2021

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Citation

Joseph, N. T. PhD; Chow, E. C. JD; Peterson, L. M. PhD; Kamarck, T. W. PhD; Clinton, M. BA; DeBruin, M. BA. 2021. "What Can We Learn From More Than 140,000 Moments of Ecological Momentary Assessment–Assessed Negative Emotion and Ambulatory Blood Pressure? A Systematic Review and Meta-Analysis." *Psychosomatic Medicine* 83.7: 746-755.

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Total Words: 6500

Number of Tables: 1

Number of Figures: 3

Conflicts of Interests and Source of Funding: None declared.

Abstract

Objective: Two decades of research has examined within-persons associations between negative emotion states and ambulatory blood pressure (ABP) using ecological momentary assessment (EMA), but no meta-analysis has been conducted. We conducted this systematic review and meta-analysis to quantify the magnitude of this association and identify moderators, review strengths and weaknesses in conceptual and measurement approaches, and provide recommendations.

Methods: We searched databases (PsychInfo, Pubmed), identified 15 studies, and obtained data from 13 studies (n = 2,511; 142,307 observations).

Results: Random effects meta-analyses demonstrated small effect rs between momentary negative emotions and systolic ABP, r = .06, and diastolic ABP, r = .05, ps <.001. Meta-regressions found that effects were larger among studies focused on anxiety, multidimensional negative emotions, predominantly female samples, or less observations of each participant, ps from .003 to .049. Qualitative review found that few studies examined moderators contributing to the substantial interindividual differences in this association.

Conclusions: The small association between momentary negative emotion and ABP extends laboratory findings on the association between the experiential and physiological aspects of emotion to the daily, natural emotional experiences of individuals. This literature could be strengthened by determining inter- and intra-individual moderators of this association (e.g., trait negative emotion and state positive emotion), examining differential associations of different negative emotions with ABP, and standardizing EMA protocols. Although the effect is small, to the extent that repeated emotion-related cardiovascular reactivity may contribute to cardiovascular disease risk, identifying daily life triggers of emotion is important.

Keywords: negative emotion, ambulatory blood pressure, ecological momentary assessment, meta-analysis, systematic review

ABP = ambulatory blood pressure; CBP = clinic blood pressure; CVD = cardiovascular disease; CVR = cardiovascular reactivity; EMA = ecological momentary assessment; mmHg = millimeters of mercury.

What Can We Learn from over 140,000 Moments of EMA-Assessed Negative Emotion and Ambulatory Blood Pressure?: A Systematic Review and Meta-Analysis

Emotions are the cornerstone of everyday human life and impact health outcomes, including cardiovascular outcomes (1-3). Laboratory studies demonstrate that negative emotions like anger involve autonomic changes, especially blood pressure fluctuations (4). Emotion-based autonomic changes that contribute to fluctuations in blood pressure and other cardiovascular indices, at the same time, may contribute to some of the psychosomatic associations between emotions and cardiovascular disease (CVD) (5). Given that emotion fluctuates from moment to moment (6) and that negative emotions like anxiety are prevalent in daily life (7-9), the connection between emotion exposures and concomitant autonomic changes might be best examined in the natural environment. For two decades, researchers have utilized ecological momentary assessment (EMA) to examine the relationship between acute, naturalistic fluctuations in emotion and ambulatory blood pressure (ABP). A systematic and meta-analytic review of this literature is warranted to shed light on mixed findings and outline conceptual and methodological complexities that influence this relationship.

Emotion has a subjective experiential component and objective physiological components, driven by central nervous system as well as peripheral autonomic and neuroendocrine influences (10). Neural activation therefore underlies the connection between subjectively reported emotion and blood pressure. Dimension theories of emotion (e.g., circumplex model; 11-12) suggest that different negative emotions share the same neural pathways, but differ in the degree to which they activate these neural pathways. Specifically, dimension theories suggest that emotions vary along a continuum according to valence (varying from positive to negative) and arousal (varying from low to high; 11-12), with different emotion

arousal levels associated with differing levels of neural activation and thus differing levels of physiological parameters (12-13). There is conceptual and empirical support for the notion that emotions with different arousal levels are associated with different amounts of blood pressure increases. For example, an earlier meta-analysis of laboratory studies found that anger (a high arousal emotion) was associated with higher blood pressure levels than less arousing negative emotions like sadness (14). A more recent meta-analysis of laboratory studies also found that laboratory inductions of anger were more strongly associated with blood pressure increases than other emotion inductions (15). Authors of this meta-analysis propose that naturalistic observations of emotion-physiology relationships shed additional light on diverse arousal emotions by capturing the emotional experiences of different people in moments during which they are exposed to various daily life situations (i.e., state emotions), and thus, a richer representation of the physiological accompaniments to subjective emotion.

Whether different state emotions experienced in a natural setting have different impacts on ABP is an important but complicated question to explore. It is important to explore because it could shed light on trait emotion studies that draw mixed conclusions as to which emotions have the most robust long-term cardiovascular implications (3). Trait emotion measures capture generalized beliefs about overall styles of responding to life whereas state emotion captures real-time reactions to contemporaneous exposures and thus are more directly tied with physiological arousal with cumulative impacts on the cardiovascular system (16). Thus, it is important to explore the physiological accompaniments to different ecologically valid state emotions within individuals as state emotions provide information distinct from trait emotion differences between individuals. However, it is complicated to explore this question because individuals tend to report multiple negative emotions in the same moment, either because they are in fact

experiencing multiple emotions or have difficulties differentiating between emotions in the moment (9;17). Nevertheless, comprehensive and systematic inspection of the state emotion-ABP literature would be another step towards determining whether some naturally experienced state negative emotions have stronger influences on blood pressure than others.

Ecological momentary assessment (EMA) – the repeated observation of psychosocial, behavioral, and physiological states as individuals engage in their daily lives - allows researchers to examine state emotion fluctuations, ABP fluctuations, and the associations between them. EMA emotion measures are less susceptible to recall bias than daily or trait measures and exhibit strong within-person reliability (18). EMA studies find that negative emotions fluctuate more on a momentary basis than a daily basis, further highlighting the importance of understanding the autonomic implications of momentary emotions (18). Further, ABP has advantages over clinic blood pressure (CBP). ABP correlates with subclinical CVD indicators like atherosclerosis independent of CBP and more strongly with clinical CVD outcomes like stroke and mortality than CBP (19-20). Also, ABP readings reflect the psychosomatic effects of momentary psychological demands (e.g., stressful work environment or home life) that cannot be measured in a clinical setting. As a result, EMA monitoring is the data collection tool best suited for capturing the ecologically valid relationship between acute naturalistic fluctuations in negative emotions and cardiovascular activity.

For two decades, researchers have examined the within-person associations between negative emotions and blood pressure using EMA (self-reports combined with ABP), but a meta-analysis or systematic review has not been conducted. In an overall examination of EMA-based psychophysiological studies, Raugh and colleagues (21) provided a clear but brief and non-exhaustive summary of some of this work. Although this summary highlighted a handful of

studies that found a positive association between negative emotion and ABP, it did not differentiate between within-person and between-person associations. Further, there are some studies that do not find an association between negative emotion and ABP (e.g., 22), some that find that some negative emotions are associated with ABP but other negative emotions are not (e.g., 23), and some that find that negative emotions are associated with only systolic or diastolic ABP (e.g., 24). A comprehensive review and meta-analysis could shed light on the determinants of these mixed findings, identifying substantive or methodological moderators of this within-person association.

Potential substantive moderators of this association include the type of negative emotion studied, trait negative emotion, and positive emotion. As discussed, the type of emotion at focus in a study may influence findings as negative emotions with differing levels of arousal may have stronger associations with ABP. Further, laboratory studies suggest that individuals with higher levels of trait emotions like anxiety exhibit stronger blood pressure responses to acute stress (25), so trait emotionality might similarly influence the extent to which state emotions in daily life are connected with ABP fluctuations. There is also some conceptual and empirical support for the notion that positive emotions may moderate the relationship between negative emotion and ABP by facilitating an "undoing" – or reduction – of the autonomic nervous system (ANS) activation produced by negative emotions that diminishes their cardiovascular impact (26-27). It would be useful to examine whether EMA research demonstrates that undoing unfolds in the moment. Finally, methodologies vary widely across EMA studies that examine the state emotion-ABP association. Some participant samples may result in stronger emotion-ABP associations given that there are demographic differences in emotion, ABP, and the association between them (e.g., 28). Some emotion measures may be more reliable or valid than others (18), resulting in stronger

emotion-ABP associations. Further, adequate variability of emotional experience and ABP must be present to find associations. Studies with more monitoring days and frequent sampling may be powered to detect stronger emotion-ABP associations given that, with more reporting opportunities, a wider range of emotions and emotional intensity might be captured.

Given the above, the current systematic review and meta-analysis aimed to advance the literature on the momentary association between state emotion and ABP by 1.) providing effect size information to assess the magnitude of this association; 2.) quantitatively exploring emotion type, emotion measurement, EMA sampling frequency, and sample demographic composition as moderators of this association; 3.) qualitatively exploring the modifying effects of positive emotions and trait negative emotion; and 4.) summarizing strengths and presenting avenues by which to improve conceptual and measurement approaches.

Methods

Study Selection

The study selection process occurred in June and July of 2019. Methods followed those prescribed by the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) statement (29). See Figure 1 for the PRISMA flow chart detailing the process. Systematic searches were conducted in major databases (PsycINFO, PubMed) using the search terms (“emotion” OR “mood” OR “affect” OR “feeling”) AND (“blood pressure”) AND ("ecological momentary assessment" OR " experience sampling*" OR “ambulatory” OR “daily life”). Initial search terms were drawn from key articles. The authors used an iterative search strategy, which included scanning the relevant retrieved articles for additional key terms and then rebuilding search strings with the newly identified key terms.

The first and second authors independently screened studies for eligibility according to the inclusion criteria. Eligibility criteria included: publication in a peer-reviewed, English language journal; focus on healthy adult samples; use of EMA to measure negative emotion; use of ABP monitoring; and within-persons analysis of the momentary association between negative emotion and ABP. Disagreement was resolved by discussion and consensus. Fifteen articles were deemed eligible.

Data Extraction

The following data was extracted from each study: author(s), publication year, sample size and composition, inclusion/exclusion criteria, number of observation days, daily observation frequency, total observations, negative emotion measurement, covariates, and significant outcome(s). Coefficients, standard errors, *F* or *t* values, *p* values, and effect estimates were extracted whenever available. In all cases, we extracted this information from the model that included the standard important time-varying blood pressure covariates (e.g., posture, activity, consumption of meals or substances), but was otherwise the least adjusted model. Authors were contacted for additional information whenever necessary. An article was excluded from meta-analysis (but not systematic review) when authors did not respond to three contact attempts one month apart. Several authors independently assessed study quality (see Supplemental Table 2).

Quantitative Analysis Approach

The random effects meta-analyses and meta-regressions for testing between-study moderators were conducted using Comprehensive Meta-Analysis, Version 3 (CMA; 30). There are several approaches to creating effect sizes to capture the strength of the fixed effects associations between quantitative variables in multilevel data (e.g., 31-33). We utilized the same approach as a recent meta-analysis of multilevel EMA data on the momentary associations

between social interactions and affect (34). Specifically, available statistical information from each study was input into CMA, which derived effect size correlations for each study using validated formulas (30;35).

Results

See Table 1 for descriptions of the reviewed studies.

Qualitative Review

Reviewed studies varied widely with respect to emotion measurement, EMA sampling schedules, sample composition, and attention to conceptual complexity of negative emotion.

Measurement of Negative Emotion

The reviewed studies tended to assess anxiety, anger, and sadness more than other negative emotions like disgust, contempt, shame or guilt. Approximately 73% of reviewed studies included assessment of anxiety, 73% anger or frustration, and 50% sadness. Over half examined the association between some combination of different negative emotions and ABP (e.g., 36) whereas the rest examined one emotion or examined different emotions separately with respect to their association with ABP (e.g., 23). Of note, some studies assessed several dimensions from the family of emotions related to anxiety (e.g., worry, jitteriness, nervousness, fear) and aggregated scores, whereas others only assessed anxiety. Similarly, some studies assessed several anger-related emotions like frustration, hostility, and irritation whereas others only assessed anger. Only one study measured emotion according to the valence-based conceptualization of emotion; specifically, they used a 7-point scale in which participants rated the extent to which they were experiencing unpleasant or negative emotion (24). Further, there were varied response formats, including visual analogue scales and Likert-like scales. The varied measurements reveal the importance of using operational definitions and common methods when

assessing emotion. Researchers tended to report the details of their emotion scales without referencing an emotion theory or providing a conceptual rationale for scale selection. Jacob and colleagues (37) was one exception, providing excellent detailing of the circumplex model of emotion and explanation for selecting the Circular Mood Scale. Four additional research groups also cited clear conceptual frameworks of emotion as foundations for their work (23-24,38-39).

EMA Schedules

The most common assessment schedule was one observation day (9 studies), with 3 of the remaining studies using a schedule of between 2 to 5 days and the other 3 using a schedule of between 6 to 10 observation days. With the exception of the study using 10 observation days, studies sampled at a frequency of at least once hourly, with the majority (n = 10) sampling at least twice hourly. Studies using one observation day tended to use more frequent sampling. Only one-third of the studies reported on compliance, making it infeasible to determine whether compliance differed by EMA schedule.

Conceptual and Methodological Complexity

Most of the reviewed studies did not comprehensively explore important concepts like emotional rumination or the moderating roles of positive emotion or trait negative emotion. One exception is Shapiro and colleagues (39), who found that some negative emotions have a lower impact on ABP when happiness levels are also high in the moment. Several other studies measured positive emotions and reported on their main effects on ABP but did not assess whether they moderated the associations between negative emotions and ABP. Several studies also assessed trait negative emotion but only two investigated whether trait negative emotion moderated the state negative emotion-ABP association. One study found a significant state negative emotion-ABP association only among those with low trait anxiety whereas another did

not find that trait depression moderated the state negative emotion-ABP association (40-41). Other studies examined whether related concepts moderated the association, finding stronger effects among those low in trait hostility (40) and high in emotion responsivity (42).

Early studies in this line of research found significant interindividual differences in ABP reactivity to negative emotion (43-44), but approximately three-fourths of the reviewed studies did not report on interindividual differences in reactivity; those that did found significant interindividual differences. In fact, one study found that a small subgroup of participants exhibited over 3 times as much ABP reactivity to negative emotion as the overall sample despite not having substantially higher exposure to negative emotions (43).

Only two studies highlighted the possibility of lagged (or lingering) effects of emotion on ABP. One of these studies (43) found that negative emotion did in fact impact later ABP, although this impact was smaller than the association between concurrent emotion and ABP. Only three studies did not covary time-varying factors like posture, physical activity, talking, temperature, and food or substance consumption. Posture was the most frequent time-varying covariate used, and activity was the second most frequent.

Sample Composition

The reviewed studies were conducted in the United States. Many focused on university students, medical employees, or professionals. Of the studies that reported racial and ethnic demographics, 67% had a sample that was over 50% composed of white participants, and 33% had a sample that was over 75% composed of white participants. Approximately 33% of the samples had approximately equal proportions of men and women, 20% were either all men or all women, and all but one of the remaining samples were mostly composed of women. Sample age

ranges spanned adulthood, with the exception that, although some studies included participants up to 81 years old, no studies focused on older adults.

Quantitative Analyses

We obtained data from 13 studies for the meta-analysis (total n = 2,511; total number of observations = 142,307). Random effects meta-analyses found that the weighted effect size of the association between momentary negative emotion and systolic ABP was r = .06, CI: .04-.08, p <. 001 and between momentary negative emotion and diastolic ABP was r = .05, CI: .03-.07, p <.001 (see Figure 2). Kendall's tau (.27 and .02, respectively for systolic and diastolic ABP) did not suggest that sample size was related to effect size. Egger's regression test (p =.12 and p =.47, respectively for systolic and diastolic ABP) and funnel plots (see Figure 3) did not identify significant publication bias or problematic outliers. Further, Orwin's fail-safe measure estimated that there would need to be 15 additional null studies for systolic ABP and 11 additional null studies for diastolic ABP to functionally change the results of this meta-analysis. Finally, Duval and Tweedie's Trim and Fill procedure (45) suggested that imputing studies to neutralize any potential publication biases would not impact the significance of the effects and would, at most, impact the effect size to a trivial degree.

Heterogeneity tests suggested significant heterogeneity (I^2 = 91 and 89, respectively for systolic and diastolic ABP), supporting our plan to explore moderators. Meta-regressions found that studies examining the association between ABP and the sum of multiple emotion items capturing different emotions found larger ABP effects than studies examining associations between single emotion items and ABP (p = .049 and .033, respectively for systolic and diastolic ABP; effect size rs for total negative emotion scales = .07 and .06 for systolic and diastolic ABP, respectively; effect size rs for single emotion items = .03 and .01 for systolic and diastolic ABP,

respectively)[1]. There were insufficient studies reporting the associations between various emotions and ABP to quantitatively explore whether ABP associations differed across the full range of negative emotions, but there were sufficient studies to compare the ABP associations of anger and anxiety. This meta-regression found that anxiety was more highly associated with ABP than anger with respect to diastolic ABP (p =.042; anxiety effect size r = .03 and anger effect size r = .01); systolic ABP results trended in the same direction (p = .20).

Although number of sampling days and sampling frequency did not significantly influence the association between state emotion and ABP, higher numbers of observations per participant in studies was significantly associated with lower emotion-systolic ABP associations, *b(SE)* = -.0004(.0002), R^2_{analog} = .20, p = .026 (diastolic ABP p = .30). Finally, studies consisting of entirely or mostly female (≥80%) samples found stronger negative emotion-ABP associations than those consisting of samples that were relatively balanced with respect to gender (p =.006 and .003 for systolic and diastolic ABP, respectively; effect size rs for predominantly female studies = .11 and .10 for systolic and diastolic ABP, respectively; effect size rs for gender balanced studies = .04 and .03 for systolic and diastolic ABP, respectively). The age and racial compositions of samples were not significant moderators, ps ranging from .32 to .97.

Discussion

Results suggest that there is a small but significant within-persons momentary association between state negative emotion and ABP, which is similar to meta-analytic findings regarding the between-persons association between trait anger and ABP (48). These findings are consistent

[1] Two of the multiple item associations were found in studies (46-47) in which researchers dichotomized the score, i.e., they created a variable indicating whether any of the emotions were endorsed, without regard for intensity. These studies found larger systolic and diastolic ABP effects than studies not involving dichotomization, ps < .001; effect size r for the studies using a dichotomized variable was .14 for systolic and diastolic ABP. Because only 2 studies by the same lab dichotimized, we interpret this with caution. When excluding these dichotomized studies, other studies using total scores of multiple items still show a significantly larger association with diastolic ABP than single item studies, p = .046.

with the possibility that acute cardiovascular changes associated with negative emotional states may contribute to the association between life experiences characterized by chronic or repeated negative emotions (i.e., depression, hostility) and CVD. Reviewed studies suggest that large increases in negative emotion from little to no emotion to high levels of emotion are associated with acute increases in ABP anywhere between 3 to 7 mmHg, with even larger increases like 20 mmHg for those who are most reactive. The finding that the overall effect size was higher among studies that tested the associations between total negative emotion and ABP than among studies that tested separate associations between one or more emotions and ABP warrants further investigation. Given that we found that anxiety was more highly associated with ABP than anger, it is possible that some emotions (like anxiety) in the composite scales account for the associations more strongly than other emotions. It is also possible that one-item emotion variables do not reliably capture negative emotion (18), and should not be used to investigate its association with ABP. These remaining uncertainties highlight the need for researchers in this area to be intentional about emotion measures, using standardized methods validated for within-persons analyses and directly aligning with the emotion theory guiding the work (49, see Ref. (50) for specific suggestions). The substantial variation in EMA sampling protocols and the finding that studies with more assessments per participant found lower emotion-systolic ABP associations further highlights the influence of methodology selection. Due to lack of reporting on compliance, it is difficult to determine whether the studies with more assessments per participant involved better or worse compliance. Reporting gaps are prevalent in the EMA literature, leading researchers to establish EMA reporting guidelines (51-52).

The finding that studies that reported on interindividual variability in the emotion-ABP association found that there were substantial individual differences in the association aligns with

laboratory findings and suggests that overall effects analyses may obscure rich individual differences. Laboratory studies suggest that some individuals exhibit very large blood pressure increases in response to negative emotions (emotion-based cardiovascular reactivity; CVR) whereas other individuals do not. The current review suggests that the same applies to the real life CVR in EMA studies. Conceptually, it is important to continue to grapple with the question of whether ABP fluctuations in response to momentary natural emotion are conceptually similar to CVR to emotions induced by laboratory exposures. Studies demonstrate small but significant associations between laboratory-obtained CVR assessments and EMA-obtained daily life CVR assessments (53-54). One recent summary suggests that real life stress-related CVR assessed using EMA might be more robust and ecologically valid than CVR to laboratory stressors (55). Further, a recent study found that the association between psychosocial stress and subclinical CVD is higher among those exhibiting higher naturalistic ABP stress reactivity (56). It is possible that the emotion-subclinical CVD association is also higher among those exhibiting high real world ABP reactivity to the negative emotions explored here. More EMA studies should report the extent to which the emotion-ABP association varies between individuals (see Refs. (56-57) for models for calculating individual ABP reactivity in EMA studies).

Individual differences in the emotion-ABP association reflect individual differences in "emotional coherence", i.e., the extent to which the subjective experiential aspects of emotion are linked with the physiological components of emotion (58). Brown and colleagues (58) found some explanations for interindividual and intraindividual differences in emotional coherence, including trait emotion suppression and state emotion intensity. Thomas and colleagues (59) found that average physical activity and momentary physical activity attenuate the between and within-persons associations between daily life stress and ABP. Perhaps the same is true for

negative emotion, given that stress and negative emotion share some generalized biological mechanisms? More work is needed to determine additional contributors to individual differences in emotion coherence that manifest in the momentary emotion-ABP association. For example, given that there are gender differences in many emotion-related concepts and that meta-regressions in the current study found that predominantly female studies found stronger momentary negative emotion-ABP associations than other studies, gender may be one contributor. The few reviewed studies that examined the moderating effects of trait emotions on the strength of the negative emotion-ABP association found mixed results. The only reviewed study that examined whether state positive emotions attenuated the momentary negative emotion-ABP association found support for this notion (39). This finding, if replicated, might have practical implications. A recent study asserts that individuals are naturally skilled at maintaining their own positive emotional states once they are activated - a skill that could perhaps be harnessed for the purpose of undoing the ABP effects of negative emotions (60).

The practical implication of the overall negative emotion-ABP association is that changing momentary negative emotions might allow individuals to avoid acute and repeated ANS activation. Mobile-based ecological momentary interventions (EMIs) are effective at modifying psychological states (61) and may be a useful tool for doing so.

Limitations

One limitation of this meta-analysis is that we were not powered to compare the differential impacts of all the different negative emotions on ABP, as the studies upon which this meta-analysis relies often combined several negative emotion facets into one variable. Further, the reviewed studies were conducted in the United States, a possible limitation given studies finding that the association between trait negative emotions and blood pressure may be stronger

in Western cultures than in other cultures (62). Additionally, samples tended to be high socioeconomic status and majority-white. To improve confidence in the generalizability of these results, researchers should actively recruit diverse samples.

Future Directions and Additional Recommendations

Despite limitations across studies, the small but consistent temporal association between negative emotion and ABP warrants further research. One of the most immediate future directions is to explore this association in ways that investigate how it changes from person to person, situation to situation, and emotion to emotion (15). We do not yet understand the complex ways in which personal, situational, and emotion-specific factors influence emotion-ABP associations found at any given moment as studies either collapse across people, situations, different emotions, or all three when reporting on this association. Special attention must also be paid to emotion measurement as work suggests that, even using the same measure, different individuals self-report on feelings differently, with some better able to distinguish between different emotions. Further, when self-reporting emotions, some individuals focus more on the valence aspects (degree of pleasantness) whereas others focus more on the arousal aspects (degree of activation) (17).

With the aim of further unpacking the emotion-ABP relationship, future directions must also include addressing the broader network of cognitive and behavioral processes in which emotions are embedded (63). By examining the cognitive and behavioral factors that precede, accompany, and follow emotions, we can determine whether those factors influence emotion-ABP associations. Specifically, we can determine whether rumination influences later ABP, whether successfully regulating a particular emotion influences the linkages between future subjective experiences of that emotion and ABP, and whether positive emotions in preceding

moments or simultaneously reduce linkages between negative emotion and ABP. Experimental studies suggest that rumination over angry feelings is associated with prolonged blood pressure responding (for a meta-analysis, see Ref. (64), an EMA study examining rumination after an laboratory anger induction found that ABP was higher during moments of rumination (65), and a recent EMA study found a marginal association between duration of rumination and systolic ABP (66). Future EMA studies should assess additional nuances of rumination to continue to disentangle acute subjective and physiological reactions to external triggers from the acute subjective and physiological reactions to rumination.

Future work should also determine which psychosocial factors exert their impact on ABP via emotion. Several EMA studies examine the impact of psychosocial factors, such as work and social demands, on ABP (67). These same psychosocial factors strongly influence emotion. Studies examining whether momentary emotion mediates momentary associations between psychosocial exposures and ABP would further advance theory and highlight modifiable targets for intervention.

Finally, EMA burst designs (68) – multiple short periods of EMA monitoring over time - could be helpful in identifying the associations between longitudinal fluctuations in between-persons factors, within-persons emotion-ABP connections, and subclinical and clinical CVD outcomes. To better inform EMA burst designs and other EMA decisions, future research should determine which EMA sampling protocols have the lowest participant burden, highest compliance, and strongest validity and reliability.

Concluding Remarks

Emotion is a complex process that is interwoven with cognitive, behavioral, and physiological dimensions of life. The literature examining the momentary association between

state emotion and ABP measured in natural environments has strengthened our knowledge of the extent to which one physiological dimension responds to fluctuating negative emotionality. With continued conceptual and methodological progress, this literature can further illuminate explanations for individual differences in emotion-ABP associations and targets for intervention aimed at enhancing health as moments unfold.

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Table 1

Reviewed studies (n = 15)

Authors	Sample Size	Observation Days	Observation Frequency (in mins)	Negative Emotion Measurement	Significant Findings
Zawadski et al., 2016	39	1	20	Unpleasant/negative	Systolic
Edmondson et al., 2015	858	1	30	Anxiety/tension	Systolic; diastolic not available
Lehman et al., 2015	68	3	60	Anger, anxiety, embarrassment, shame, worry (separately)	Systolic (anxiety)
Smith et al., 2012	188	1	Random	Total negative emotion	Systolic
Brown et al., 2011	202	1	20	Presence of any negative emotion	Systolic, diastolic
Ilies et al., 2010	67	10	4 random/day	Total negative emotion	Systolic, diastolic
Brondolo et al., 2003	104	1	20	Anxiety, irritation, sadness (separately)	None
Kamarck et al., 2002	340	6	45	Total negative emotion	Systolic, diastolic
Shapiro et al., 2001	203	4	20	Anger, anxiety (separately)	Systolic, diastolic
Carels et al., 2000	162	1	4 random/hr	Total negative emotion	Systolic, diastolic (high emotional responsivity group)
Jacob et al., 1999	69	1	30	Anxious/annoyed	Systolic, diastolic

Räikkönen et al., 1999	100	3	30	Total negative emotion	Systolic, diastolic (low hostility group)
Brown et al., 1998	60	1	15	Presence of any negative emotion	Systolic, diastolic
Kamarck et al., 1998	120	6	45	Total negative emotion	Systolic, diastolic
Schwartz et al., 1994	246	1	15	Presence of separate negative emotions	Systolic (anger, anxiety, tension); diastolic (anger, anxiety, tension)

Figure 1

PRISMA Flow Diagram of the Search Process

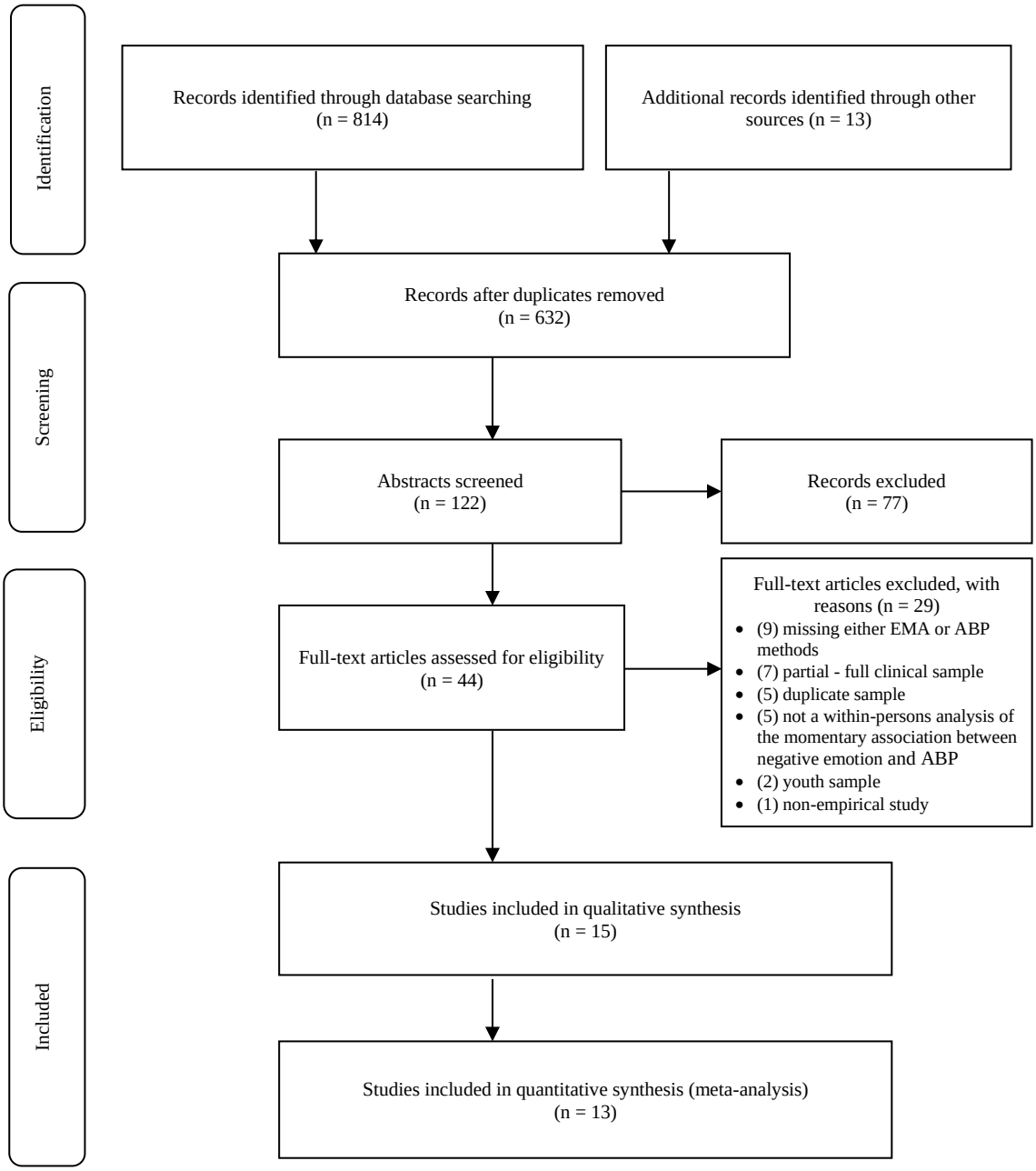
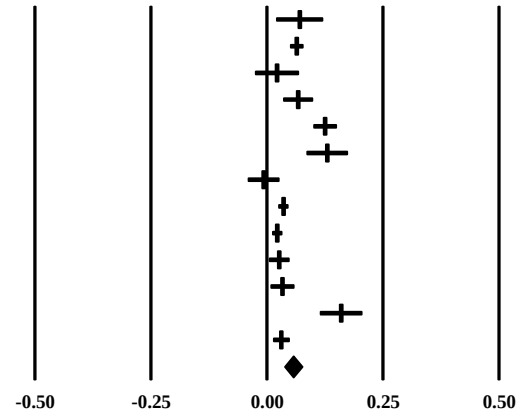


Figure 2

Meta-Analysis of the Association between EMA-Assessed Negative Emotion and ABP

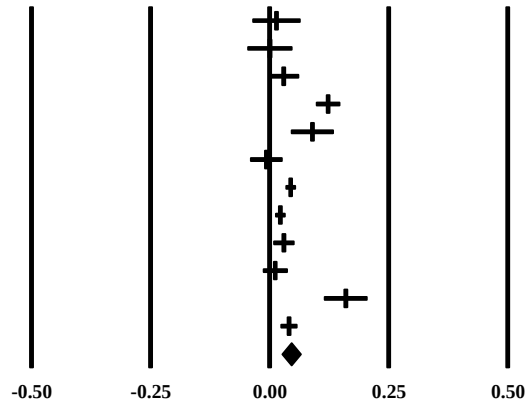
Systolic ABP

Study name	Correlation	Lower limit	Upper limit	p-Value	Total
Zawadski et al., 2016	0.07	0.02	0.12	0.01	1540
Edmondson et al., 2015	0.06	0.05	0.08	0.00	20916
Lehman et al., 2015	0.02	-0.02	0.07	0.36	1770
Smith et al., 2012	0.07	0.04	0.10	0.00	3846
Brown et al., 2011	0.13	0.10	0.15	0.00	6125
Ilies et al., 2010	0.13	0.09	0.17	0.00	1937
Brondolo et al., 2003	-0.01	-0.04	0.03	0.68	3450
Kamarck et al., 2002	0.04	0.03	0.05	0.00	36074
Shapiro et al., 2001	0.02	0.01	0.03	0.00	37352
Carels et al., 2000	0.03	0.01	0.05	0.02	8358
Raikkonen et al., 1999	0.03	0.01	0.06	0.01	6050
Brown et al., 1998	0.16	0.11	0.20	0.00	1809
Kamarck et al., 1998	0.03	0.01	0.05	0.00	13080
Overall Weighted Effect	0.06	0.04	0.08	0.00	



Diastolic ABP

Study name	Correlation	Lower limit	Upper limit	p-Value	Total
Zawadski et al., 2016	0.01	-0.04	0.06	0.57	1540
Lehman et al., 2015	0.00	-0.05	0.05	0.98	1770
Smith et al., 2012	0.03	-0.00	0.06	0.07	3846
Brown et al., 2011	0.12	0.10	0.15	0.00	6125
Ilies et al., 2010	0.09	0.05	0.13	0.00	1937
Brondolo et al., 2003	-0.01	-0.04	0.03	0.69	3450
Kamarck et al., 2002	0.04	0.03	0.05	0.00	36074
Shapiro et al., 2001	0.02	0.01	0.03	0.00	37352
Carels et al., 2000	0.03	0.01	0.05	0.01	8358
Raikkonen et al., 1999	0.01	-0.01	0.04	0.35	6050
Brown et al., 1998	0.16	0.11	0.20	0.00	1809
Kamarck et al., 1998	0.04	0.02	0.06	0.00	13080
Overall Weighted Effect	0.05	0.03	0.07	0.00	



Note. Total is the number of observations rather than participants.

Figure 3

Meta-Analysis Funnel Plots for the Association between EMA-Assessed Negative Emotion and ABP