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Between-person and within-person approaches to the prediction of ambulatory blood pressure: the role of affective valence and intensity

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Abstract Identifying momentary influences on ambulatory blood pressure (ABP) will help explain ABP variability; however, most research only examines aggregate ABP at the between-person level. This study used within-person methods to examine whether affective dimensions—valence and arousal—differentially predicted momentary ABP levels. A community sample ($n = 39$) wore an ABP cuff that took BP measurements every 20 min for 24 h. At each measurement, participants reported levels of valence and arousal on electronic diaries. Multilevel modeling was used to examine the effects of momentary and person-averaged levels of valence and arousal on ABP. Greater momentary negative valence and arousal predicted higher systolic BP compared to more positive or lower arousal assessments; higher averaged levels of arousal predicted higher DBP. The results suggest the independence of the effects of valence and arousal on BP. These findings have important implications for designing interventions to lower ABP.

Keywords Ambulatory blood pressure · Affect · Valence · Arousal · Multilevel modeling

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Introduction

Ambulatory blood pressure (ABP) is a well-established predictor of essential hypertension, coronary heart disease, stroke, and cardiovascular and all-cause mortality (Fagard et al., 2008; Kikuya et al., 2005). Moreover, ABP contributes to and has been hypothesized as a cause of target organ damage, including left ventricular hypertrophy (Bliziotis et al., 2012) and kidney damage (Palatini, 2008; Samuels et al., 2012). Based on the strong and broad range of associations between ABP and these sub-clinical and clinical outcomes, there have been calls for behavioral interventions targeted at reducing ABP (e.g., Hermida et al., 2013; Verdecchia, 2000). Designing effective behavioral interventions requires an understanding of those factors that have salubrious and deleterious effects on ABP as they occur in daily life. However, rather than examining the *momentary* associations between situational and individual factors with the concomitant ABP (a within-person approach), almost all the existing research has focused on examining *aggregate* associations between environmental and personality factors with averaged ABP levels (a between-person approach). Such studies sacrifice the ability to understand the variability of ABP and how momentary factors might predict such variability. The present study examined how one's affective state reported at each ABP measurement—including valence (positive and negative) and arousal (intensity) dimensions—predicts ABP at that moment.

Predicting mean ABP versus momentary ABP: between-person versus within-person approaches

Traditionally, researchers have examined how personality and other individual difference measures, such as trait anger (e.g., Schum et al., 2003) and trait anxiety (e.g.,

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Räikkönen et al., 1999), relate to aggregated levels of ABP (i.e., an averaged ABP value calculated as the mean across all measurement occasions). This between-person approach reveals *who* might be susceptible to poor cardiovascular health, such as by indicating that those who are angrier on average are also those who have higher average ABP levels. Yet, this approach provides limited evidence to suggest underlying mechanisms for the relationship between trait anger and averaged ABP as other confounding variables may explain this association. Because of its weakness concerning the ability to identify causal mechanisms by which environmental and individual differences affect ABP, it is not helpful in identifying potentially useful interventions that might be deployed to lower ABP.

One way to supplement the between-person approach is to statistically model associations between repeated assessments of ABP and relevant situational and individual factors over time. This within-person approach thus reveals *under what conditions a given individual* tends to be at risk for elevated BP (and the ensuing clinical effects) at a particular moment, and can offer useful intervention sites to target. For example, the within-person approach might test whether when a particular individual feels angry at a particular moment he or she also has higher ABP compared to other moments when that same person feels less angry. An advantage of this approach is that people are used as their own control or comparison, thus greatly reducing the potential for confounding variable to explain the observed relationships (Smyth & Stone, 2003). In addition, by examining anger and ABP over time, one gains better access to the extent to which these variables dynamically co-vary indicating precise moments when a person may be vulnerable (e.g., when anger is high). Work in this area has found in-the-moment associations between more socially evaluative threats (Smith et al., 2012), higher anxiety (Edmondson et al., 2015), rumination (Ottaviani et al., 2011), negative social interactions (Brondolo et al., 2003), and negative affect, arousal, task demand, and social conflict (Kamarck et al., 2002) with higher levels of momentary ABP, thus suggesting the viability of such an approach. Moreover, recent work has advocated for the use of within-person assessments and analyses to examine psychosomatic questions, such as how affect and BP relate (Blackwell et al., 2006; Myers et al., 2012).

Although there are circumstances in which the between- and within-person approaches converge, we cannot assume that results across levels will always concur (Kramer, 1983; Portnov et al., 2007). For example, it is widely recognized that exercise is good for cardiovascular health, but such conclusions tend to be drawn from between-person evidence. Indeed, those who exercise more are likely to have a lower resting heart rate (Fletcher et al., 1996) and BP (Cornelissen & Smart, 2013). Yet, at the within-person level, when heart rate and BP are measured during exercise, they are higher in moments when a person is exercising relative to moments when that same person is not exercising (Achten & Jeukendrup, 2003; Arai et al., 1989; Calvacante et al., 2015). Likewise, there may be moments when a relationship at one level is weak or non-significant, but is strong at another level. As the principle of ergodicity explains, it cannot be assumed that factors that predict between-person or interindividual variation would also predict within-person or intraindividual variation (Molenaar & Campbell, 2009). This is because these two approaches ask fundamentally different questions, requiring different data structures and statistical analyses to test. In the example of exercise, the within-person question is referring to a physiological reaction that the body has when demand is placed on it, whereas the between-person question refers to effects of physical conditioning and training over time; in other words, relationships between variables at different levels may factor in different information and require different assumptions for why that relationship exists. Thus, returning to ABP, knowing that trait angry people tend to have higher ABP levels, on average, does not allow us to presuppose that a person's BP increases when he or she is angry.

Affective states and blood pressure

There is a great deal of past work identifying the importance of emotions and BP; however, this work is not without complication. Researchers have often adopted a categorical approach to determining effects of emotions on cardiovascular health, typically comparing positive and negative emotions. Although associations have been found between emotional states and blood pressure (BP), the findings are inconsistent. For example, anger, anxiety, and sadness have been related to increased BP (James et al., 1986; Shapiro et al., 1997; Suls et al., 1995), whereas general negative affect has been associated with lower BP (Watson & Pennebaker, 1989) or has shown no association (Warner & Strowman, 1995). Likewise, pleasantness and happiness (James et al., 1986; Shapiro et al., 1997) have been associated with a decrease in BP, whereas general positive affect also has been associated with an increase in BP (Watson & Pennebaker, 1989; Warner & Strowman, 1995). These mixed findings may be the result of only examining emotions along a valence dimension, when in fact emotions states are composed of a distinct patterning of valence *and* arousal (Russell, 1980; Watson & Tellegen, 1985). Thus, lumping of all emotions into only valenced categories may obscure the differential impact of discrete emotions on autonomic functioning.

Of particular relevance to the present study, the circumplex model of affect conceptualizes emotion along two orthogonal dimensions: valence (pleasantness or unpleasantness) and arousal (activation or deactivation) (Russell, 1980; Watson & Tellegen, 1985). For example, sadness involves negative valence and low arousal, whereas happiness typically involves positive valence and high arousal. In relation to cardiovascular functioning, emotions with high arousal and/or negative valence are proposed to be associated with increases in BP, whereas emotions indicative of low arousal and/or positive valence might be associated with dampening of BP (Cohen & Pressman, 2006). Indeed, in a laboratory task in which participants recalled events differing on valence and arousal dimensions, systolic BP was higher during negatively-valenced than positively-valenced tasks, but pre-ejection period lengthened more during low arousal compared to high arousal tasks (Neumann & Waldstein, 2001). These differential effects of valence and arousal pose a potential problem when studying the relation between emotional states and BP as some emotions may be composed of affective components in such a way to have competing effects on BP (e.g., sadness that has negative valence but low arousal components), whereas other emotions an exacerbating effect (e.g., anger that combines high arousal and negative valence). Thus, there is a need for further understanding as to how valence and arousal may differential affect BP.

Additionally, it is important to examine these relationships in ecologically valid experiences of affect and BP to enhance the generalizability of findings. Results of studies that have measured affect and cardiovascular function in everyday life are mixed. In one study, heart rate was assessed at three 5-min intervals each hour for eight consecutive hours, along with ratings of valence and arousal (Brosschot & Thayer, 2003). Valence did not predict contemporaneous levels of heart rate, but did predict higher heart rate 5 min subsequent to initial measurement, whereas arousal only predicted higher contemporaneous levels of heart rate. Notably, both valence and arousal predicted increased levels of heart rate. In another study, ABP was recorded every 30 min 1 day per week for four consecutive weeks, along with mood assessed on a circular mood scale that corresponded with the circumplex model (Jacob et al., 1999). Participants in anxious/annoyed (high arousal and negative valence) and elated/happy (positive valence ranging from neutral to moderate arousal) moods had increased BP compared to a "mellow" category (representing positive valence and neutral arousal). Although these results suggest that arousal may be a key factor in predicting BP, it is unclear whether it was arousal itself or some combination of arousal and valence that drove effects. The present study sought to extend this work by examining valence and arousal measured as separate dimensions as informed by the circumplex model of affect.

The present study

The purpose of the present study was twofold. First, it examined factors that predict momentary levels of ABP (as opposed to averaged ABP levels). Second, it explored whether affective components differentially predicted these momentary ABP levels. To accomplish these goals, participants wore ABP monitors for 24 h in which BP measurements were taken every 20 min during waking hours. At the completion of each ABP reading, participants reported on their affective states. Importantly, this measurement approach combined with multilevel modeling allowed for the examination of both within-person and between-person relationships of these affective dimensions on ABP (i.e., by having a momentary affect value predict a momentary ABP value, and by having affect averaged across all occasions predict ABP values). We hypothesized that high (vs. low) arousal would be related to higher ABP whereas positive (vs. negative) valence would be related to lower ABP. Additionally, we predicted that these relationships would be stronger at the within-person than between-person level.

Method

Participants

A community sample of 39 adults (26 women, 13 men; aged 28–77, $M = 51.69$, $SD = 12.94$; identifying primarily as non-Hispanic White, 94.6 %) participated in the study. Participants were not eligible for the study if they were unable to wear the ABP monitor overnight, had ever felt faint or dizzy when having their BP measured, were younger than 25 years, or had difficulty reading text on a small screen. Two additional participants were enrolled but excluded from data analyses due to technical malfunctions.

The data were collected as part of an ABP validation study (ScottCare ABP Recorder 320; Cleveland, Ohio), albeit sampling a set of behavioral and personality dimensions not usually included in such studies (Zawadzki et al., 2013). The sample size for the validation was determined by the recommended protocol laid out by the European Hypertension Society for validation of ABP monitors (O'Brien et al., 2002). As such, we performed a series of power analyses to determine whether there was appropriate power to detect the proposed effects for the present paper. We tested the power for a model predicting systolic BP (SBP), and then separately diastolic BP (DBP), as a function of the time of day, momentary valence and arousal, and person-averaged valence and arousal. Using the Monte Carlo procedure in Mplus version 7.3 (Bolger & Laurenceau, 2013; Muthén & Muthén, 2011), all power analyses averaged parameters across 1000 simulations for 39 participants and 35 observations (matching the number of participants and observations per participant in the present study). We varied each potential effect size associated with momentary and average levels of affect to range from small to large effects ($b = .20$, .35, .50, .80). We examined a range of variances for these effects (1.00, 2.00, 3.00) and residual variances (40, 60, 80), while holding the effect of time ($b = .20$) and all other parameters constant. The means and range of variances of valence and arousal were based on a secondary data analysis of mood in the Daily Stress Project from MIDUS (Midlife in the United States). The parameters for the intercept and the intercept's random effects were the means and standard deviations of the average second and third readings in the Biomarker Project from MIDUS. The results of the power analyses suggest sufficient power to detect at least medium to large effects of momentary valence and arousal predicting SBP and DBP with power above .80. For person-averaged valence and arousal, analyses suggest power to detect large effects of SBP at .72 and DBP at above .80. Given the focus of this paper of using momentary levels of valence and arousal to predict momentary ABP, the results suggest adequate power of at least .80 for detecting medium to large effect sizes for the proposed within-person analyses.

Materials

Baseline

Participants first completed demographic information, including age, gender, and race, and then completed a series of health and psychosocial measures, including self-reported health. Self-reported health was assessed using four items from the general health or subjective well-being subscale of the Health Survey-Short Form 36 (SF-36; McHorney et al., 1993), specifically: "I seem to get sick a little easier than other people" (reverse-coded); "I am as healthy as anybody I know"; "I expect my health to get worse" (reverse-coded); and "My health is excellent." Participants responded to all items using a 1 (*Strongly Disagree*) to 4 (*Strongly Agree*) scale. Items were averaged together after reverse coding ($\alpha = .72$), with higher scores indicating better self-reported health. Self-reported health was controlled for in analyses due to its possible impact on overall levels of BP.

Ambulatory blood pressure

Participants were fitted with a BP cuff on their non-dominant arm that was connected to the ScottCare ABP Recorder 320. The ScottCare monitor uses the oscillometric method for BP estimation and has been validated in comparison to standardized auscultatory methods (Zawadzki et al., 2013). SBP and DBP readings were automatically taken every 20 min during waking hours for up to 24 h. Participants provided 14–59 ABP readings ($M = 39.49$, $SD = 9.63$) for a total of 1540 readings.

Electronic diary

Participants completed ratings in a provided electronic diary (Palm Z22; Palm Inc., Sunnlyvale, California) immediately after each BP reading. Participants used separate 7-point scales to indicate their momentary valence, 1 (*unpleasant/negative*) to 7 (*pleasant/positive*), and momentary arousal, 1 (*sleepy*) to 7 (*active/alert*). In addition to these momentary measures, average valence and average arousal scores were calculated by averaging all momentary values for each person to indicate their general levels of valence and arousal across the measurement period.

Participants also completed two sets of measurements that were used as control variables in analyses as these variables have known relationships with BP. First, they indicated their activity level, assessed by reporting of whether the participant was lying down, sitting, or standing. If participants reported they were standing, they additionally indicated if they were mildly, moderately, or heavily active. These two items were then recoded into a single variable in the following way: ranging from 0 (lying or sitting down) to 4 (standing and heavily active).

Second, participants separately indicated if they had ingested caffeine, used tobacco, or ingested food in the previous 10 min. Total number of diary entries ranged from 4 to 59, with all but three participants providing data from at least 20 measurements occasions ($M = 35.08$, $SD = 12.68$). Analyses using only participants who provided at least 20 measurements produced a similar pattern of results; thus we retained all participants in the analyses reported below.

Procedure

All procedures were approved by the relevant Institutional Review Board. Participants were recruited through newspaper ads and paid \$75 for their participation. Informed consent was obtained from all individual participants included in the study. After providing informed consent, participants completed baseline materials. Next they were fitted with the ScottCare ABP monitor. Each device was validated on a per person basis by comparing concurrent SBP and DBP estimates taken by the ABP monitor and by a trained listener using a mercury column sphygmomanometer (Zawadzki et al., 2013). Once validated, the device was worn for the next 24 h. Participants were also trained on how to use the electronic diary. The ABP device automatically initiated each reading, after which participants were instructed to self-initiate and complete the electronic diary. Once the 24-h testing period ended, participants returned to the lab and were debriefed. All procedures performed in this study were in accordance with the ethical standards of the relevant institution and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Analytic plan

The data had a two-level structure in which observations (Level 1) were nested within individuals (Level 2). Multilevel analyses conducted using the PROC MIXED command in SAS 9.3 examined whether valence and arousal contemporaneously predicted SBP and DBP. Machine and movement errors for the ABP devices and levels of compliance for the electronic diary resulted in differing amounts of data across participants. In general, multilevel analyses are robust to missing and uneven levels of data and are recommended for analyzing data of this sort (Schwartz & Stone, 1998).

Modeling decisions were informed by recent texts (Bolger & Laurenceau, 2013; Singer & Willett, 2003) and were as follows: Random intercepts were included to account for expected differences in participants starting SBP and DBP. An autoregressive covariance structure was used that assumed that observations closer in time were more highly correlated than those further apart. For each model, we provided a pseudo-r^2 statistic as an estimate of effect size determining the proportion of the total outcome variance accounted for by the model's predictors. This statistic was calculated by computing a predicted outcome value for each measurement for each person, and then squaring the sample correlation between the observed and predicted values (Singer & Willett, 2003). Finally, time was modeled as the number of minutes elapsed since midnight.

A set of three models were run. The first was a base model that looked at the associations between momentary valence and arousal, and person-averaged valence and arousal on SBP and DBP; this model only controlled for time of day. Second, the following person level dimensions were included as control variables: sex, age, and general health. Third, momentary level variables were included as control variables: activity level, caffeine use, tobacco use, and ingestion of food. This set of models allowed us to detect whether any initially observed effects for valence and arousal are robust when known influences on BP levels were controlled for. Across all models, the simultaneous examination of valence and arousal tested the independent effect of each affective dimension on ABP. Including both momentary and person-averages of valence and arousal allowed for the partitioning of within-person and between-person associations between affect and ABP. This approach is similar to person-mean centering the within-person or momentary valence and arousal predictors of ABP, except that it also models average levels to compare associations at each level. More concretely, these models revealed the impact of one's general valence or arousal levels on BP (the person-average), as well as the contemporaneous association of deviations from this general valence or arousal levels at a particular time (the momentary level).

Results

Across all participants, SBP ($M = 120.56$, $SD = 11.11$) and DBP ($M = 75.91$, SD 6.82) were in the normotensive range. Also, participants generally reported affect that was moderately positively valenced ($M = 5.38$, $SD = 0.78$) and of moderate arousal ($M = 5.22$, $SD = 0.90$).

Multilevel models examined the momentary and person-averaged effect of valence and arousal on SBP and DBP. Three sets of models were run that examined (1) only the associations of the affective dimensions with BP (Model 1), (2) Model 1's associations while also controlling for person-level factors (age, sex, and self-reported health; Model 2), and (3) Models 1 and 2's associations while also controlling for momentary-level factors (physical positioning, and ingestion of caffeine, tobacco, and/or food; Model 3). Results were fairly consistent across models.

As shown in Table 1, the analyses for Model 3 demonstrated the following: For valence, when a person had more positive affect than typical in a particular moment they had lower SBP ($p = .006$) but not DBP ($p = .834$). A person's average levels of valence were unrelated to SBP ($p = .449$) and DBP ($p = .820$). For arousal, when a person had higher levels of self-reported arousal than typical for that individual, in that particular moment they had higher SBP ($p = .003$) but not DBP ($p = .228$). A person's average level of arousal was unrelated to SBP ($p = .784$), but those who had higher levels of arousal on average also had higher levels of DBP ($p = .031$).

As a follow-up, we explored whether valence and arousal interacted to predict either SBP or DBP. We re-ran Model 3 including an interaction term of momentary valence and arousal levels and an interaction term of the person-averaged levels of valence and arousal. None of the interaction terms were significant ($ps > .140$).

Table 1 Parameter estimates (Standard Errors) for systolic and diastolic blood pressure

	SBP			DBP		
	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
Fixed effects						
Intercept	106.78*** (13.02)	101.76*** (15.58)	100.29*** (15.77)	65.09*** (7.20)	69.97*** (8.15)	65.61*** (8.39)
Time	.001 (.002)	.001 (.002)	.002 (.002)	−.001 (.001)	−.002 (.001)	−.002 (.001)
Sex	–	−2.23 (4.34)	−2.21 (4.34)	–	.93 (2.26)	1.21 (2.26)
Age	–	.19 (.13)	.19 (.13)	–	−.04 (.07)	−.03 (.07)
General Health	–	.26 (3.68)	.35 (3.68)	–	−2.92 (1.91)	−2.88 (1.91)
Activity Level	–	–	−.20 (.56)	–	–	.87* (.42)
Caffeine	–	–	1.15 (2.57)	–	–	2.89 (1.93)
Tobacco	–	–	1.03 (1.02)	–	–	.35 (.76)
Food	–	–	2.89* (1.45)	–	–	−.07 (1.09)
Momentary Valence	−1.29** (.48)	−1.28** (.49)	−1.36** (.49)	−.21 (.37)	−.13 (.37)	−.08 (.37)
Average Valence	4.22 (3.89)	3.06 (3.99)	3.02 (3.98)	−.21 (2.14)	−.50 (2.10)	−.48 (2.10)
Momentary Arousal	1.20** (.41)	1.24** (.41)	1.26** (.42)	.48 (.31)	.55^{+} (.32)	.39 (.32)
Average Arousal	−1.66 (3.35)	−1.25 (3.77)	−1.03 (3.77)	2.55 (1.83)	3.82^{+} (1.96)	4.27* (1.98)
Random effects						
Initial Status	105.80*** (27.92)	108.04*** (30.18)	107.28*** (20.08)	26.15*** (8.16)	23.32** (7.92)	23.71** (7.97)
Autocorrelation	.43*** (.10)	.44*** (.10)	.47*** (.11)	.59*** (.10)	.62*** (.10)	.60*** (.10)
Residual	52.39* (25.67)	54.66* (25.63)	61.30** (23.93)	46.93*** (9.40)	48.87*** (8.89)	48.72*** (9.15)
Model statistics						
AIC	8389.1	8235.8	8221.3	7788.0	7639.2	7625.9
BIC	8395.8	8242.4	8227.9	7794.7	7645.8	7632.5
Pseudo r^2	.032	.057	.064	.048	.063	.073

$^{+}$ $p < .10$; * $p < .05$; ** $p < .01$; *** $p < .001$. Time is the number of minutes that elapsed since midnight. Sex (0 = male; 1 = female), caffeine (0 = no caffeine; 1 = yes caffeine in last 10 min), tobacco (0 = no tobacco; 1 = yes tobacco in last 10 min), and food (0 = no food; 1 = yes ingested food in last 10 min) were entered as dichotomous variables. Age, general health, and activity level were entered as continuous variables. Valence and arousal are the momentary reports of these affective dimensions ranging from 1 to 7; average valence and arousal are person-averages across all measurement occasions

Discussion

This study utilized a within-person approach to examine momentary predictors of ABP. In particular it tested whether valence and arousal assessed in everyday life differentially predicted ABP. As expected (Cohen & Pressman, 2006; Neumann & Waldstein, 2001), momentary levels of valence and arousal had differential effects on SBP. Specifically, individuals' momentary experience of positively valenced affect at a level above their norm resulted in lower SBP compared to moments when affect was less positive. In contrast, individuals' who momentarily experienced higher arousal than their usual were more likely to have higher SBP compared to moments when affect was less arousing. Moreover, because these facets were tested simultaneously in the same model, they suggest important unique effects of valence and arousal on SBP. Interestingly, none of the momentary affective dimensions predicted DBP, though these person-average results should be interpreted with caution as adequate power was only present to detect large effects. However, higher person-average levels of arousal predicted greater DBP levels.

These findings highlight the fact that relationships across levels—in this case at the between-person and within-person levels—do not always concur (Kramer, 1983; Portnov et al., 2007). Although much is known at the between-person level, far fewer studies have examined in-the-moment effects of ABP (for exceptions see Brondolo et al., 2003; Edmondson et al., 2015; Jacob et al., 1999; Kamarck et al., 2002; Ottaviani et al., 2011; Smith et al., 2012). Thus, there is continued need to test momentary relationships with ABP.

Implications

The results suggest multiple points at which interventions may be effective for BP reduction. First, given the associations of person-averaged levels of arousal and DBP, it suggests between-person targets, namely those who have higher levels of high arousal affect. Second, given the momentary associations of valence and arousal with SBP, it suggests within-person targets, namely when one's affect was higher arousal and more negative than typical. As such, one could consider the value of different interventions depending on which level was targeted. At the person level, one may wish to screen for those who tend to have high arousal and implement an intervention akin to mindfulness as a way to help individuals relax in general (Jain et al., 2007). Conversely, any individual could be targeted at the momentary level, but one would need to develop ways to predict or identify when a person has high arousal emotions, or teach the person to detect these moments themselves, so as to know when to intervene. Once moments are detected, an ecological momentary intervention or just-in-time intervention in which the intervention is delivered at the precise moment of need or vulnerability may be developed (Heron & Smyth, 2010). For example, a person may be encouraged to engage in a controlled breathing exercise when he or she feels intense or high arousal emotion, as controlled breathing has been shown to reduce BP levels (Kaushik et al., 2006).

More generally, these results shed light on previous research finding mixed effects when examining the relationships between emotions and BP (Shapiro et al., 1997; Suls et al., 1995; Warner & Strowman, 1995; Watson & Pennebaker, 1989). Typically positive and negative emotions are compared only along a valence dimension. Although valence predicted SBP as expected, arousal also had an independent effect on SBP suggesting that emotions cannot simply be grouped dichotomously by valence. However, arousal and valence may represent only two of many dimensions that differentiate discrete emotions. For example, reporting high arousal and high negativity may qualify as anger, but could also reference intense sadness (e.g., sobbing). In such instances, it is the goal relation and functional motivation that distinguishes these (and other) emotions. As such, corresponding immediate and long-term consequences of discrete emotions on biological processes may vary despite each being of negative valence and high level of arousal (Moons et al., 2010). Specifically, intense anger may increase blood flow to promote a readiness for confrontation of a blocked goal, whereas intense sadness may motivate extreme withdrawal (Lazarus, 1991). Thus it is important to note that although a particular emotional state may be associated with increased BP, such change in physiology is likely adaptive so long as it is contextually appropriate and not chronic. Future investigations may wish to measure additional dimensions of affect and/or include reporting of discrete emotional states to further understand momentary impacts on ABP.

For DBP, the momentary measures of affect were not significant. This result is not surprising given the general tendency for momentary stressors to more strongly relate with and impact SBP than DBP (Gerin et al., 2006; Knight & Rickard, 2001). Yet, person-averaged levels of arousal were associated with higher DBP. These person-averages reflect a general tendency to experience more intense emotions, which could cause a cumulative burden over time and have a greater potential to impact physiological regulation. This interpretation suggests that even experiencing large amounts of positively valenced affect, which had a dampening effect on SBP at the momentary level, may have negative consequences if that emotion tends to be high intensity.

Limitations and future directions

Based on average levels of ABP, most participants were in the normotensive range indicating a relatively healthy population. Future work may wish to examine the impact of affect on ABP for hypertensive patients. In addition, although the central purpose of this paper was to predict momentary ABP levels, we did not have a measure to control for whether participants were taking medications to control BP levels. It seems unlikely that these medications would alter the strength of the relationship between affect and ABP at the momentary level, particularly given our person-centered approach. However, this additional variance could be important to control for in future studies.

The proposed study also had a small sample, although participants responded to a large number of diary assessments and ABP measurements. A priori *p*ower analyses suggested that this number of observations across this sample size provided good power to detect the within-person effects of at least medium effect sizes, but we were limited to only having the power to detect large effects at the between-person level. As such, future work aimed at exploring relationships at the between-person level would be advised to use larger sample sizes, as increased measurement occasions cannot substantially increase power at this level (Bolger & Laurenceau, 2013).

Furthermore, the present findings warrant additional study with more diverse populations. Most participants identified as non-Hispanic Caucasian, thus limiting generalizability to other racial and ethnic groups. It would be important to test whether the demonstrated pathways are similar across other racial and ethnic groups. In particular, African-Americans have higher prevalence of hypertension than Caucasians (Nwankwo et al., 2013), but this has only been examined as a between-person relationship. It might be that African-Americans experience more moments of high arousal and negatively valenced emotion, which could explain why they generally have higher BP levels. It is also possible that African-Americans might be more physiologically reactive to those moments of negatively-valenced affect. For example, in a prospective study, it was found that Black women with higher negative affect had higher BP than Black and White men and White women with similar levels of negative affect (Jonas & Lando, 2000). Alternatively, these high levels may be due to other factors, such as chronic stress due to discrimination and racism-related vigilance (Hicken et al., 2014).

Finally, our measurement of arousal and valence consisted of single items. This methodological decision was made so as to ensure that the diary assessments were short in duration, particularly because participants responded to a prompt every 20 min. Although this decision limited participant burden, it may have reduced the measurement reliability. Future work may wish to expand measurement items examining arousal and valence or use a measure of affect in which the individual plots their affective experience on a circumplex model. In addition, using bipolar items for valence and arousal necessitated the assumption of linear relationships of these variables. For example, the data assumed that positive and low arousal affect was equally important as negative and high arousal affect. Yet, recent work at the between-person level has suggested the potential unique importance of positive psychological well-being for predicting cardiovascular health (Boehm & Kubzansky, 2012). Given other work that suggests that positive and negative affect may be separate dimensions (Watson, 1988; Watson et al., 1988; cf. Russell & Carroll, 1999), it would be interesting to disentangle positive and negative affect using distinct measures. Likewise, work in the physical activity domain has suggested that levels of activity are independent predictors of health compared to sedentary moments (for a review see Katzmarzyk, 2010); findings such as these might suggest that affect with high activation or arousal is not necessarily the opposite of low activation arousal. Future work may wish to explore positive and negative valence, and high and low arousal, as separate constructs to test whether there are indeed linear relationships for valence and arousal.

Conclusions

This paper underscores the importance of using within-person study design and analysis to predicting ABP in contrast to the more traditional practice of using between-person designs that aggregate across measurements. Understanding factors that predict ABP is important for designing effective interventions to reduce ABP (Verdecchia, 2000). This study identified that affect negative in valence and high in arousal was associated with greater SBP at the momentary level, and that those who consistently experience high arousal affect had higher DBP. Although it seems unlikely to prevent the experience of any high arousal emotion, an important step for interventions may be to help individuals to reduce the intensity of these emotions. For example, interventions aimed at improving emotion regulation skills has shown associated benefits for cardiovascular health (Appleton et al., 2013). In sum, while much work has been done to identify who might be vulnerable to poor cardiovascular health (i.e., the between-person approach), continued efforts are needed to better understand under what conditions a person is vulnerable in any particular moment (the within-person approach) so as to optimize the designing of interventions to lower ABP.

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Compliance with ethical standards

Conflict of interest Matthew J. Zawadzki, Jennifer Mendiola, Eric A. Walle and William Gerin declare that they have no conflict of interest

Human and animal rights and Informed consent All procedures followed were in accordance with ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2000. Informed consent was obtained from all patients for being included in the study.

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