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Journal

Health Psychology, 36(8)

ISSN

0278-6133

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Publication Date

2017-08-01

DOI

10.1037/hea0000466

Peer reviewed

Health Psychology
2017, Vol. 36, No. 8, 811–818

0278-6133/17/$12.00 http://dx.doi.org/10.1037/hea0000466

Revisiting the Lack of Association Between Affect and Physiology: Contrasting Between-Person and Within-Person Analyses

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Objective: Despite experimental manipulations that reliably elicit affective and physiological responses, the relationship between the two frequently appears small or nonexistent. We propose that this is, at least in part, due to a mismatch between the nature of the question being asked and the analytic methods applied. For example, to test if levels of affect reliably covary with physiology over time—a within-person question—one cannot apply analytic approaches that test whether people are similarly reactive across domains—a between-person question. The purpose of this paper is to compare within-person and between-person analyses testing the association between affect and physiology. ***Method:*** Participants ($N = 60$) recalled an event from their lives that made them angry. Self-reported anger and objective blood pressure levels were recorded at baseline, after the recall, and 5 times during recovery. ***Results:*** Between-person correlations between anger and blood pressure were nonsignificant across all phases of the study, suggesting that those least/most reactive for anger were not least/most reactive for blood pressure. These null findings held regardless of whether linear or nonlinear assumptions were modeled. In contrast, within-person multilevel modeling indicated a clear relationship, suggesting that when a person was angrier that person's blood pressure was higher compared with when that person was less angry. ***Conclusion:*** Results suggest the importance of appropriately matching analytic strategy to the nature of the question regarding the relationships between affect and physiology. Implications for past and future research are discussed.

Keywords: affect, correlation, physiology, anger, blood pressure

Measuring affect and physiology and examining how these variables relate and change over time are important questions for biobehavioral and psychophysiological research. Such evidence helps to better understand the etiology and progression of disease and inform interventions. However, researchers studying the association between affective and physiological changes in the laboratory face a conundrum. Although experimental manipulations often increase self-reported negative affect (e.g., the experience of anger) and influence physiological responses (e.g., raise blood pressure [BP]), the relationship between the changes in affect and physiology is often statistically nonsignificant or modest in magnitude. For example, a meta-analysis indicated that changes in negative affect due to a stressor only accounted for 2–12% of changes in cardiovascular responses despite large changes in cardiovascular responses after the stressor (Feldman et al., 1999). If participants report more negative affect as a result of a stressor, and their bodies react to the same stressor, then one would reasonably expect that the changes in affect and physiology would be strongly associated.

Understanding the Lack of Correspondence

Many explanations have been offered for the lack of association between affect and physiology (Gerin et al., 1999; Hilmert & Kvasnicka, 2010). For example, how variables are measured may not be adequate because affect is usually measured at the end of a study period (e.g., baseline) whereas physiology is often continuously measured (Feldman et al., 1999; Lovallo & Gerin, 2003). Another explanation questions the ability of participants to accurately report on their affective states (Sato & Kawahara, 2011; Thomas & Diener, 1990) and if self-reports of affect are valid indicators of one's "true experience" (Russell & Barrett, 1999). For example, individuals may report how they want others to think they are feeling rather than what they are actually experiencing

This article was published Online First March 9, 2017.

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Portions of this work were presented in an oral session at the 2013 Annual Meeting of the American Psychosomatic Society in Miami, Florida.

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(Fisher, 1993; Fisher & Dubé, 2005) whereas physiological responses tend to be more objective (Barger, Kircher, & Croyle, 1997). Common to these and related explanations are critiques on methods and the assumptions of if and how affect can be measured. These issues are important to consider in any experiment, and how they are dealt with likely influences the strength of any observable relationship between affect and physiology.

The Distinct Questions Tested by Between-Person and Within-Person Analyses

This paper outlines a different, yet complementary, approach suggesting that the null or modest associations may be due in large part to using between-person analyses to test within-person questions. For example, the within-person question asks if moments (within an individual) characterized by greater anger are associated with higher BP levels compared with moments with less anger. Analyzing this question requires repeated measurements of anger and BP for each person and statistical models that account for time (e.g., multilevel modeling) so as to assess one's trajectories across multiple variables. Indeed, these within-person approaches have been applied to test, for example, the relationship between engagement in leisure and mood, stress, and heart rate levels (Zawadzki, Smyth, & Costigan, 2015) as well as socially evaluative threats and ambulatory BP levels (Smith, Birmingham, & Uchino, 2012). Moreover, there have been increasing calls to use these analytic techniques with repeated-measures data in psychosomatic medicine (Blackwell, de Leon, & Miller, 2006; Myers et al., 2012). In fact, Feldman and colleagues (1999) concluded their meta-analysis with a call for needing to examine the relationships between affect and physiology using within-person methods.

However, despite such calls, even when experimental data allow for more complex modeling, only between-person analyses have typically been conducted. Although often important in their own right, between-person analyses answer a fundamentally different question than within-person analyses. Between-person analyses compare one individual to another; for example, in testing the extent to which people who are highly reactive in one domain (compared with other people) are also highly reactive in another domain (compared with other people). Conducting these analyses requires having single data points for anger and BP to compare across people, which can mean aggregating variables (e.g., calculating a difference score between anger at baseline and after an argument). These between-person approaches have successfully been used to show that those who are provoked during a task involving active coping were those with the greatest cardiovascular activity (Bongard, Pfeiffer, al'Absi, Hodapp, & Linnenkemper, 1997), that different emotions produce distinct cardiovascular profiles (Sinha, Lovallo, & Parsons, 1992), and that coherence between responding to anger provocation was higher when comparing within systems (automatic and reflexive) versus across them (Evers et al., 2014).

Both between-person and within-person questions are important, and for many studies it may be possible to utilize both approaches within the same dataset. However, as alluded to earlier, they test different questions that may not converge on a similar answer (e.g., Hoffman & Stawski, 2009). Hypothetical data are depicted in Figure 1 to demonstrate such a situation. The left side depicts a scatterplot between BP and anger change scores before and after a stressor. Across individuals, larger magnitudes of change occurred for anger than BP for some and for BP than anger for others. As a result, the between-person analyses reveal a weak correlation, even though all people demonstrated an increase in anger and BP as a result of the stressor. In contrast, the right side shows standardized anger and BP data from three of those individuals over time. Within individuals, a fairly consistent effect exists in which every time an anger score increased BP also increased—albeit at slightly different rates. As a result, the within-person analyses (e.g., multilevel modeling) reveal a positive relationship. These seemingly opposite results highlight that the nature of relationships between variables at one level cannot be assumed to exist at another (i.e., the ecological fallacy; Kramer, 1983; Portnov, Dubnov, & Barchana, 2007). This issue has been explored in the context of aging and cognition (e.g., Sliwinski & Mogle, 2008) and more generally discussed as a theoretical/analytic issue (e.g., Molenaar & Campbell, 2009), underscoring the need for more careful attention and exploration.

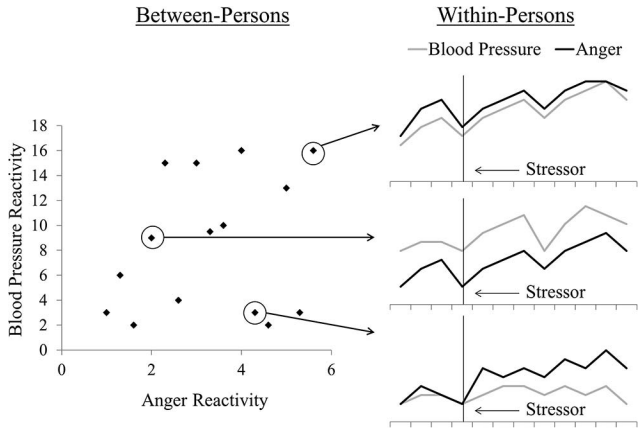

Figure 1. Hypothetical data comparing between-person and within-person analyses. The scatterplot on the left depicts the correlation between BP and anger change scores; the line graphs to the right are time series representations of data from three individuals depicted in the scatterplot to the left. The figure depicts that between-person and within-person analyses can operate independently of each other.

The Present Research

This study examined the relationship between anger and BP using between-person and within-person analyses. An experiment was conducted in which participants had engaged in an anger recall task, and anger and BP levels were recorded at baseline, immediately after the anger recall, and at multiple postrecall recovery periods. Although we expected within-person relationships and thus proposed the need for multilevel modeling to test change over time, we also conducted a series of bivariate correlations and regressions (between-person analyses) in order to mirror what has typically been done with data of this sort. On the basis of the reported literature, we did not predict significant associations between anger and BP using the between-person analyses, but we did expect to identify such associations with the within-person analyses.

Method

Participants

In exchange for payment ($25), community participants (N = 60) completed the study. There were 30 men and 30 women, aged 18–79 years (M = 37.93, SD = 13.86), who identified as White (39; 65%), Black or African American (14; 23.3%), Asian or Pacific Islander (3, 5.0%), or other/declined to state (4; 6.7%). Most participants indicated they were not Hispanic (53, 88.3%). Participants were excluded if they had a history of cardiovascular problems, including hypertension and coronary heart disease. Data for this study were collected in 2004–2005 and have been reported elsewhere (Gerin, Davidson, Christenfeld, Goyal, & Schwartz, 2006).

Procedure

Participants were recruited by advertisements at the Cornell University Medical Center. To participate in the study, participants were asked to refrain from smoking and drinking caffeine for 4 h before the study. Upon coming to the laboratory, participants provided informed consent. They then completed a three-part study. First, baseline assessments of self-reported anger and BP were recorded (i.e., baseline phase).

Next, participants completed an anger recall task lasting approximately 5 min in which they reported how they felt now concerning an incident that had occurred during the prior year in which they had become upset and angry (i.e., recall phase). Following prior protocols, participants were instructed to select an incident that was poorly resolved and still made them upset when they thought about it (Ironson et al., 1992). During the recall task, the experimenter adopted a neutral countenance, nodding and making eye contact to encourage participants to continue speaking but offering neither agreement nor disagreement with the statements.

Finally, participants sat for a 12-min recovery period in a room with no distractions (i.e., recovery phase). All procedures were approved by the Cornell Institutional Review Board.

It should be noted that participants also completed a similar protocol described here on another day 1 week apart. The sessions were identical except that participants recalled a different upsetting and unresolved incident and sat in a room with distractions such as posters on the walls and magazines and games. These sessions were counterbalanced. The study found that when recovering in the room that contained the distractions, the distractions disrupted the ruminative process and sped up BP recovery compared with when distractions were not present (Gerin et al., 2006). Given the present focus of this paper, we present the results only for when no distractions were present during recovery because this condition better represents traditional experimental paradigms testing the effects of a stressor on affect and physiology.

Materials

For the current study, we focus solely on two sets of measurements: self-reported anger scores and BP levels. Participants reported how angry they felt on a 1 (*not at all*) to 7 (*very much*) scale at baseline, immediately after the anger recall task, and then 5 times during the recovery phase at 2-min intervals. Systolic BP (SBP) and diastolic BP (DBP) were collected using an Ohmeda Finapres 2300 BP monitor (Datex-Ohmeda, Englewood, CO), which takes and records beat-to-beat pressures in a noninvasive manner using the Peñaz method (Wesseling, 1990). To record BP, a finger cuff was worn on the third finger of the nondominant hand. This method of BP measurement has been shown to relate to intra-arterial readings extremely well (Parati, Casadei, Groppelli, Di Rienzo, & Mancia, 1989). The BP data were collected continuously during the study but then aggregated into the following roughly equally spaced units to correspond to the self-reported anger ratings: an average from the last 2 min of baseline phase, an average of the recall phase, and averages for five 2-min intervals during the recovery phase.

Analytic Approach

We performed three sets of analyses that tested (a) between-person associations between anger and BP assuming linear relationships, (b) between-person associations between anger and BP allowing for nonlinear relationships, and (c) multilevel modeling examining between-person and within-person associations between anger and BP.

First, for the between-person associations assuming linear relationships, we calculated change scores for anger and BP from baseline to the study phase of interest (e.g., the change in anger from baseline to the first interval of the recovery phase). We should note that although a change score calculates a difference within a person over time, the analyses we are conducting compare one person's difference to another person's difference and not what happens when that difference occurs; thus, it is conceptually a between-person analysis. We then ran two sets of correlations. One correlated the change in anger from baseline to study phase of interest with the change in SBP or DBP over the same period. The other performed a partial correlation of change in anger from baseline to study phase of interest with the change in SBP or DBP over the same phase while controlling for baseline anger and SBP or DBP. We acknowledge that issues may exist with the use of change scores in analyses (Gardner & Neufeld, 1987; Norman, 1989); however, we performed these analyses to replicate an approach that is often used to analyze data of this sort. In an attempt to impose fewer assumptions on the data compared with the change score approach, we also regressed phase-specific scores (e.g., the first interval of the recovery phase) for BP on anger at the same phase while controlling for baseline BP.

Second, for between-person associations allowing for nonlinear relationships, area under the curve (AUC) was calculated using the trapezoidal method across all phases of the study (baseline, recall, five intervals of the recovery period) for anger, SBP, and DBP; anger AUCs were then correlated with AUCs for SBP and DBP. Patterns are nearly identical if the AUC calculation only includes the recall and the recovery phases, and regardless of whether baseline SBP or DBP is included as a predictor in the analyses. We also considered the possibility that anger and BP have different rates of recovery. As an alternative to the AUC approach that better accounts for this, we also computed maximum value scores for anger, SBP, and DBP during the recovery phase by subtracting baseline anger/BP from the highest anger/BP score across the five intervals of the recovery phase. The max anger scores were then

regressed on maximum value SBP and DBP scores while controlling for baseline SBP or DBP.

Finally, we used multilevel models to examine between-person and within-person associations of anger with BP during recovery. We focused on recovery because we only had a single baseline measure; thus, we did not feel we could properly test changes from baseline to after the recall with this single measure. It should be noted that there are many ways to conduct these procedures (e.g., different statistical programs, different modeled parameters), with the results reported here representing only one possible model that was guided by recent texts (Bolger & Laurenceau, 2013; Singer & Willett, 2003). Specifically, a two-level model was fit to the data using SAS (v. 9.4) PROC Mixed with observations at each phase of the study (Level 1) nested within individuals (Level 2). The models predicted momentary SBP or DBP starting at the recall phase (Level 1), as a function of baseline SBP or DBP (Level 2), time in minutes since the recall period entered as a linear and quadratic trend (Level 1), person anger means (i.e., Level 2; an average of each person's anger scores across all measurements that was grand mean centered), and person mean-centered momentary anger scores (i.e., Level 1; momentary ratings of anger within individuals centered around the participant's mean anger score). The quadratic effect of time tested for the expected possibility that recovery happened faster during the beginning of the recovery period rather than similar levels of recovery over time. We allowed for participants to vary on their starting levels and recovery over time; thus, we entered random intercepts and slopes (linear and quadratic). We also allowed the predicted effect of anger on BP to differ across people; thus, we entered a random effect for the person mean-centered momentary anger score. Finally, we allowed for the possibility that observations closer in time were more strongly related to each other than those farther apart (i.e., controlled for autocorrelations of the error terms using an autoregressive structure).

Results

Anger Recall Task Manipulation Check

We conducted one-way (baseline phase, recall phase, the five intervals of the recovery phase) repeated-measures analyses of variance (ANOVAs) with SBP, DBP, and anger as the dependent variables in separate models. As can be seen in Table 1, SBP, DBP, and anger dramatically increased as a result of the recall task and then quickly started to recover. Thus, results suggest that BP and anger levels were successfully manipulated with the anger induction.

Between-Person Analyses

We examined whether the increases in BP and anger due to the manipulation and subsequent patterns of recovery were related using four common types of between-person analyses: (a) We performed two sets of analyses of change scores. One correlated the change in anger from baseline to study phase of interest with the change in SBP or DBP over the same period. The other performed a partial correlation of change in anger from baseline to study phase of interest with the change in SBP or DBP over the same phase while controlling for baseline anger and SBP or DBP.

Table 1
Repeated-Measures ANOVAs of BP and Anger Scores

Phase of study	SBP, *M* (*SD*)	DBP, *M* (*SD*)	Anger, *M* (*SD*)
Baseline	120.46 (20.98)[a]	70.10 (11.83)[a]	1.18 (.60)[a]
Recall	140.75 (25.68)[b]	82.24 (15.21)[b]	2.70 (1.45)[b]
Recovery 1	129.77 (12.01)[c]	75.66 (13.73)[c]	2.18 (1.46)[c]
Recovery 2	129.85 (24.01)[c]	75.60 (13.59)[c]	1.95 (1.49)[c,d]
Recovery 3	127.26 (23.35)[d]	74.10 (13.21)[d]	1.68 (1.36)[d]
Recovery 4	127.28 (22.91)[d]	73.99 (13.34)[d]	1.70 (1.33)[d]
Recovery 5	128.66 (23.41)[c,d]	74.69 (13.67)[c,d]	1.65 (1.33)[d]
Model statistics			
F	40.39	50.73	13.21
df	6, 354	6, 354	6, 354
p	<.001	<.001	<.001
η_p^2	.41	.46	.18

Note. Differing superscript letters denote when one phase differs from the others at the $p < .05$ level. Each column represents a separate repeated-measures ANOVA for SBP, DBP, and anger scores.

(b) We regressed phase-specific scores for SBP or DBP on anger at the same phase while controlling for baseline SBP or DBP. (c) Using the trapezoidal method, AUC was calculated across all time points of the study for anger, SBP, and DBP; anger AUCs were then correlated with AUCs for SBP and DBP. (d) Finally, maximum value scores for anger, SBP, and DBP were calculated during the recovery phase by subtracting baseline anger/SBP or DBP levels from the highest anger/SBP or DBP levels during the five intervals of the recovery phase; the maximum value anger scores were then regressed on maximum value SBP and DBP scores while controlling for baseline SBP or DBP. Table 2 indicates that, using between-person analyses, affect ratings do not relate to physiological changes, regardless of specific approach.

Within-Person Analyses

Finally, we examined if within-person analyses would demonstrate a significant association between affect and physiology within persons over time. The models entered both a person-averaged anger score (thus conceptually replicating the between-person analyses reported earlier) as well as momentary ratings of anger (that test the within-person association of anger with BP). These models also controlled for baseline BP, and continuous time as the recall phase was entered as a linear and a quadratic trend. Of note, as Table 3 shows in the fixed effects portion, person-level mean anger was not related to either SBP ($p = .347$) or DBP ($p = .658$). In contrast, one's momentary anger significantly related to SBP ($p = .048$) and DBP ($p = .041$), even when controlling for baseline SBP or DBP, time trends, and the person's overall anger score. In other words, in moments when a person reported being angrier than typical, that person's BP was higher compared with moments when that same person reported being less angry (the within-person effect). In contrast, as noted, the person-averaged anger scores were unrelated to BP (the between-person effect).

Discussion

Although not a new proposition, there is growing awareness that between-person and within-person analytic approaches test different questions. In the context of this paper, the between-person

Table 2
Correlations and Regressions for Change, Phase-Specific, AUC, and Max Scores for Anger on BP

Type of test	SBP	DBP
Correlation of change scores		
Recall − Baseline	.13 (p = .131)	−.002 (p = .986)
Recovery 1 − Baseline	.08 (p = .546)	.08 (p = .542)
Recovery 2 − Baseline	.17 (p = .204)	.12 (p = .357)
Recovery 3 − Baseline	.03 (p = .850)	.10 (p = .445)
Recovery 4 − Baseline	.04 (p = .775)	.06 (p = .660)
Recovery 5 − Baseline	.06 (p = .633)	−.02 (p = .894)
Partial correlation of change scores controlling for baseline BP and anger		
Recall − Baseline	.12 (p = .384)	−.03 (p = .847)
Recovery 1 – Baseline	.09 (p = .518)	.05 (p = .715)
Recovery 2 – Baseline	.18 (p = .171)	.11 (p = .422)
Recovery 3 – Baseline	.04 (p = .796)	.11 (p = .430)
Recovery 4 – Baseline	.05 (p = .725)	.04 (p = .784)
Recovery 5 – Baseline	.09 (p = .495)	−.06 (p = .676)
Regression of phase-specific scores controlling for baseline BP		
Recall	.06 (p = .451)	−.02 (p = .762)
Recovery 1	.05 (p = .515)	.36 (p = .722)
Recovery 2	.10 (p = .166)	.05 (p = .453)
Recovery 3	.02 (p = .796)	.05 (p = .426)
Recovery 4	.02 (p = .725)	.02 (p = .764)
Recovery 5	.05 (p = .482)	−.03 (p = .665)
Correlation of AUC	.05 (p = .734)	.07 (p = .620)
Regression of max scores controlling for baseline BP		
Max – Baseline	.05 (p = .714)	.04 (p = .785)

Note. For correlations, the correlation coefficient (Pearson's r) is reported; for regressions, the standardized beta estimate (β) is reported.

analyses test if individuals are similarly reactive across affective and physiological channels whereas the within-person analyses test whether or not changes in affective states relate to corresponding changes in physiology within persons over time. The results demonstrate the potential independence of these separate questions; each gives us important, but different, information. Namely, the data do not support the (between-person) hypothesis that individuals who are highly reactive across affective channels (compared with other people) are also highly reactive across physiological channels (compared with other people) in response to this anger recall task. These results are consistent with the results of a meta-analysis that concluded that changes in negative affect accounted for only a small amount of the variance of the changes in physiology due to a stressor (Feldman et al., 1999), but they extend this prior work by also examining within-person associations. In contrast to the lack of between-person associations, we found evidence supporting the within-person hypothesis. That is, when anger levels were higher for a person at a particular moment during recovery, that person's BP was also higher at that moment compared with when that person's anger was lower (i.e., anger levels reliably covaried with BP levels).

An additional point is that, although affect and physiology potentially overlap at the within-person level, they also represent distinct systems and are influenced by multiple factors. As with any imperfectly measured system, the differences in these systems and measurement capability prohibit ever being able to observe a 1:1 relationship. For example, physiology can be measured (near) continuously, whereas most assessments of affect occur during discrete moments often measured after the event of interest has concluded (Feldman et al., 1999; Lovallo & Gerin, 2003). In addition, measures of affect may require reflection on the part of the participant that may not accurately represent what one was feeling at that time (Russell & Barrett, 1999) compared with measures of physiology that are often passively and/or objectively measured. Thus, although the results of the present study suggest the potential utility of using within-person analyses as an additional tool to study the relationship between affect and physiology, this approach is still constrained by limits on the measurement of affect and physiology.

Implications

Examining how affect and physiology are related to each other is an important question for biobehavioral medicine and psychophysiological research. These results highlight the importance of matching one's proposed research question to the analyses conducted. Many researchers have successfully used between-person analyses to test whether people are similarly reactive across affective and physiological domains and other interesting between-person questions (Bongard et al., 1997; Evers et al., 2014; Sinha et al., 1992). Some prior studies may have prematurely rejected within-person hypotheses regarding how affect and physiology are related if such conclusions were based solely on between-person analyses. Testing the within-person associations—how increases/decreases in affect relate to changes in physiology over time within the same individuals—requires an analytic approach tailored to this type of question. Neither between-person nor within-person approaches are intrinsically superior (or even preferable); rather, they offer complementary ways to examining different components of how affect and physiology may be related. As such,

Table 3
Estimates (SE) of Multilevel Models Examining Within-Person Anger Scores Predicting SBP and DBP

Effect	SBP	DBP
Fixed effects		
Intercept	20.81* (8.70)	11.94** (4.18)
Baseline BP	0.96*** (0.07)	0.98*** (0.06)
Minutes Elapsed	−3.68*** (0.41)	−2.20*** (0.22)
Minutes Elapsed^2	0.27*** (0.04)	0.16*** (0.02)
Person-Averaged Anger	1.41 (1.49)	0.31 (0.71)
Momentary Anger	0.79* (0.39)	0.43* (0.20)
Random effects		
Level 2 (between-person)		
Intercept	200.36*** (43.09)	62.40*** (12.49)
Intercept × Minutes Elapsed	−15.75* (7.42)	−6.69** (2.47)
Minutes Elapsed	4.37* (2.42)	1.33* (0.77)
Intercept × Minutes Elapsed^2	0.70 (0.59)	0.32+ (0.20)
Minutes Elapsed × Minutes Elapsed^2	−0.30 (0.21)	−0.09 (0.07)
Minutes Elapsed^2	0.02 (0.02)	0.01 (0.01)
Intercept × Momentary Anger	1.71 (6.81)	−0.24 (2.07)
Minutes Elapsed × Momentary Anger	−1.99 (1.26)	−0.45 (0.39)
Minutes Elapsed^2 × Momentary Anger	0.14 (0.11)	0.04 (0.03)
Momentary Anger	1.18 (1.43)	0.23 (0.37)
Level 1 (within-person)		
Autocorrelation	0.08 (0.18)	0.09 (0.20)
Residual	28.42*** (6.88)	8.31*** (2.16)

Note. Minutes Elapsed is the number of minutes that has passed since the end of the recall phase (recall is coded as 0). Person-Averaged Anger is an average of all of the anger scores across the study and tests the between-person effect of anger on BP. Momentary Anger is person mean-centered variable of anger (i.e., momentary anger score minus the person's average anger) and tests the within-person effect of anger on BP.
$^{+}p < .10$. $^{*}p < .05$. $^{**}p < .01$. $^{***}p < .001$.

researchers may have the opportunity to explore past data to test for within-person relationships if only between-person analyses were originally applied.

In addition, the within-person approach allows for conducting analyses that better characterize relationships between variables over time and individuals' rates of change. For example, we made the assumption that anger and BP would be similarly related across the study. However, we also could have tested whether the strength of the within-person relationship varies depending on some time-varying or environmental influence (e.g., are anger and BP more strongly related while experiencing stress than when resting or recovering from stress?). As another example, we could have tested whether certain stable individual differences or environmental factors moderate the relationship between anger and physiology provided we had these measures at baseline (e.g., do emotionally reactive individuals show stronger relationships between anger and BP than less reactive individuals?). In fact, we could have combined the questions raised in both examples and examined whether the within-person relationship between anger and BP is stronger at certain times for certain types of people. That is, within-person analyses can go beyond simply examining if affect and physiology are related, allowing for the examination of more complex questions of how, when, and in what contexts they show associations.

Limitations and Future Directions

Although the within-person approach offers great power and flexibility to test models, it requires sufficient individuals and observations per individual. Moreover, if the researcher is interested in understanding how the relationships between affect and physiology might differ within individuals across different phases or environmental influences (e.g., baseline vs. recovery periods; stressor present vs. not present), then it is necessary to collect enough measurements to model change in both phases. Some of these issues were evident in the present study. For example, because we only had one measurement of anger at baseline, we were unable to examine the relationship between anger and BP over the course of baseline as we did for the recovery phase. Thus, we cannot determine whether the relationships between anger and BP are always strong or whether they are only strong when a person is under duress (i.e., the relationship is strengthened when one is recovering from stress). For future research, we recommend collecting multiple observations per person for each phase of interest so as to maximize the types of within-person analyses that can be tested.

We were also limited in this study to examining the relationships between anger and BP, but many other emotions and physiological outcomes are important to study. For example, cross-sectional work has found that trait levels of anxiety (e.g., Räikkönen, Matthews, Flory, Owens, & Gump, 1999) and depressed mood (e.g., Jones-Webb, Jacobs, Flack, & Liu, 1996) are related to higher BP; it would be interesting to test these associations at the within-person level and with experimental designs that allow for more causal inferencing. Moreover, one's emotions have been shown to predict heart rate (Brosschot & Thayer, 2003), heart rate variability (e.g., McCraty, Atkinson, Tiller, Rein, & Watkins, 1995), and cortisol and markers of inflammation (e.g.,

Denson, Spanovic, & Miller, 2009). Future work may wish to expand what aspects of affect and physiology are explored using within-person approaches.

Finally, although this study focused on the relationship between experimentally manipulated anger and BP in the laboratory, these relationships could be explored in many other contexts. Notably, there is increasing interest in examining mood/affect and physiology in daily life using daily diary methods and ecological momentary assessment (EMA; see Smyth & Heron, 2012; Smyth & Stone, 2003). Indeed, some work has found associations between negatively valenced and high arousal affect and ambulatory BP (e.g., Kamarck et al., 2002; Zawadzki, Mendiola, Walle, & Gerin, 2016). Because EMA and daily diary studies typically collect multiple assessments within and across days, the data for these studies are naturally suited to within-person multilevel modeling. The greater density of measurements can allow for a more nuanced understanding of how time-varying contextual features can impact the nature and strength of the relationship between affect and physiology. That said, studies using these methods typically lack experimental manipulations of the constructs of interest; thus, they are limited in being able to directly address causal claims. However, some work has integrated experimental manipulations with EMA designs. For example, one study experimentally induced positive and negative cognitive states (e.g., rumination) in the field across multiple days using EMA and then assessed the resultant mood effects (e.g., Huffziger et al., 2013). Thus, this work suggests the potential to more strongly test causality in environments with high ecological validity.

Conclusions

Understanding how affect and physiology are related within individuals has implications ranging from understanding basic emotional and physiological processes that can impact the etiology and progression of disease to better informing the design of interventions. In addition to the long and fruitful use of between-person analytic approaches in the context of experimental manipulations, within-person analyses provide an important and complementary analytic approach when the data allow for such (i.e., repeated assessments within individuals). Given that many research designs already call for repeated assessments of affect and physiology, and the greater availability of statistical programs to conduct multilevel modeling, there are now fewer barriers to conducting these analyses (whether in reanalyzing data from past studies or collecting new data). Thus, there is great potential to use within-person analyses to help explore how affect and physiology are coupled and, in turn, to push forward an understanding of how, when, and in what contexts they show associations.

References

Barger, S. D., Kircher, J. C., & Croyle, R. T. (1997). The effects of social context and defensiveness on the physiological responses of repressive copers. *Journal of Personality and Social Psychology, 73,* 1118–1128. http://dx.doi.org/10.1037/0022-3514.73.5.1118

Blackwell, E., de Leon, C. F. M., & Miller, G. E. (2006). Applying mixed regression models to the analysis of repeated-measures data in psychosomatic medicine. *Psychosomatic Medicine, 68,* 870–878. http://dx.doi.org/10.1097/01.psy.0000239144.91689.ca

Bolger, N., & Laurenceau, J. P. (2013). *Intensive longitudinal methods: An introduction to diary and experience sampling research*. New York, NY: Guilford Press.

Bongard, S., Pfeiffer, J. S., al'Absi, M., Hodapp, V., & Linnenkemper, G. (1997). Cardiovascular responses during effortful active coping and acute experience of anger in women. *Psychophysiology, 34,* 459–466. http://dx.doi.org/10.1111/j.1469-8986.1997.tb02390.x

Brosschot, J. F., & Thayer, J. F. (2003). Heart rate response is longer after negative emotions than after positive emotions. *International Journal of Psychophysiology, 50,* 181–187. http://dx.doi.org/10.1016/S0167-8760(03)00146-6

Denson, T. F., Spanovic, M., & Miller, N. (2009). Cognitive appraisals and emotions predict cortisol and immune responses: A meta-analysis of acute laboratory social stressors and emotion inductions. *Psychological Bulletin, 135,* 823–853. http://dx.doi.org/10.1037/a0016909

Evers, C., Hopp, H., Gross, J. J., Fischer, A. H., Manstead, A. S. R., & Mauss, I. B. (2014). Emotion response coherence: A dual-process perspective. *Biological Psychology, 98,* 43–49. http://dx.doi.org/10.1016/j.biopsycho.2013.11.003

Feldman, P. J., Cohen, S., Lepore, S. J., Matthews, K. A., Kamarck, T. W., & Marsland, A. L. (1999). Negative emotions and acute physiological responses to stress. *Annals of Behavioral Medicine, 21,* 216–222. http://dx.doi.org/10.1007/BF02884836

Fisher, R. J. (1993). Social desirability bias and the validity of indirect questioning. *Journal of Consumer Research, 20,* 303–315. http://dx.doi.org/10.1086/209351

Fisher, R. J., & Dubé, L. (2005). Gender differences in responses to emotional advertising: A social desirability perspective. *Journal of Consumer Research, 31,* 850–858. http://dx.doi.org/10.1086/426621

Gardner, R. C., & Neufeld, R. J. (1987). Use of the simple change score in correlational analyses. *Educational and Psychological Measurement, 47,* 849–864. http://dx.doi.org/10.1177/0013164487474001

Gerin, W., Bovbjerg, D. H., Glynn, L., Davidson, K., Sanders, M., Sheffield, D., & Christenfeld, N. (1999). Comment on "negative emotions and acute cardiovascular responses to laboratory challenges". *Annals of Behavioral Medicine, 21,* 223–224. http://dx.doi.org/10.1007/BF02884837

Gerin, W., Davidson, K. W., Christenfeld, N. J., Goyal, T., & Schwartz, J. E. (2006). The role of angry rumination and distraction in blood pressure recovery from emotional arousal. *Psychosomatic Medicine, 68,* 64–72. http://dx.doi.org/10.1097/01.psy.0000195747.12404.aa

Hilmert, C., & Kvasnicka, L. (2010). Blood pressure and emotional responses to stress: Perspectives on cardiovascular reactivity. *Social and Personality Psychology Compass, 4,* 470–483. http://dx.doi.org/10.1111/j.1751-9004.2010.00275.x

Hoffman, L., & Stawski, R. S. (2009). Persons as contexts: Evaluating between-person and within-person effects in longitudinal analysis. *Research in Human Development, 6,* 97–120. http://dx.doi.org/10.1080/15427600902911189

Huffziger, S., Ebner-Priemer, U., Eisenbach, C., Koudela, S., Reinhard, I., Zamoscik, V., . . . Kuehner, C. (2013). Induced ruminative and mindful attention in everyday life: An experimental ambulatory assessment study. *Journal of Behavior Therapy and Experimental Psychiatry, 44,* 322–328. http://dx.doi.org/10.1016/j.jbtep.2013.01.007

Ironson, G., Taylor, C. B., Boltwood, M., Bartzokis, T., Dennis, C., Chesney, M., . . . Segall, G. M. (1992). Effects of anger on left ventricular ejection fraction in coronary artery disease. *The American Journal of Cardiology, 70,* 281–285. http://dx.doi.org/10.1016/0002-9149(92)90605-X

Jones-Webb, R., Jacobs, D. R., Jr., Flack, J. M., & Liu, K. (1996). Relationships between depressive symptoms, anxiety, alcohol consumption, and blood pressure: Results from the CARDIA Study. Coronary Artery Risk Development in Young Adults Study. *Alcoholism: Clinical*

and Experimental Research, 20, 420–427. http://dx.doi.org/10.1111/j.1530-0277.1996.tb01069.x

Kamarck, T. W., Janicki, D. L., Shiffman, S., Polk, D. E., Muldoon, M. F., Liebenauer, L. L., & Schwartz, J. E. (2002). Psychosocial demands and ambulatory blood pressure: A field assessment approach. *Physiology & Behavior, 77,* 699–704. http://dx.doi.org/10.1016/S0031-9384(02)00921-6

Kramer, G. H. (1983). The ecological fallacy revisited: Aggregate-versus individual-level findings on economics and elections, and sociotropic voting. *The American Political Science Review, 77,* 92–111. http://dx.doi.org/10.2307/1956013

Lovallo, W. R., & Gerin, W. (2003). Psychophysiological reactivity: Mechanisms and pathways to cardiovascular disease. *Psychosomatic Medicine, 65,* 36–45. http://dx.doi.org/10.1097/01.PSY.0000033128.44101.C1

McCraty, R., Atkinson, M., Tiller, W. A., Rein, G., & Watkins, A. D. (1995). The effects of emotions on short-term power spectrum analysis of heart rate variability. *The American Journal of Cardiology, 76,* 1089–1093. http://dx.doi.org/10.1016/S0002-9149(99)80309-9

Molenaar, P. C., & Campbell, C. G. (2009). The new person-specific paradigm in psychology. *Current Directions in Psychological Science, 18,* 112–117. http://dx.doi.org/10.1111/j.1467-8721.2009.01619.x

Myers, N. D., Brincks, A. M., Ames, A. J., Prado, G. J., Penedo, F. J., & Benedict, C. (2012). Multilevel modeling in psychosomatic medicine research. *Psychosomatic Medicine, 74,* 925–936. http://dx.doi.org/10.1097/PSY.0b013e3182736971

Norman, G. R. (1989). Issues in the use of change scores in randomized trials. *Journal of Clinical Epidemiology, 42,* 1097–1105. http://dx.doi.org/10.1016/0895-4356(89)90051-6

Parati, G., Casadei, R., Groppelli, A., Di Rienzo, M., & Mancia, G. (1989). Comparison of finger and intra-arterial blood pressure monitoring at rest and during laboratory testing. *Hypertension, 13,* 647–655. http://dx.doi.org/10.1161/01.HYP.13.6.647

Portnov, B. A., Dubnov, J., & Barchana, M. (2007). On ecological fallacy, assessment errors stemming from misguided variable selection, and the effect of aggregation on the outcome of epidemiological study. *Journal of Exposure Science & Environmental Epidemiology, 17,* 106–121. http://dx.doi.org/10.1038/sj.jes.7500533

Räikkönen, K., Matthews, K. A., Flory, J. D., Owens, J. F., & Gump, B. B. (1999). Effects of optimism, pessimism, and trait anxiety on ambulatory blood pressure and mood during everyday life. *Journal of Personality and Social Psychology, 76,* 104–113. http://dx.doi.org/10.1037/0022-3514.76.1.104

Russell, J. A., & Barrett, L. F. (1999). Core affect, prototypical emotional episodes, and other things called emotion: Dissecting the elephant. *Journal of Personality and Social Psychology, 76,* 805–819. http://dx.doi.org/10.1037/0022-3514.76.5.805

Sato, H., & Kawahara, J. (2011). Selective bias in retrospective self-reports of negative mood states. *Anxiety, Stress, & Coping: An International Journal, 24,* 359–367. http://dx.doi.org/10.1080/10615806.2010.543132

Singer, J. D., & Willett, J. B. (2003). *Applied longitudinal data analysis: Modeling change and event occurrence*. New York, NY: Oxford University Press. http://dx.doi.org/10.1093/acprof:oso/9780195152968.001.0001

Sinha, R., Lovallo, W. R., & Parsons, O. A. (1992). Cardiovascular differentiation of emotions. *Psychosomatic Medicine, 54,* 422–435. http://dx.doi.org/10.1097/00006842-199207000-00005

Sliwinski, M. J., & Mogle, J. (2008). Time-based and process-based approaches to analysis of longitudinal data. In S. M. Hofer & D. F. Alwin (Eds.), *Handbook of cognitive aging* (pp. 477–491). Thousand Oaks, CA: Sage. http://dx.doi.org/10.4135/9781412976589.n28

Smith, T. W., Birmingham, W., & Uchino, B. N. (2012). Evaluative threat and ambulatory blood pressure: Cardiovascular effects of social stress in daily experience. *Health Psychology, 31,* 763–766. http://dx.doi.org/10.1037/a0026947

Smyth, J. M., & Heron, K. E. (2012). Health psychology. In M. R. Mehl & T. S. Conner (Eds.), *Handbook of research methods for studying daily life* (pp. 569–584). New York, NY: Guilford Press.

Smyth, J. M., & Stone, A. A. (2003). Ecological momentary assessment research in behavioral medicine. *Journal of Happiness Studies, 4,* 35–52. http://dx.doi.org/10.1023/A:1023657221954

Thomas, D. L., & Diener, E. (1990). Memory accuracy in the recall of emotions. *Journal of Personality and Social Psychology, 59,* 291–297. http://dx.doi.org/10.1037/0022-3514.59.2.291

Wesseling, K. H. (1990). Finapres, continuous noninvasive finger arterial pressure based on the method of Penaz. In W. Meyer-Sabellek, R. Gotzen, M. Anlauf, & L. Steinfeld (Eds.), *Blood pressure measurement* (pp. 161–172). Darmstadt, Germany: Steinkopff Verlag. http://dx.doi.org/10.1007/978-3-642-72423-7_18

Zawadzki, M. J., Mendiola, J., Walle, E. A., & Gerin, W. (2016). Between-person and within-person approaches to the prediction of ambulatory blood pressure: The role of affective valence and intensity. *Journal of Behavioral Medicine, 39,* 757–766. http://dx.doi.org/10.1007/s10865-016-9746-6

Zawadzki, M. J., Smyth, J. M., & Costigan, H. J. (2015). Real-time associations between engaging in leisure and daily health and well-being. *Annals of Behavioral Medicine, 49,* 605–615. http://dx.doi.org/10.1007/s12160-015-9694-3

Received June 28, 2016
Revision received November 14, 2016
Accepted November 27, 2016 ■