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ARTICLE

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Stress buffering after physical activity engagement: An experience sampling study

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Abstract

Objectives: While encountering daily hassles is a normative experience, it poses a threat to individuals' daily affective well-being. However, physical activity engagement may help to reduce the current stress-related impact on affective well-being (i.e. stress buffering), which we investigate in this study. Furthermore, we examined the possible moderating role of people's global stress context (i.e. exposure to major life events and chronic stress) on this within-person stress-buffering effect.

Design: We approached these ideas using six-times-a-day experience sampling assessments over a period of 22 days.

Methods: Drawing on a broad national sample of 156 middle-aged adults from the EE-SOEP-IS study, we aimed to elucidate the naturally occurring within-person dynamics of current stress, physical activity engagement, and momentary affect within individuals' everyday lives. Major life events and chronic stress were measured as between-person variables.

Results: Multilevel analyses revealed significant within-person associations of current stress and physical activity engagement with momentary affect. Stress-related negative affect was lower when individuals engaged in physical activity, in accordance with the idea of a within-person stress-buffering effect of physical activity engagement. For individuals exposed to more severe major life events, the stress-buffering effect of physical activity engagement for negative affect was lower. Chronic stress did not moderate the within-person stress-buffering effect.

Conclusions: Overall, results add to the existing literature that links physical activity to increased stress resilience and emphasizes the need for taking the global between-person stress context into account.

KEYWORDS
experience sampling methodology, physical activity, positive and negative affect, stress, stress buffering

Statement of contribution

What is already known on this subject?

- Not only global stress (i.e. major life events or chronic stress), but also current stress has substantially adverse effects on affective well-being.
- The response to current stress is influenced by the global stress context.
- Physical activity engagement can buffer stress-related reductions in affective well-being when facing global stress.

What does this study add?

- Physical activity engagement buffers against higher negative affect associated with current stress.
- The global stress context moderates stress buffering after physical activity engagement.
- Past major life events are associated with reduced stress-buffering effects.

BACKGROUND

People commonly experience daily hassles in their everyday life, such as rushing to work or having minor arguments with a friend, which are related to health and well-being. Daily hassles are associated with increased cortisol levels (Almeida et al., 2009), blood pressure (Weber et al., 2022), and heart rate variability (Sin et al., 2016) as well as with reduced affective well-being and symptoms of anxiety and depression (Jacobs et al., 2007; Schönfeld et al., 2016). However, daily hassles and the response to current stress (i.e. in-the-moment or immediate reports of stressful experiences, for a stress typology, see Epel et al., 2018) are complex. That is, multiple dimensions of stress like major live events or chronic stress can shape how current stress relates to physical and mental health (Almeida et al., 2011; Epel et al., 2018). Relatedly, the transdisciplinary stress model emphasizes the importance to shift from a linear (i.e. looking at isolated stressors) towards a transdisciplinary conceptualization of stress (Epel et al., 2018). More specifically, the transdisciplinary stress model suggests that contextual factors, such as past major life events and chronic stress, build an idiographic layer which shapes baseline allostatic states and mental filters and thus influences individuals' current stress responses (Epel et al., 2018). According to the transdisciplinary stress model, health behaviours play a crucial role since they not only interact with the current stress response but also with the contextual factors that themselves shape the current stress response (Epel et al., 2018). In our study, by adopting a transdisciplinary stress perspective, we examined physical activity engagement and global stress (i.e. the severity of major life events and chronic stress levels) as two aspects that might uniquely and conjointly shape the current stress response. This was done by analysing data from an experience sampling study assessing current stress levels, physical activity engagement, and affective well-being as within-person factors and global stress (i.e. major life events and chronic stress) as a between-person factor.

Within-Person stress buffering through physical activity

In addition to the above-mentioned negative effects of daily hassles, higher affective reactivity (i.e. a stronger affective response to a stressor than to a stressor-free moment; Smyth et al., 2017) is associated with elevated inflammation (Sin et al., 2015), an increased risk for developing chronic physical health conditions (Piazza et al., 2013), and a higher overall mortality (Mroczek et al., 2015). However, the negative effects of stress on affective well-being can be counteracted (i.e. buffered), and an important way to do so is to engage in regular physical activity (Childs & de Wit, 2014; Pauly et al., 2019; von Haaren et al., 2015). Stress buffering generally refers to the ability of a health-promoting factor (e.g. social support or physical activity) to not only directly promote health but also to indirectly buffer the health-compromising effects of stress (Cohen & Wills, 1985). Regular physical activity is associated with reduced physiological stress reactivity in the form of a decreased response in blood pressure (Hamer et al., 2006), heart rate (Forcier et al., 2006) and cortisol secretion (Puterman et al., 2011; Zschucke et al., 2015). Moreover, evidence from randomized controlled trials shows that regular physical activity reduces affective reactivity to real-life stressors (von Haaren et al., 2015), possibly by buffering the negative effects of stress on the autonomic nervous system (i.e. via increased heart rate variability; von Haaren et al., 2016). In addition to regular physical activity, also daily physical activity is associated with higher positive affect, while the association with lower negative affect appears to be inconsistent (Liao et al., 2015).

To date, only very few studies investigated the within-person stress-buffering effect of physical activity on affective states. Flueckiger et al. (2016) analysed same-day couplings using a daily diary design and focused on self-reports of daily stress and physical activity. In a student sample, the authors found that when engaging in more physical activity than usual, both the decreases in positive affect and the increases in negative affect associated with daily stress were buffered. Puterman et al. (2017) also took a daily diary approach to investigate daily stress buffering in a nationally representative sample. The findings revealed that while all people experienced more negative affect on stressful days, individuals who were physically active showed lower increases. The influence of daily stress buffering on positive affect, however, was not investigated.[1] A limitation of the daily diary approach, as used by Flueckiger et al. (2016) and Puterman et al. (2017), is the retrospective measurement in the evening, asking how high participants' stress levels were and whether they engaged in physical activity in the past 24 h. Since the effects of physical activity engagement on positive affect might decay after 3 h (Wichers et al., 2012) and affect levels might change even faster (Santangelo et al., 2016), a 24-h recall might overlook or underestimate the short-term stress-buffering dynamics. For an adequate capturing of these dynamics, the experience sampling methodology (ESM) is ideally suitable and allows to investigate stress buffering in closer proximity to the actual experiences (i.e. on several occasions within individuals' days; McLean et al., 2020). By increasing the resolution from a daily to a momentary level, ESM might thus help to capture the within-person stress-buffering dynamics more appropriately (Puterman et al., 2017).

On a momentary level, it still remains unclear whether an engagement in physical activity can buffer effects of stress on affective well-being. An experience sampling study with multiple-times-per-day assessments from Schultchen et al. (2019) found beneficial effects for physical activity, indicating increased positive affect as well as decreased negative affect and stress after engaging in physical activity. However, a potential stress-buffering 'moderation' effect of physical activity was not part of the scope of their study (Schultchen et al., 2019). Pauly et al. (2019) investigated stress buffering for negative affect in older adults using objectively measured physical activity (i.e. accelerometry) and cortisol (i.e. saliva sampling). The authors found a reduced coupling between negative affect and cortisol in older adults' daily lives for individuals with higher average daily steps compared to individuals with lower average daily steps (Pauly et al., 2019). Despite these recent scientific advances, the question remains whether these results are generalizable from habitual (e.g. average daily steps; Pauly et al., 2019) to momentary physical activity engagement.

Global stress context and within-Person stress buffering

Turning to a more global perspective on stress reactivity, an important contextual factor is a person's global stress level, which includes past major life events and current chronic stress (Epel et al., 2018). Exposure to global stress is not only associated with reduced levels of affective well-being (Luhmann et al., 2012; Mata et al., 2012), but also influences the response to current stress. For example, when confronted with daily hassles, people who experienced childhood trauma secrete less cortisol (Carpenter et al., 2011) than people without such global stress burden. Likewise, chronic stress can increase the affective reactivity to stressors in daily life (Epel et al., 2018; Koffer et al., 2016).

In general, individuals are also known to be better off (i.e. have higher global levels of affective well-being) when they engage in more physical activity. This also holds for major life events (Brown & Siegel, 1988) and chronic stress (Klaperski et al., 2012; Wegner et al., 2014), suggesting that physical activity may be a protective factor for global well-being when facing global stress. However, more research is needed on whether and how global stress and physical activity conjointly shape the experience of and response to current stress. Since high global stress levels appear to make people especially vulnerable to the effects of current stress (Carpenter et al., 2011; O'Donovan et al., 2012), it is crucial to identify ways and means that could help people under more global stress to buffer this additional stress burden and maintain their affective well-being despite the experience of current stress. Given the beneficial effects of physical activity on affective well-being on the momentary and global levels (Schultchen et al., 2019; von Haaren et al., 2015), the engagement in physical activity might also be one way of reducing the adverse effects of global stress on current stress responses. That is, not only might individuals with more global stress have relatively higher global levels of well-being when they habitually engage in physical activity. They might also show stronger stress buffering after being physically active simultaneously to experiencing current stress.

The present study

Taking a transdisciplinary stress perspective, this study pursues two aims: First, we aim to replicate previous findings showing that physical activity engagement buffers the negative effect of current stress on momentary affective well-being (Flueckiger et al., 2016; Pauly et al., 2019; Puterman et al., 2017). In this study, we extend prior findings to both positive and negative affect as well as to middle-aged adults. As an advancement, we use ESM with repeated measures across the day to investigate physical activity engagement. Second, by following recent conceptualizations in the transdisciplinary stress model, this study aims to elucidate whether people who experience higher global stress (and thus may be especially vulnerable to the effects of current stress) might show a differently pronounced coupling between current stress and affective well-being after having engaged in physical activity. Given that lower levels of affective well-being before engaging in physical activity predict larger affective improvements (Gauvin et al., 2000; Reed & Ones, 2006), we tentatively assume that high levels of global stress (which often correspond to lower levels of affective well-being, e.g. Luhmann et al., 2012) are associated with a stronger stress-buffering effect.

Accordingly, we test the following hypotheses: (H1) After participants engaged in physical activity, both the negative association between current stress and positive affect, as well as the positive association between current stress and negative affect, will be attenuated (i.e. stress-buffering effects). (H2) When participants report higher levels of global stress (i.e. more severe major life events or chronic stress), stress-buffering effects will be stronger.

METHOD

Participants and procedures

The present study is part of a larger study on Everyday Experiences in the Innovation Sample of the Socioeconomic Panel (EE-SOEP-IS; Siebert et al., 2017). The EE-SOEP-IS study drew participants from the ongoing SOEP-IS study, which is an ongoing panel study with the intention to establish a random sample of German households and to represent the German resident population (Richter & Schupp, 2015). Despite selection processes (self-selection at inclusion, selective drop-out), the panel study is more heterogeneous than psychological studies usually are (i.e. in terms of more diversity regarding the urban–rural dimension, geographical location, SES, etc.). Comparisons of this study's sample with the parent sample (Siebert et al., 2017) revealed no differences in gross income and years of education, marginally more unemployment in this study, and more openness to experiences, but no differences in other personality dimensions. Criteria for inclusion in the EE-SOEP-IS study were previous participation in two or more annual waves of the SOEP-IS study since 2009, and, because participants were visited at their homes, a residency within a 60-km radius of any high-speed-connected railway station. The larger EE-SOEP-IS study consisted of three waves that were each 1 year apart, on average (for details, see Blanke et al., 2020). The present study is focusing on the second wave.

Based on previous experiences with ESM dropout rates and a priori statistical analyses with other datasets, the study's principal investigator aimed at 70 measurement occasions and a sample size of 180 participants for Wave 1. In total, 179 participants (53% female) completed Wave 1. At Wave 2, which was the focus of the present study because of the assessment of major life events, 156 participants (53% female) provided ESM data and were included in all analyses. On average, they were 51 years old at Wave 2 (SD = 5.84, range: 39–62) and completed 69 measurement occasions/'beeps' (SD = 10.10, range: 10–86). For statistical analyses, all beeps were considered, irrespective of whether responses were provided for all questions (i.e. including partially incomplete beeps). In Wave 2, trained interviewers from the Humboldt-Universität zu Berlin visited participants at their homes, where they first provided informed consent before participating in the study. During these visits, participants were asked to undertake a semi-structured interview regarding their exposure to major life events and to answer computerized questionnaires. At the end of the home visits, participants were provided with smartphones (Huawei Ascend G330) and were introduced to the smartphones and questions at their homes (in accordance with Liao et al., 2016) using a customized ESM software (Riediger et al., 2009). The ESM phase began on the subsequent day (for a visualization and description of the ESM design, see Figure 1). Participants received €20 for the session at their homes and €60–€70 for the subsequent ESM phase (if they responded to a minimum of 60 out of the 72 prompts, compensation was €70). Data for Wave 2 were collected from February to June 2017. The study was approved by the local institutional review board.

Measures

Momentary affect

Momentary affect was measured by asking participants how they were feeling at the very moment of the ESM prompt. They had to rate how well each of the 12 expressions applied to them (i.e. six items each for positive affect, PA, and for negative affect, NA), using a 7-point scale ranging from *0* (*does not apply at all*) to *6* (*applies strongly*). We assessed both low arousal PA (i.e. the items well, relaxed, and satisfied) and low arousal NA (i.e. the items downhearted and distressed) as well as high arousal PA (i.e. the items joyful, interested, and inspired) and high arousal NA (i.e. the items nervous, jittery, angry, and upset). The specific items, some of which came from the PANAS scale (Watson & Clark, 1994), were chosen in accordance with a dimensional model of affect (Barrett & Russell, 1998). They were previously used in other intense longitudinal designs, where they showed sufficient variability (Blanke et al., 2020; Riediger et al., 2014; Röcke et al., 2009). Since we did not have hypotheses for specific items but expected associations with both positive and negative affect more generally, we used an average score across the six PA and NA items, respectively. High within-person construct reliability estimates (Ω_W = .83 for PA and Ω_W = .89 for NA, respectively) support this approach. We estimated construct reliabilities according to Lai (2021; i.e. an improved estimation of reliability in multilevel modelling, based on the method first suggested by Geldhof et al., 2014), using the compRelSEM-function of the R package semTools, version 0.5–6.

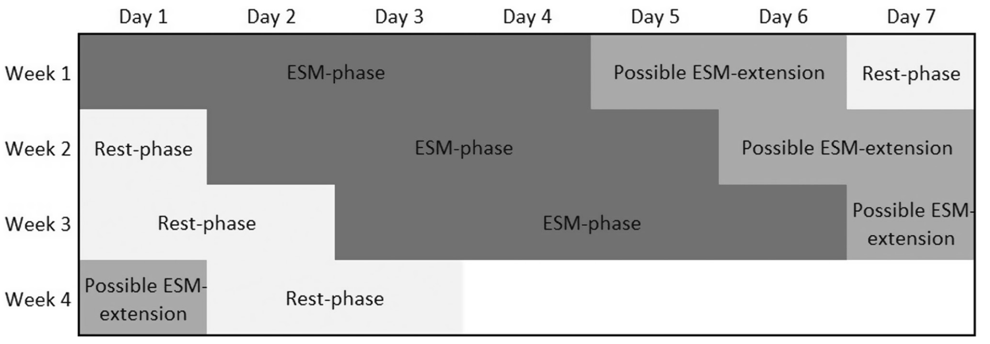

FIGURE 1 Overview of ESM design. *Note*: ESM, experience sampling methodology. The regular ESM phase spanned over 22 days and consisted of three 4-day periods with ESM and rest phases in between. Each 4-day-ESM phase could be extended by a maximum of 2 days in case of low response (i.e. the completion of four or less beeps per day) and was followed by 2 resting days. This 8-day rhythm of the ESM assessments was repeated three times and secured a mix of weekdays and weekend days. Moreover, the initial weekday of the first ESM phase varied between individuals and across weekdays and weekend days to avoid confounding through the weekday. On each of the ESM days, six beeps per day occurred semi-randomly in 2-h time slots (i.e. between 8–10, 10–12 and so forth), while ensuring that two beeps were not scheduled directly after one another. Moreover, participants individually selected a 12-h time window (e.g. 8 AM to 8 PM).

Current stress

For measuring levels of current stress (for a stress typology, see Epel et al., 2018), we asked participants on each occasion 'how stressed have you felt since the last ESM prompt (or since waking up)?'. The answers were given on a 7-point scale ranging from *0* (*not at all*) to *6* (*very much*).

Physical activity engagement

Physical activity engagement was assessed dichotomously by asking participants whether they engaged in physical activity since the last ESM prompt or since waking up (coded *yes* = 1, *no* = 0). On average, participants reported to have engaged in physical activity since the last beep on 27% of measurement occasions (SD = .22, range: .00–.99). While we acknowledge that objective and more nuanced assessments of physical activity are the gold standard (Reichert et al., 2020), we measured physical activity engagement using a single-item question because physical activity was not the main focus of the larger study, and to keep participant burden as low as possible (Collins & Muraven, 2007).

Global stress

We considered two aspects of global stress, namely major life events and chronic stress. To assess participants' lifetime exposure to major life events, we used semi-structured interviews based on an adapted version of the Social Readjustment Rating Scale (Hobson et al., 1998). The interviews contained questions regarding 32 life events and one option for 'other events', which, if applicable, the participants specified. Participants were asked whether each event had occurred in their lifetime. If participants repeatedly experienced an event, they were asked to focus on the most severe one. To measure the perceived severity of the events, participants indicated how difficult it was for them to deal with the event on a 5-point scale ranging from *0* (*very easy*) to *5* (*very difficult*). We used the average ratings of each person across all reported events as an indicator of the severity of major life events.

For the measurement of participants' levels of chronic stress, we used a shortened version of the Trier Inventory of Chronic Stress (TICS, Schulz & Schlotz, 1999). Participants rated six items (e.g. 'too many obligations that I have to fulfill'), answering how often they experienced each of them in the past 12 months. They indicated their answer on a 5-point scale, ranging from *0* (*not at all*) to *4* (*often*). For analyses, we used average scores across the six items. The between-person construct reliability for the six items was good, $\Omega_B = .83$.

Statistical analysis

We used multilevel modelling (MLM) to account for the hierarchical data structure with momentary measurement occasions nested within individuals. MLM allowed us to investigate within-person associations among stress, physical activity engagement, and affect, as well as these associations' interactions with between-person global stress levels. We estimated MLM parameters with restricted maximum likelihood (REML) estimation. Data were analysed using R Statistical Software version 4.1.2 (R Core Team, 2021). We estimated multilevel models using the lmer-function of the R package lme4 (version 1.1–28) and modelled the following equations.

Level-1 equation (within-Person level)

$$\begin{aligned}\text{Affect (PA/NA)}_{ti} &= \beta_{0i} + \beta_{1i}\,(\text{current stress})_{ti} + \beta_{2i}\,(\text{physical activity engagement})_{ti} \\ &+ \beta_{3i}\left(\text{current stress}_{ti} {}^{*} \text{physical activity engagement}\right)_{ti} \\ &+ \beta_{4}\,(\text{measurement occasion})_{ti} + \epsilon_{ti}.\end{aligned}$$

In this equation, affect (PA or NA, respectively) is the predicted outcome on a given measurement occasion (t) within an individual (i). As within-person parameters, the regression slopes for the effects of current stress (β_{1i}), physical activity engagement (β_{2i}), and the interaction between current stress and physical activity engagement (β_{3i}) were estimated. Moreover, we included measurement occasion as an additional predictor (β_4) to control for potential linear time trends. Because of problems regarding model convergence when including a random effect of measurement occasion, we only modelled its fixed effect. We centred current stress around individuals' means to separate within and between variances. Positive values represent current stress levels above individuals' means.

Level-2 equations (between-Person level)

$$\gamma_{0i} = \gamma_0 + \gamma_{01}(\text{major life events})_i + \zeta_{0i}$$

$$\gamma_{1i} = \gamma_1 + \gamma_{11}(\text{major life events})_i + \zeta_{1i}$$

$$\gamma_{2i} = \gamma_2 + \gamma_{21}(\text{major life events})_i + \zeta_{2i}$$

$$\gamma_{3i} = \gamma_3 + \gamma_{31}(\text{major life events})_i + \zeta_{3i}$$

In these Level-2 equations for major life events as a global contextual factor, the intercept and slopes for a given individual (i) are functions of the samples' average level (γ_0) and slopes (γ_1, γ_2, and γ_3, respectively), the effects of major life events (γ_{01}, γ_{11}, γ_{21} and γ_{31}, respectively), as well as the residual variances (ζ_{0i}, ζ_{1i}, ζ_{2i} and ζ_{3i}, respectively). Analogously, we formulated equations for chronic stress as a global contextual factor. We centred both major life events and chronic stress around the grand mean to facilitate the interpretation of the resulting estimates (Eid et al., 2017). Thus, intercepts represent the level of the criterion variables, positive and negative affect, for persons with average levels of major life events and chronic stress. Interactions with level-1 predictors represent deviations from level-1 effects for persons with average levels of major life events and chronic stress.

RESULTS

Descriptive statistics and correlations for Level-1 and Level-2 study variables are reported in Table 1. The intraclass correlations for positive affect, negative affect, and current stress in Table 1 indicated substantive variance at both the between- and within-person level, thus supporting the nested data-analytical approach. Over the course of the study, we found negative linear time trends for positive affect (estimate = −.001, SE = .000, 95% CI = [−.002, −.001], p < .001), but no change over time for negative affect (estimate = .000, SE = .000, 95% CI = [−.001, .000], p = .323).

Within-Person stress buffering after physical activity engagement (H1)

As a prerequisite for testing the stress-buffering hypothesis, we first replicated within-person main effects of current stress on both positive and negative affect: When individuals were confronted with more current stress since the last ESM prompt than usual, they experienced less positive affect (estimate = −.13, SE = .01, 95% CI = [−.16, −.11], p < .001) and more negative affect (estimate = .20, SE = .01, 95% CI = [.18, .23], p < .001). Building on these main effects of current stress, we then tested whether physical activity engagement moderates (i.e. buffers) these effects for positive and negative affect (H1). As shown in Table 2, physical activity engagement only buffered current stress effects for negative affect (estimate = −.05), but not for positive affect (estimate = .02), yielding partial support for H1. That is, while the association between current stress and negative affect was less pronounced when people engaged in physical activity since the last ESM prompt, the association between current stress and positive affect remained unaltered. Moreover, main effects of physical activity engagement indicate that people experienced more positive and less negative affect when having engaged in physical activity since the last ESM prompt.

Global stress context and within-Person stress buffering (H2)

Next, we tested the possible role of the global stress context for the effect of physical activity engagement on stress reactivity (H2). We segmented this step into separate analyses for major life events and

TABLE 1 Descriptive statistics and correlations of study variables.

Variable	n	M (SD)	95% CI	ICC	1	2	3	4	5	6
1. Positive affect [0–6]	156	3.19 (.81)	[3.06, 3.32]	.47	—	−.37	−.21			
2. Negative affect [0–6]	156	1.03 (.88)	[.89, 1.17]	.56	−.25*	—	.34			
3. Current stress [0–6]	156	1.45 (.97)	[1.29, 1.60]	.37	−.19*	.67*	—			
4. Physical activity engagement [0%–100%]	156	27% (22%)	[23%, 30%]		.13	−.10	−.22*	—		
5. Major life events [0–5]	156	2.60 (.84)	[2.47, 2.73]		−.12	.27*	.13	.05	—	
6. Chronic stress [0–4]	154	1.66 (.72)	[1.54, 1.77]		−.25*	.46*	.46*	−.20*	.29*	—

Note: Means and standard deviations for variables one to four represent aggregated individual means and standard deviations, respectively. The average of all within-person correlations (Level-1) is shown above the diagonal. Between-person correlations (Level-2) are shown below the diagonal.

Abbreviations: CI, confidence interval; ICC, intraclass correlation.

*p < .05.

TABLE 2 Within-Person effects of current stress and physical activity engagement on positive and negative affect.

Variable	Estimate	*SE*	95% CI	Random effects estimate (*SD*)
DV: Positive affect				
Intercept	3.19*	.07	[3.06, 3.31]	.63 (.79)*
Current stress	−.14*	.01	[−.17, −.11]	.02 (.15)*
Physical activity engagement	.25*	.03	[.19, .30]	.04 (.21)*
Current stress × physical activity engagement	.02	.02	[−.01, .05]	
DV: Negative affect				
Intercept	1.06*	.07	[.92, 1.20]	.77 (.88)*
Current stress	.21*	.01	[.19, .24]	.02 (.14)*
Physical activity engagement	−.08*	.03	[−.13, −.03]	.05 (.22)*
Current stress × physical activity engagement	−.05*	.01	[−.08, −.02]	

Abbreviations: CI, confidence interval; DV, dependent variable.
*$p < .05$.

chronic stress as respective moderators. When looking at the cross-level moderation of major life events on within-person stress buffering, results differed for positive and negative affect (see Table 3). Contrary to our predictions, major life events did not moderate within-person stress buffering for positive affect (three-way interaction; estimate = .01). For negative affect, the severity of major life events was a relevant moderator for stress buffering, but contrary to our hypothesis (three-way interaction; estimate = .06). As illustrated in Figure 2, the stress-buffering effect for negative affect was particularly pronounced when the severity of major life events was lower. That is, the difference in negative affect levels associated with physical activity compared to physical inactivity (i.e. the stress-buffering effect) is smaller when the severity of major life events was higher. Furthermore, the severity of major life events was associated with higher levels of negative affect, but not lower levels of positive affect. Regarding the two-way interactions, major life events did not moderate affect–physical activity engagement and affect–current stress relationships.

Chronic stress did not moderate the stress-buffering effect for positive affect (three-way interaction; estimate = .04) or negative affect (three-way interaction; estimate = .01, see Table 4). Moreover, higher chronic stress levels were associated with lower levels of positive affect and higher levels of negative affect. Concerning the two-way interactions, individuals experiencing more chronic stress had relatively lower levels of positive affect when experiencing more current stress since the last ESM prompt, while the current stress–negative affect associations remained unchanged by chronic stress. The associations between affect and physical activity engagement were not moderated by chronic stress.[2]

DISCUSSION

In this study, we argue that the experience of current stress might depend on the engagement in physical activity and individuals' global stress contexts (i.e. past major life events and current chronic stress). Correspondingly, we pursued two main goals. First, by using ESM methodology, we tested the stress-buffering hypothesis and investigated whether the coupling of current stress and affective well-being is altered after having engaged in physical activity since the last ESM prompt. Second, we analysed whether interindividual differences in the magnitude of this stress-buffering effect are related to individuals' global stress levels.

Within-Person stress buffering after physical activity engagement

As a prerequisite for investigating stress buffering, we largely replicated prior findings showing that individuals experience lower positive and higher negative momentary affect when they were more stressed

TABLE 3 Effects of major life events, current stress, and physical activity engagement on positive and negative affect.

Variable	Estimate	*SE*	95% CI	Random effects estimate (*SD*)
DV: Positive affect				
Intercept	3.19*	.07	[3.06, 3.32]	.63 (.79)*
Current stress	−.14*	.01	[−.17, −.11]	.02 (.15)*
Physical activity engagement	.25*	.03	[.19, .30]	.04 (.21)*
Current stress × physical activity engagement	.02	.02	[−.01, .05]	
Major life events	−.12	.08	[−.27, .03]	
Current stress × major life events	.00	.02	[−.03, .04]	
Physical activity × major life events	−.02	.03	[−.08, .05]	
Current stress × physical activity engagement × major life events	.01	.02	[−.03, .05]	
DV: Negative affect				
Intercept	1.05*	.07	[.92, 1.19]	.72 (.85)*
Current stress	.21*	.01	[.19, .24]	.02 (.14)*
Physical activity engagement	−.08*	.03	[−.13, −.03]	.05 (.22)*
Current stress × physical activity engagement	−.05*	.01	[−.08, −.02]	
Major life events	.28*	.08	[.12, .44]	
Current stress × major life events	−.00	.02	[−.04, .03]	
Physical activity engagement × major Life events	.03	.03	[−.03, .09]	
Current stress × physical activity engagement × major life events	.06*	.02	[.03, .10]	

Abbreviations: CI, confidence interval; DV, dependent variable.

*$p < .05$.

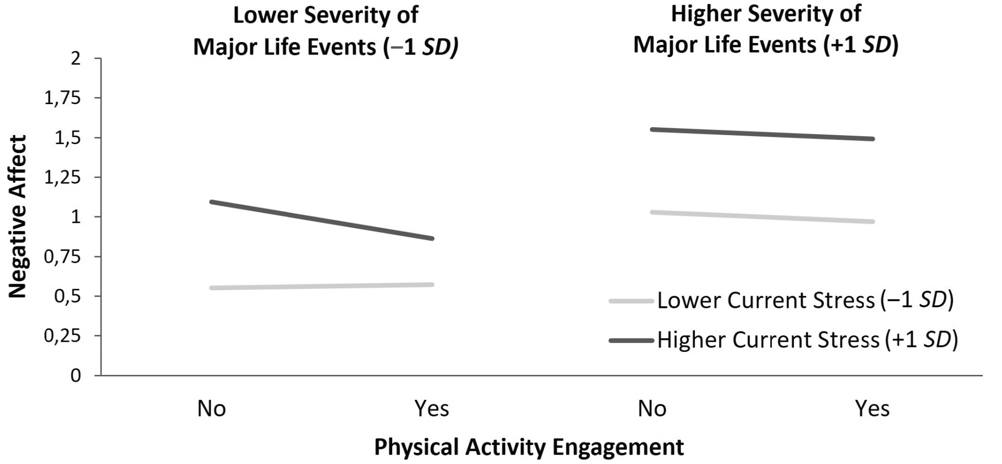

FIGURE 2 Interaction effect among current stress, physical activity engagement, and the severity of major life events in the prediction of negative affect. *Note*: Illustration of the interaction effect as presented in Table 4, lower part, controlling for all other effects. We assessed both current stress and the severity of major life events as continuous variables. The dichotomy between low- and high-stress scores was only used for illustrating purposes.

since the last ESM prompt than usual (Jacobs et al., 2007; Puterman et al., 2017). With regards to stress buffering, current stress was indeed less strongly associated with negative affect when people engaged in physical activity since the last ESM prompt. These findings extend prior research (Flueckiger et al., 2016; Puterman et al., 2017) insofar as we found the stress-buffering effect in a middle-aged population. Also,

TABLE 4 Effects of chronic stress, current stress, and physical activity engagement on positive and negative affect.

Variable	Estimate	*SE*	95% CI	Random effects estimate (*SD*)
DV: Positive affect				
Intercept	3.19*	.06	[3.06, 3.31]	.61 (.78)*
Current stress	−.14*	.01	[−.16, −.11]	.02 (.14)*
Physical activity engagement	.25*	.03	[.19, .30]	.04 (.21)*
Current stress × physical activity engagement	.01	.02	[−.02, .05]	
Chronic stress	−.26*	.09	[−.43, −.09]	
Current stress × chronic stress	−.06*	.02	[−.10, −.03]	
Physical activity × chronic Stress	.00	.04	[−.07, .08]	
Current stress × physical activity engagement × chronic stress	.04	.02	[−.01, .09]	
DV: Negative affect				
Intercept	1.05*	.06	[.92, 1.18]	.60 (.78)*
Current stress	.21*	.01	[.19, .24]	.02 (.14)*
Physical activity engagement	−.08*	.03	[−.13, −.02]	.05 (.22)*
Current stress × physical activity engagement	−.05*	.02	[−.08, −.02]	
Chronic stress	.56*	.09	[.39, .73]	
Current stress × chronic stress	.04	.02	[.00, .07]	
Physical activity × chronic stress	−.02	.04	[−.09, .05]	
Current stress × physical activity engagement × chronic stress	.01	.02	[−.03, .05]	

Abbreviations: CI, confidence interval; DV, dependent variable.

*$p < .05$.

by having implemented repeated ESM measures across the day, we could analyse stress buffering in closer proximity to the actual experiences (i.e. on several occasions within individuals' days; McLean et al., 2020). Contrasting the findings of Flueckiger et al. (2016), current-stress-related decreases in positive affect were not weaker after people engaged in physical activity.

One reason for the discrepancy between our results and those reported by Flueckiger et al. (2016) might be the differences in time intervals between measurement occasions. While Flueckiger et al. (2016) retrospectively asked participants about the past 24 h (including a potential recall bias; Prince et al., 2008), we conducted six measurements per day that were scheduled around 2 h apart from each other. In our sampling scheme, participants rather relied on their actual experiences, whereas answers in diary studies might be influenced by beliefs about oneself or by semantic knowledge (for a distinction between these different sources of information, see Robinson & Clore, 2002). If this was the case, stress buffering for positive affect, as observed by Flueckiger et al. (2016), might reflect that people belief in a buffering effect related to physical activity. Of course, these are speculations and more empirical support is needed before more sound decisions can be drawn. Furthermore, Flueckiger et al. (2016) examined a student population while our sample consisted of middle-aged adults. Hence, further investigations are needed to tell with higher certainty whether or not we can maintain positive affect in stressful moments by engaging in physical activity, and whether age is a moderating factor.

Global stress context and within-Person stress buffering

Building on the stress-buffering hypothesis, we considered current stress theory (Epel et al., 2018) which emphasizes the contextual dependence of current stress, and incorporated it into the investigation of within-person stress buffering. Regarding major life events, findings contrasted the hypotheses and followed different patterns for positive and negative affect. For positive affect, the severity of major life events did not moderate how well physical activity engagement buffered the negative effects of current stress. For negative affect, major life events did moderate stress buffering after physical activity engagement, but in the opposite direction to our assumption: With higher severity of major life events, having engaged in physical activity buffered the adverse association between current stress and negative affect less strongly as compared to a lower severity of major life events. While visual inspections suggest a rather small effect size, we interpret this finding as indication for a vulnerability that people face after having encountered more severe major life events. This finding of vulnerability connects with previous between-person results that reported weaker habitual stress buffering in individuals with more major life events (Stults-Kolehmainen et al., 2014), and extends these results by taking the within-person level into account. For a better understanding of this vulnerability, future investigations could take the temporal level into account and differentiate between major life events experienced in early childhood and later life. Given the increased risk of developing psychiatric disorders in later life following adversity in early childhood (e.g. McLaughlin et al., 2010), the temporal dimension of major life events could help to examine whether this vulnerability effect might be primarily driven by major life events in early childhood.

Our second indicator of global stress, chronic stress, did not moderate how well physical activity engagement buffered the effect of current stress on affective well-being, neither when looking at positive nor negative affect. This finding is at odds with a previous between-person study that reported habitual physical activity to be especially protective for mental well-being when people were more chronically stressed (Klaperski et al., 2012). However, it has to be noted that habitual physical activity engagement refers to a different aspect of physical activity than physical activity in everyday live (Gardner et al., 2016). Moreover, Klaperski et al. (2012) classified people as being chronically stressed when they experienced high levels of general stress on two measurement occasions which were 10 months apart. This conceptualization contrasts current definitions of chronic stress (e.g. see Epel et al., 2018), and may have rather measured repeated (i.e. episodic) than chronic stress experience, which is more persistent in nature. Since the trait-measure approach used in the current study is different from the conceptualizations mentioned above, results are hard to compare.

Strengths, limitations, and future directions

The current study has several strengths. First, when compared to other ESM studies (Perski et al., 2022), the large sample size and number of measurement occasions allowed to observe a high range and variance of current stress levels. Second, the present approach using repeated measures across the day goes beyond prior research using end-of-day recalls and provides a more natural and representative glimpse of the short-term dynamics of within-person stress buffering. In fact, such an approach focusing on the momentary level (i.e. across moments within individuals' days) might be necessary for capturing within-person stress-buffering effects (Wichers et al., 2012). Third, by considering current stress buffering in the global stress context, and by thus conceptualizing stress using between- and within-person factors, we investigated the long-standing stress-buffering hypothesis by incorporating state-of-the-art stress theory (Epel et al., 2018).

However, there are also limitations. Most importantly, physical activity engagement was subjectively measured using ESM self-reports, instead of objective measures such as accelerometry (Prince et al., 2008). Relatedly, we only measured the engagement but not the duration or intensity of physical activity, which might have also influenced our results. Given that more intense physical activity leads to stronger affective improvements subsequently (Carels et al., 2007; Guérin et al., 2013), stress buffering might also be stronger with higher intensity of physical activity, although the role of the intensity for stress buffering needs further investigation. Future studies could thus extend our study design by using wearables (e.g. fitbits) in order to obtain more nuanced information about physical activity (e.g. intensity, duration, and type; Dunton, 2017; Reichert et al., 2020) and examine present hypotheses more comprehensively by also measuring sedentary behaviour and sleep parameters. Moreover, since habitual physical activity is associated with reduced affective reactivity (Childs & de Wit, 2014; Pauly et al., 2019; von Haaren et al., 2015), future related studies of momentary stress buffering after physical activity engagement should also include habitual physical activity as a potential moderator. Another limitation is that we cannot make claims on causality since we analysed concurrent associations between current stress, physical activity engagement, and affect. Hence, it is also possible that higher positive and lower negative affect lead to higher physical activity engagement (for empirical support, see, e.g. Kushlev et al., 2020; Liao et al., 2017). Therefore, the term stress buffering needs to be understood in the sense of concurrent moderation. In the next step, and for moving the current state of the research towards investigating causal effects, experimental manipulations of physical activity (for more details, see Carraro & Gaudreau, 2013) could be combined with event-contingent sampling (i.e. instead of receiving random prompts, participants start the ESM questionnaires manually before and after they engaged in physical activity). One might also criticize that major life events, even though thoroughly measured through semi-structured interviews, were reported retrospectively and might thus be subject to memory biases. Moreover, we assessed all stress variables with self-reports, which may show no or only small associations with physiological stress indicators (Epel et al., 2018).

Regarding future directions, mechanisms and dynamics of how physical activity is related to affect and stress buffering in everyday life need to be better understood. From a transdisciplinary stress perspective, that would make examining the appraisals and physiological responses regarding physical activity engagement and current stress necessary for understanding stress buffering more holistically (Epel et al., 2018). This understanding could provide a basis for the development of tailored interventions, encouraging individuals to incorporate physical activity into their daily lives. Another way to take the present study further would be to investigate the relationship between short-term dynamics of stress buffering and long-term health outcomes. For instance, it could be explored whether people who are better at buffering current stress effects with physical activity would also be less likely to develop mental or physical health problems in the long run. Moreover, in addition to examining physical activity, future studies should also investigate the influence of other health behaviours (e.g. sleep, cigarette and alcohol consumption, and nutrition; Dalton & Hammen, 2018; Perski et al., 2022) on the within-person stress-buffering effect.

CONCLUSION

The current study extends previous daily diary studies by using repeated measures across the day to investigate the within-person dynamics of stress, physical activity engagement and affect, and by incorporating the global stress context in this endeavour. Put in a nutshell, results revealed that stress was negatively related to affective well-being. Physical activity engagement was positively associated with affective well-being and buffered the adverse effect of current stress on negative affect. Regarding the global stress context (i.e. exposure to major life events and chronic stress), moderation effects were found for major life events only. That is, people experiencing more severe major life events showed a lower stress-buffering effect for negative affect after having engaged in physical activity. Taken together, evidence is consolidating that physical activity is an important health behaviour for maintaining affective and mental well-being when encountering current stress. In addition to stress management trainings, tailored intervention programs aiding individuals to integrate physical activity into their daily lives are highly needed.

AUTHOR CONTRIBUTIONS

Leo Gerstberger: Conceptualization; data curation; formal analysis; methodology; visualization; writing – original draft; writing – review and editing. **Elisabeth S. Blanke:** Conceptualization; investigation; methodology; project administration; supervision; writing – review and editing. **Jan Keller:** Supervision; writing – review and editing. **Annette Brose:** Conceptualization; funding acquisition; investigation; methodology; project administration; supervision; writing – review and editing.

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CONFLICT OF INTEREST STATEMENT

None to declare.

DATA AVAILABILITY STATEMENT

The data of Wave 1, including documentation of all measures, can be publicly assessed from the repository of the German Institute for Economic Research (DIW; https://www.diw.de/en/diw_01.c.601784.en/soep-is_innovative_modules.html). The data of Wave 2, which is the focus of the current study, will also be made available via the DIW. All code used for data analyses is publicly available under the following repository: https://osf.io/5yzwn/.

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ENDNOTES

[1] It should be noted that, for the purpose of consistency with the scientific literature, we use the term stress buffering despite the cross-sectional nature of our data. Thus, as also discussed in the limitations, stress buffering in our study should be understood in the sense of concurrent moderation.

[2] To determine how robust the above-reported results are, we performed outlier analyses using the cooks.distance-function of the R package influence.ME (version 0.9–9). For all analyses, removing outliers did not change the significance of any estimate relevant for the hypotheses, thus supporting the robustness of the reported results.

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