertia and external events: The roles of exposure, reactivity, and recovery. *Emotion, 15,* 625–636. http://dx.doi.org/10.1037/emo0000059

Koval, P., Kuppens, P., Allen, N. B., & Sheeber, L. (2012). Getting stuck in depression: The roles of rumination and emotional inertia. *Cognition and Emotion, 26,* 1412–1427. http://dx.doi.org/10.1080/02699931.2012.667392

Koval, P., Pe, M. L., Meers, K., & Kuppens, P. (2013). Affect dynamics in relation to depressive symptoms: Variable, unstable or inert? *Emotion, 13,* 1132.

Krull, J. L., & MacKinnon, D. P. (2001). Multilevel modeling of individual and group level mediated effects. *Multivariate Behavioral Research, 36,* 249–277.

Kuppens, P. (2015). It's about time: A special section on affect dynamics. *Emotion Review, 7,* 297–300. http://dx.doi.org/10.1177/1754073915590947

Kuppens, P., Allen, N. B., & Sheeber, L. B. (2010). Emotional inertia and psychological maladjustment. *Psychological Science, 21,* 984–991. http://dx.doi.org/10.1177/0956797610372634

Kuppens, P., Van Mechelen, I., Nezlek, J. B., Dossche, D., & Timmermans, T. (2007). Individual differences in core affect variability and their relationship to personality and psychological adjustment. *Emotion, 7,* 262–274. http://dx.doi.org/10.1037/1528-3542.7.2.262

Lee, C., & Russell, A. (2003). Effects of physical activity on emotional well-being among older Australian women: Cross-sectional and longitudinal analyses. *Journal of Psychosomatic Research, 54,* 155–160. http://dx.doi.org/10.1016/S0022-3999(02)00414-2

Lovibond, S. H., & Lovibond, P. F. (1995). *Manual for the depression anxiety stress scales* (Vol. 56). Sydney, New South Wales, Australia: Psychology Foundation of Australia.

Paffenbarger, R. S., Jr., Lee, I.-M., & Leung, R. (1994). Physical activity and personal characteristics associated with depression and suicide in

American college men. *Acta Psychiatrica Scandinavica, 89*(s377), 16–22. http://dx.doi.org/10.1111/j.1600-0447.1994.tb05796.x

Peeters, F., Nicolson, N. A., Berkhof, J., Delespaul, P., & deVries, M. (2003). Effects of daily events on mood states in major depressive disorder. *Journal of Abnormal Psychology, 112,* 203–211. http://dx.doi.org/10.1037/0021-843X.112.2.203

Penedo, F. J., & Dahn, J. R. (2005). Exercise and well-being: A review of mental and physical health benefits associated with physical activity. *Current Opinion in Psychiatry, 18,* 189–193. http://dx.doi.org/10.1097/00001504-200503000-00013

Petruzzello, S. J., Landers, D. M., Hatfield, B. D., Kubitz, K. A., & Salazar, W. (1991). A meta-analysis on the anxiety-reducing effects of acute and chronic exercise. Outcomes and mechanisms. *Sports Medicine, 11,* 143–182. http://dx.doi.org/10.2165/00007256-199111030-00002

Rejeski, W. J., Thompson, A., Brubaker, P. H., & Miller, H. S. (1992). Acute exercise: Buffering psychosocial stress responses in women. *Health Psychology, 11,* 355–362. http://dx.doi.org/10.1037/0278-6133.11.6.355

Runyan, J. D., Steenbergh, T. A., Bainbridge, C., Daugherty, D. A., Oke, L., & Fry, B. N. (2013). A smartphone ecological momentary assessment/intervention "app" for collecting real-time data and promoting self-awareness. *PLoS One, 8*(8), e71325. http://dx.doi.org/10.1371/journal.pone.0071325

Schuch, F. B., Vancampfort, D., Richards, J., Rosenbaum, S., Ward, P. B., & Stubbs, B. (2016). Exercise as a treatment for depression: A meta-analysis adjusting for publication bias. *Journal of Psychiatric Research, 77,* 42–51. http://dx.doi.org/10.1016/j.jpsychires.2016.02.023

Stephens, T. (1988). Physical activity and mental health in the United States and Canada: Evidence from four population surveys. *Preventive Medicine, 17,* 35–47. http://dx.doi.org/10.1016/0091-7435(88)90070-9

Ströhle, A. (2009). Physical activity, exercise, depression and anxiety disorders. *Journal of Neural Transmission, 116,* 777–784.

Ströhle, A., Höfler, M., Pfister, H., Müller, A.-G., Hoyer, J., Wittchen, H.-U., & Lieb, R. (2007). Physical activity and prevalence and incidence of mental disorders in adolescents and young adults. *Psychological Medicine, 37,* 1657–1666. http://dx.doi.org/10.1017/S003329170700089X

Suls, J., Green, P., & Hillis, S. (1998). Emotional reactivity to everyday problems, affective inertia, and neuroticism. *Personality and Social Psychology Bulletin, 24,* 127–136. http://dx.doi.org/10.1177/0146167298242002

Szuhany, K. L., Smits, J. A. J., Asmundson, G. J. G., & Otto, M. W. (2014). *Exercise for mood and anxiety disorders*. Oxford Handbooks Online. http://dx.doi.org/10.1093/oxfordhb/9780199935291.013.20

Thompson, R. J., Mata, J., Jaeggi, S. M., Buschkuehl, M., Jonides, J., & Gotlib, I. H. (2012). The everyday emotional experience of adults with major depressive disorder: Examining emotional instability, inertia, and reactivity. *Journal of Abnormal Psychology, 121,* 819–829. http://dx.doi.org/10.1037/a0027978

Tordeurs, D., Janne, P., Appart, A., Zdanowicz, N., & Reynaert, C. (2011). [Effectiveness of physical exercise in psychiatry: A therapeutic approach?]. *L'Encéphale, 37,* 345–352. http://dx.doi.org/10.1016/j.encep.2011.02.003

Trull, T. J., Solhan, M. B., Tragesser, S. L., Jahng, S., Wood, P. K., Piasecki, T. M., & Watson, D. (2008). Affective instability: Measuring a core feature of borderline personality disorder with ecological momentary assessment. *Journal of Abnormal Psychology, 117,* 647–661. http://dx.doi.org/10.1037/a0012532

Wang, L. P., Hamaker, E., & Bergeman, C. S. (2012). Investigating inter-individual differences in short-term intra-individual variability. *Psychological Methods, 17,* 567.

Wichers, M. (2014). The dynamic nature of depression: A new micro-level perspective of mental disorder that meets current challenges. *Psychological Medicine, 44,* 1349–1360. http://dx.doi.org/10.1017/S0033291713001979

Wipfli, B. M., Rethorst, C. D., & Landers, D. M. (2008). The anxiolytic effects of exercise: A meta-analysis of randomized trials and dose-response analysis. *Journal of Sport & Exercise Psychology, 30,* 392–410. http://dx.doi.org/10.1123/jsep.30.4.392

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