Abstract

Sighing is a common nonverbal everyday behavior thought to signal the experiencing of negative emotions. Prior research from a small-scale study suggests that observed daily expressions of sighing is associated with subclinical depression (Robbins et al., 2011). This paper replicates and extends these findings, hypothesizing that individual differences in negative emotionality are associated with frequency of spontaneous sighing. Study 1 ($N = 320$) documents a strong lay assumption that frequent sighing signals dispositional negative emotionality. Study 2 estimates the actual association between daily sighing, assessed naturalistically using the Electronically Activated Recorder (EAR), and negative emotionality in a large, diverse, pooled sample ($N = 469$). Bayesian tests across six measures (neuroticism, depression, anxiety, stress, fatigue, loneliness) strongly support the null model. Together, results suggest the common intuition that people who sigh frequently experience more negative emotionality is inaccurate. Assessing whether an individual sighs more (or less) than others cannot be used to infer that they experience more negative emotions.

Keywords: Sighing, Depression, Electronically Activated Recorder, Emotion, Mobile Sensing

Is Frequent Sighing an Indicator of Dispositional Negative Emotionality?

A Multi-Sample, Multi-Measure Naturalistic-Observation Study¹

“After prolonged suffering the eyes become dull and lack expression, and are often slightly suffused with tears. (...) The breathing becomes slow and feeble, and is often interrupted by deep sighs”

(Darwin, *The Expression of the Emotion in Man and Animals*, Ch. 7: *Low Spirits, Anxiety, Grief, Dejection, Despair*; 1972; p. 177)

Sighing is a ubiquitous expressive behavior that both laypersons and scientists routinely assume conveys important psychological information about the tendency to experience negative emotions. Intuitively, we assume that people who sigh frequently tend to be sad, stressed, overwhelmed, or frustrated. For example, in a science news article by National Public Radio (NPR), a journalist suggested that anxious people might sigh so often that it interferes with their daily lives (Hamilton, 2016). In a popular press article, a professional counselor suggested that people who frequently sigh around their romantic partners are unhappy in their relationships (Deitz, 2015). And, on a health blog associated with the Cleveland Clinic, a psychologist started answering the posted question “I sigh a lot – what does that mean?” by saying “Negative emotional states — such as fear, anxiety and sadness — are in fact associated with sighing more often” (Fisher, 2018). The popular media and practicing therapists—perhaps spurred by lay conventions—appears to have very clear assumptions and intuitions about the meaning of a sigh.

¹ Author contributions: the 1st, 2nd, and 9th authors developed the study concept. The 1st author conducted and analyzed Study 1 and drafted the full manuscript. The 1st and 2nd authors analyzed Study 2. The 3rd author cleaned all data and aided with drafting the methods. The 4th to 9th authors oversaw the collection of Study 2 datasets. All authors contributed to editing the manuscript.

Popular notions about sighing are not entirely separate from the existing body of scientific research. Indeed, researchers have linked sighing conceptually and empirically to negative emotionality (Roth, 2005; Teigen, 2008; Wilhelm, Trabert, & Roth, 2001). Other researchers identify it as commonly occurring during moving emotional experiences, described as “the thrills” (Goldstein, 1980), and find an association between sighing rate (measured physiologically) and arousal experienced in response to emotional photographs and guided imagery (Vlemincx, Van Diest, & Van Den Bergh, 2015). In controlled laboratory settings, sighing is associated with anxiety (Abelson, Weg, Nesse, & Curtis, 2001; Wilhelm et al., 2001), pain (Keefe & Block, 1982), or frustration when completing a difficult task (Teigen, 2008). Sighing can also be associated with anticipatory relief. In one study, participants viewed shapes that cued whether they would hear a blast of white noise (Vlemincx et al., 2009). Sighing was more frequent during cued “relief” trials when the visual cue indicated no noise blast, than in the “stress” trials.

Early theoretical work suggests that sighing is associated with emotional responses, including being nervous, fatigued, or excited, but not with physical disease or abnormality in the heart or lungs (Straus, 1952). Physiological examinations of sighing find that it is associated with normal total lung capacity, suggesting no obvious anatomical explanation for why some people sigh more than others (Aljadeff, et al., 1993; Leiner & Abramowitz, 1958). It may be more common among individuals with specific medical diagnoses (e.g. pulmonary tuberculosis), as compared to other diagnoses, but not necessarily compared to healthy adults (Leiner & Abramowitz, 1958). A review of physiological research on sighing suggests that it is a response to changes in levels of blood gases and triggers arousal, which can be useful for infants refreshing their oxygen supply, and for adults resetting their breathing to a healthy pattern of

variability (Ramirez, 2014). Activity in several brain regions, including the amygdala and the hypothalamus, are associated with sighing (Ramirez, 2014). There is some evidence in small studies, however, that people with panic disorder sigh more frequently than healthy controls ($N = 26$ panic disorder patients in Schwartz, Goetz, Klein, Endicott, and Gorman, 1996; $N = 15$ panic disorder patients in Wilhelm, Trabert, and Roth, 2001), demonstrating that sighing has been associated with at least one mental health outcome.

Only one prior study (to our knowledge) has examined sighing naturalistically, as it occurs in the course of daily life. A small study with 13 women with rheumatoid arthritis found preliminary evidence for a link between daily expressions of sighing and depression (Robbins, Mehl, Holleran, & Kasle, 2011). This study used the Electronically Activated Recorder (EAR) to sample ambient sounds throughout the day and determine instances of sighing via behavioral coding (Mehl, Pennebaker, Crow, Dabbs, & Price, 2001). Importantly, the EAR provided a way to passively track daily sighing while limiting reactivity or the risk that the act of measurement interfered with the phenomenon (e.g., having to monitor and report sighs might alter one's natural sighing rate via induced self-awareness). The study found that sighing correlated highly with both the Beck Depression Inventory (BDI; Beck, Ward, Mendelson, Mock, & Erbaugh, 1961) scores ($r = .71$; 95%CI [.38; .90]) and the Center for Epidemiological Studies Depression scale (CES-D; Radloff, 1977) scores ($r = .68$; 95%CI [.02; .91]). Further, and consistent with the idea that sighing might signal broader negative emotionality than depression specifically, sighing also correlated substantially with anxiety as reported on the Beck Anxiety Inventory ($r = .52$; 95%CI [-.01; .87]; Beck, Epstein, Brown, & Steer, 1988) and neuroticism as reported on the Big Five Inventory ($r = .76$; 95%CI [.34; .90]). The strong and consistent correlations in this small study support the intuitive notion that individual differences in sighing tend to signal individual

differences in negative emotionality, such as sadness, stress, or anxiety.

Although the prior literature appears to support the association between sighing and negative emotionality, establishing sighing as a reliable marker of negative emotionality ultimately requires testing the replicability and generalizability of the effect. This is particularly true because there is evidence that sighing can indicate relief after experienced stress (Vlemincx et al., 2009). The only previous study that (to our knowledge) assessed sighing in the naturalistic context of daily life used a very small sample size (Robbins et al., 2011; Schönbrodt & Perugini, 2013) and low statistical power is known to be the prime risk factor for scientific false positive findings (Altmejd et al., 2019). Further, the effect was derived from a very specific population, women diagnosed with rheumatoid arthritis. The link between sighing and the experience of negative emotions, however, is not hypothesized to be unique to this population, and should hold at a much broader, general level.

Our study intentionally addresses sighing from a “lay observer” perspective. This follows from Funder’s (2009) argument that psychology research should be “based on observations of interesting and important behaviors observed in interesting and important situations” (p. 343). It also follows from Block’s (1993) arguments that “[lay observer’s questions] lie behind the wide and demanding lay interest in psychology. Academic and research psychologists sometimes forget, or do not recognize, that these lay questions are fair questions ... [that] deserve far more serious scientific attention” (p. 10). Although one tradition of sighing research defines sighing in terms of very specific respiratory patterns that cannot be independently validated without physiological recording equipment, this project follows a tradition grounded in the observation of everyday behavior that can be readily recognized by all members of a society. This approach directly addresses the kinds of observations raised in the introductory paragraph by journalists

and therapists. When lay persons talk about sighing indicating negative states, they mean sighing as it is experienced, observed, and commonly understood (rather than physiologically measured). This research is well suited to test these kinds of claims, precisely because it uses a lay definition.

The current investigation follows up on Robbins and colleagues' (2011) preliminary study in two ways. First, we wanted to capture people's intuitions about the association between sighing and negative emotionality. Although both prior research and popular treatment in the media suggest that frequent sighing is associated with a tendency to experience negative emotions more frequently, this evidence is anecdotal and may not represent typical perceptions of non-psychologists. This is particularly important because anecdotal evidence suggests that sighing might be associated with relief, which is a positive experience. Since there are ready examples of sighing being associated with positive emotion, it should be confirmed with empirical evidence that a strong lay assumption exists tying frequent sighing to dispositional negative emotionality. Specifically, we assumed lay people would think of a person who sighs a lot as frequently experiencing negative emotions. We also assumed that people who think they sigh a lot, would rate themselves as being high in negative emotionality.

Second, we wanted to juxtapose this lay assumption against the actual association between daily sighing and negative emotionality observed in daily life. We did this using a much larger and more diverse sample than Robbins and colleagues (2011) by pooling data from four archival studies from our labs, and using a broader set of measures that, together, more comprehensively cover the underlying construct of negative emotionality (i.e. neuroticism, depression, anxiety, stress, fatigue, and loneliness). Based on the earlier study, we expected a relatively consistent positive association between participants' daily sighing frequency (as

measured by the EAR), and our available measures of self-reported negative emotionality. Importantly, we had no prior expectation about stronger or weaker associations in selected samples or with selected measures. Our hypotheses were that prior results would replicate, but no formal preregistration was created. All experiments, conditions, data exclusions, and methods for calculating sample size measures are included. Not all measures are included, because these are large-scale studies with many different variables collected addressing several different research questions.

Study 1

Our first study aimed to empirically document the intuitive lay assumption that people who sigh a lot tend to be high on negative emotionality. We did this via a correlational survey study. Note that all materials and data for this study are available on the OSF. (<https://osf.io/yzg2m/>).

Methods

Participants. We recruited 350 participants for this study through the website Prolific. Our key survey questions asked participants to report on how they view people who sigh a lot (“Compared to people who sigh less, I think people who sigh more are ...”) on a one to five Likert-style scale (ranging from “strongly disagree” to “strongly agree”). Our key hypothesis tests were t-tests comparing the means of the sample to the midpoint of the scale (which indicates a ‘neutral’ opinion or no assumed association). Assuming we wanted 80% power, we would need a sample of 300 people to detect an effect of approximately $d = .16$. We believed the

effect size would be substantially greater than this, but powered our study to detect an effect in this range because we determined it would be our smallest effect size of interest (SESOI; Lakens, 2014). The smallest effect size of interest was roughly calibrated to guidelines provided by Funder and Ozer (2019). Based on their review of the literature, a small effect is $r = .10$. A $d = .16$ corresponds to $r = .08$, which is slightly smaller than their small effect guideline. We acknowledge that this was only a rough calibration, and that we were very conservative in our estimate of the sample size needed to detect an effect. This was in line with our broad goal to describe the assumptions that the lay public had about sighing. We recruited significantly more to ensure that we had over 300 people after removing those who failed the attention check.

Note that data analysis was conducted in a Bayesian framework, and there is some debate over whether power analyses are required in this analysis framework. We chose to conduct a frequentist power analysis for planning purposes, but to retain our Bayesian analysis framework to more easily estimate the evidence in favor of the null hypothesis. We specified that all participants had to be from the U.S, to keep the cultural context comparable to Study 2. Participants were compensated \$1.27 for each survey, which was estimated to take 5-8 minutes (planned hourly rate: \$15; effective hourly rate (based on actual task completion time): approximately \$38).

We employed two attention checks during the survey. The first listed a series of hobbies and asked participants to choose a specific one if they were paying attention. Based on this attention check, we eliminated two participants. The second attention check asked participants to respond whether, compared to people who sigh less, people who sigh more are more likely to sigh frequently. If participants did not respond with “somewhat agree” or “strongly agree” their responses were cut. This resulted in cutting responses for 28 more people. The final sample was

therefore 320 people (enough for 80% power to detect an effect of $d = .157$). Participants were 45% female, 52% male, and the remainder either did not identify as one of these (5 participants) or did not respond (2 participants). The average age was 32.8 years old ($SD = 11.8$). Participants were 73% white, 10% East or Southeast Asian (including Pacific Islanders), 3% black, 3% Hispanic or Latino, and 2% South Asian (e.g. from India or Pakistan). The remainder of participants were of mixed ethnicity or did not report their ethnicity.

Measures and Procedures. Participants were asked a series of questions about themselves and about their perceptions of people who sigh frequently. In the questions about others, participants were asked to respond to the prompt, “Compared to people who sigh less, people who sigh more...” with several statements, like “Are more fatigued.” Participants responded on a five-point Likert scale (from “strongly disagree” to “strongly agree”). The statements included the following measures of negative emotionality: stress, fatigue, depression, anxiety, loneliness; and measures of the Big Five personality traits. In the questions about themselves, participants were asked to rate the degree to which they agreed with a series of “I am” statements on a five-point Likert scale (from “disagree strongly” to “agree strongly”). These were in the form “I am often...” followed by the terms: stressed, anxious, depressed, lonely, tired. A second set asked about personality traits (e.g., “I am extraverted”), and a third set asked about frequently using common non-verbal behaviors (e.g., laughing, crying). One of these questions was “I sigh a lot” (from “disagree strongly” to “agree strongly”). Sighing was not defined for participants, as it was intended to be interpreted as a lay term with a commonly understood meaning. A lay definition was chosen because it matched the methods used for the most closely relevant precedent in the scientific literature, and because our focus is on testing popular beliefs and understanding, as

opposed to technical definitions based on potentially unobservable physiological changes.

Participants completed the brief study online, via the Qualtrics survey software.

Results and Discussion

Perceptions of Others. We analyzed the perceptions of others' sighing using Bayes Factors providing evidence in favor of a model where the average response was greater than the midpoint of the scale (i.e., 3). Bayes Factors are continuous measures of the strength of evidence in favor of a hypothesis, given data. Typically, any Bayes Factor over 10 is considered strong evidence in favor of the hypothesis, while any Bayes Factor over 100 is considered extreme evidence in favor of the hypothesis (Lee & Wagenmakers, 2013). Full results are presented in Table 1. Responses show that participants thought those who sigh more were higher in every trait associated with negative emotionality, including being stressed, anxious, depressed, lonely, tired, and neuroticism. Importantly, speaking to participants' ability and motivation to discriminate and provide differentiated responses, they indicated that they do not believe sighing more is associated with extraversion, agreeableness, openness, nor conscientiousness.

Table 1: Perceptions of People Who Sigh Frequently

Variable	<i>M</i>	<i>SD</i>	<i>% Above Midpoint</i>	BF ₊₀
Extraversion	2.50	0.95	14.1%	0.004
Agreeableness	2.56	0.87	12.8%	0.005
Openness	2.59	0.81	10.9%	0.005
Conscientiousness	3.06	0.89	28.2%	0.243
Neuroticism	3.83	0.92	77.2%	> 100
Depressed	3.65	0.93	64.4%	> 100
Anxious	3.78	0.82	72.5%	> 100

Stressed	4.06	0.84	83.1%	> 100
Tired	3.96	0.88	78.4%	> 100
Lonely	3.43	0.97	54.4%	> 100

Note: Mean (M) and Standard Deviations (SD) are on a scale of 1 to 5. BF_{+0} indicates the Bayes Factor in favor of a model where the average score is above the midpoint of the scale (3). “% Above Midpoint” indicates the proportion of people who responded to the survey question above the midpoint (i.e., 4 or 5).

Self-Perceptions. The correlations of a person’s self-reported sighing frequency with negative emotionality is given in Table 2. Bayes Factors were computed to provide the strength of evidence in favor of a model where there is a significant correlation between the variables. All associations between sighing and negative emotionality constructs, except loneliness, had extreme evidence ($BF_{10} > 100$) in their favor. There was only moderate evidence in favor of an association between sighing and loneliness. Results also demonstrated discriminant validity, as there was no evidence in favor of associations with extraversion, conscientiousness, agreeableness, nor with openness to new experiences. In fact, Bayes Factors suggested that a model of no association was moderately supported for extraversion, agreeableness, and conscientiousness.

Table 2: Self Perceptions and Sighing

Variable	M	SD	$Pearson's\ r$	BF_{10}
Sighing	3.01	1.26	---	
Extraversion	2.19	1.29	-.09 [-.19, .02]	0.23

Sighing and Negative Emotionality 12

Agreeableness	3.90	0.86	-.00 [-.11, .11]	0.07
Openness	4.04	0.95	-.12 [-.23, -.01]	0.72
Conscientiousness	4.06	0.91	-.05 [-.16, .06]	0.10
Neuroticism	3.16	1.35	.29 [.18, .38]	> 100
Depressed	3.12	1.42	.26 [.15, .36]	> 100
Anxious	3.47	1.35	.34 [.24, .43]	> 100
Stressed	3.52	1.27	.34 [.24, .43]	> 100
Tired	3.76	1.25	.37 [.27, .46]	> 100
Lonely	3.02	1.42	.17 [.06, .28]	8.29

Note. *M* and *SD* are used to represent mean and standard deviation, respectively. *Pearson's r* indicates the Pearson's correlation of the variable with frequency of sighing. Values in square brackets indicate the 95% confidence interval for each correlation. The confidence interval is a plausible range of population correlations that could have caused the sample correlation (Cumming, 2014). BF_{10} indicates the Bayes Factor in favor of the association between these variables being non-zero.

Together, the results of our survey indicate, as expected, that people perceive a strong

association between sighing and negative emotionality, broadly construed. This association holds whether we ask about a participant's perceptions of others' sighing and negative emotionality or about their own sighing and negative emotionality. The findings that participants perceived their own and others' sighing to be unrelated or to have opposite relations with personality traits not intuitively associated with sighing alleviate (but, of course, cannot rule out) concerns around potential response biases (e.g., acquiescence, demand characteristics).

Further, follow-up tests examining the potential moderating effects of participants' gender or background in psychology found no statistically significant moderation by either factor on any of the associations between sighing and negative emotionality. In fact, our 28 participants with some psychology background (11 with a graduate level degree) had slightly stronger beliefs that sighing indicated negativity in other people.

Our results therefore support the previous research literature suggesting a link between lay impressions of frequent sighing and individual differences in negative emotionality. In Study 2, we used a large sample to test the actual association of the frequency with which people sighed over several days, measured with the EAR, and their level of negative emotionality, measured with self-report measures of different aspects of negative emotionality.

Study 2

The goal of Study 2 was to juxtapose the assumed association between sighing and negative emotionality, documented in Study 1, with the actual association between daily sighing and negative emotionality. For this, our measure of sighing was derived from naturalistic observation: the frequency of sighs unobtrusively recorded over the course of several days using

the EAR method. This measure involves the coding of audible instances of sighing recorded from people's moment-to-moment daily life. Although some prior research has studied sighing at a physiological level, defining it according to patterns of respiration (e.g., Schwartz et al., 1996; Vlemincx et al., 2010; Wilhelm, Trabert, & Roth, 2001), physiological signals cannot be directly perceived by others. As the focus of this manuscript is on sighing as an observable indicator of negative emotionality, the use of an observable cue—the sound of the sigh—is more appropriate for our purpose.

Method

This study reports results from four different samples, examining the relationship between naturalistically observed daily sighing and a set of available self-report measures covering the theoretical construct of negative emotionality. Sample size was determined by availability of data. Power calculations indicate that this sample was sufficiently powered ($1 - \beta = 0.8$) to detect an association of approximately $r = 0.13$, a relatively small effect size (Funder & Ozer, 2019). The procedures and data collected for each sample were part of larger studies collected to examine other aims (Bourassa et al., 2019; Hasselmo et al., 2018; Kaplan et al., 2018; O'Hara et al., 2020; Polsinelli et al., 2020; Robbins, Lopez, Weihs, & Mehl, 2014; Robbins, Karan, Lopez, & Weihs, 2018). For ease of comparison, details of the methods are presented together. A similar integrative analysis through data-pooling approach was recently employed by Milek et al. (2018) using three of these four samples. Note that the analyses were planned beforehand based on an assessment of which variables associated with negative emotionality were available in the datasets, and we included all negative emotionality variables that were identified in our review of

the datasets.

Participants

Sample 1 (Cancer). Breast cancer patients and their cohabitating partners were recruited during visits to an oncologist at a cancer center in the Southwest United States. Couples were eligible for participation if (a) patients' primary diagnosis was Stage I, II, or III breast cancer and they were receiving adjuvant treatment at the time of the study (chemotherapy or radiation)²; (b) the couples were living together in a marriage-like relationship; (c) both members of the couple were over 21 years of age; and (d) they spoke English primarily in their daily conversations. Fifty-six couples gave their consent to participate in the study. Due to the non-independence of the data, one member was randomly selected (either the patient or the caregiver) to be included in the current study. Of the selected data, the average age was 56 years old ($SD = 13.8$); 58% were female and 42% male; and 81.5% were white, 11.1% were Hispanic or Latino, 3.7% were Black or African American, 1.9% were Asian, and 1.9% were Native American or Alaskan Natives. For more details on the sample, please see Robbins et al. (2014).

Sample 2 (Divorce). Adults separated from their marital partners were recruited from the Tucson, Arizona, area. There were 140 participants recruited, but the final sample included only the 122 participants for whom valid EAR data was recorded. The average age was 43 years old ($SD = 10.7$); 69.9% were female and 30.1% were male; and 62.5% were white, 21.3% were Hispanic or Latino, 5.1% were Black or African American, 2.2% were Asian, and 2.2% were

² Note that a handful of participants with Stage 0 and Stage IV breast cancer were given special exemption to participate. This decision was made toward the end of the study to maximize the sample size. These couples were not outliers in their levels of psychological adjustment or in their frequency and type of their cancer conversations; they were therefore retained in the final sample for analyses.

Native American or Alaskan Natives. For more details on the sample, please see Bourassa et al. (2019), Hasselmo et al. (2018), and O'Hara et al. (2020).

Sample 3 (Meditation). Healthy adults living in Atlanta, GA were recruited for a randomized controlled trial of a meditation intervention being conducted at the Emory University Center for Health and Well-being (ClinicalTrials Identifier: NCT01643369). Two hundred and sixty-one individuals were recruited, and 223 provided usable data for this study. The average age was 34 years old ($SD = 8.3$); 63.6% were female, 34.7% were male, and 1.8% did not indicate gender; and 47.6% were white, 4.4% were Hispanic or Latino, 33.8% were Black or African American, 11.1% were Asian, 0.9% were Native American or Alaskan Natives, and 0.9% were Native Hawaiians or other Pacific Islanders. Only data collected prior to randomization was used. Note that screening for this study involved removing individuals who were experiencing psychiatric difficulties using symptom checklists; this led to lower rates of anxiety and depression in this sample than in others (see Table 3). For more details on the sample, please see Kaplan et al. (2018).

Sample 4 (Aging). Participants were recruited through fliers, email listservs, and community events for two dissertation studies on cognition and aging. Exclusion criteria included (a) having a neurological disorder, (b) having had a head injury with loss of consciousness for five minutes or longer, (c) a history of alcohol or drug abuse, (d) a significant psychiatric disorder, (e) current use of psychotropic medications, (f) a score of 21 or greater on the Center for Epidemiological Studies Depression scale (CES-D) (Radloff, 1977), (g) and being under 65 years old. There were 107 participants included in this sample. The average age was 76 years old ($SD = 5.9$); 54.2% were female and 45.8% were male; and 99.1% were white, with 0.9% not indicating their race. For more details on the samples, please see Polsinelli (2017) and

Moseley (2018).

Procedures

In all studies, individuals completed a series of questionnaires assessing depression and several other constructs, including anxiety, loneliness, stress, fatigue, and satisfaction with life (see measures section). The EAR in the four samples consisted of a mobile device (Apple iPod touch device in the Meditation, Divorce, and Aging studies; HP iPAQ in the Cancer and the Meditation study) loaded with an EAR app (iEAR app in the Meditation, Divorce, and Aging study; Windows Mobile software in the Cancer and Meditation study). For more details on the different generation EAR systems see Mehl (2017) and the original study publications. More detailed descriptions of the procedures for each study can be found in earlier publications.

Sample 1 (Cancer). Both the woman with cancer and her cohabitating partner completed a series of questionnaires including the measures described below, except the loneliness and anxiety scales. They then each wore the EAR for three consecutive days from Friday afternoon to Monday morning. The average number of valid sound files per participant was 188 files ($SD = 58$). The EAR recorded periodically for 50 seconds every 9 minutes with a blackout period overnight (Robbins et al., 2014).

Sample 2 (Divorce). Participants first completed a series of questionnaires including all those described below, then wore the EAR over the course of a weekend (Friday evening to Monday morning). The average number of valid sound files per participant was 176 files ($SD = 60$). The EAR recorded periodically for 30 seconds every 12 minutes with a blackout period overnight (Bourassa et al., 2019; Hasselmo et al., 2018). This study involved follow-up assessments, but only the data from Wave 1 were included here, because this was the wave closest to the personality measure.

Sample 3 (Meditation). Participants completed a series of questionnaires, including the measures described below except for the fatigue scale, prior to randomization to receive the meditation intervention. Participants wore the EAR for three days (Friday night through Monday morning) before and after an eight-week meditation intervention. The average number of valid sound files per participant was 149 files ($SD = 59$). The EAR recorded periodically for 50 seconds every 9 minutes for the first groups of the participants ($N = 90$), and then for 30 seconds every 12 minutes for the remaining participants ($N = 93$) (Kaplan et al., 2018). This study involved pre and post-intervention assessments, but only the pre-intervention data were used, because all other assessments involved baseline relationships uninfluenced by experimental manipulation.

Sample 4 (Aging). Participants first completed a series of questionnaires, except for the measures of stress and anxiety described below, and then wore the EAR over the course of four and a half consecutive days, of which two were weekdays and two were weekend days. The average number of valid sound files per participant was 306 files ($SD = 74$). The EAR recorded for 30 seconds on average every 12 minutes, with each recording occurring randomly between 6 and 18 minutes after the previous one (Polsinelli, 2017; Moseley, 2018).

Measures

For all scales a percentage of maximum possible (POMP) score was calculated (Cohen, Cohen, Aiken, & West, 1999). This put all measures on the same metric (values ranging from 0 to 100), and allowed for comparisons of constructs like depression and anxiety measured using different instruments across samples. Exploratory factor analysis revealed that the POMP scores were best represented as having only one underlying dimension; details of the analysis including full R script are available on the OSF (<https://osf.io/yzg2m/>). An overall negative emotionality

score per person was therefore calculated by Z-scoring and averaging the POMP scores of each measure.

Neuroticism. The Big Five Inventory (BFI) was administered in the Cancer, Divorce, and Meditation samples (John & Srivastava, 1999). The Ten Item Personality Inventory (TIPI) was administered in the Aging sample (Gosling, Rentfrow, & Swann, 2003). The TIPI was originally validated against the BFI, and results indicated high convergence among the personality facets as measured by these two scales (Gosling, Rentfrow, & Swann, 2003).

Depressive Symptoms. The Center for Epidemiological Studies Depression scale (CES-D) assesses self-reported depressive symptoms over the past week, asking participants to rate how often they experienced symptoms on a scale from 0 (rarely) to 3 (all of the time); a 10-item version of this scale was used in the Divorce, Aging, and Cancer samples (Andresen, Malmgren, Carter, & Patrick, 1994). The Beck Depression Inventory (BDI) was used in the Meditation sample (Beck, Ward, Mendelson, Mock, & Erbaugh, 1961).

Anxiety. In the Divorce sample, participants completed the 20-item trait scale of the State-Trait Anxiety Inventory (STAI; Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983). In the Meditation sample participants completed the Beck Anxiety Inventory (BAI; Beck, Epstein, Brown, & Steer, 1988). No measure of anxiety was included in the Aging and Cancer samples.

Stress. The Perceived Stress Scale (PSS) is a ten-item measure of an individual's appraisals of their own lives as stressful (Cohen, Kamarck, & Mermelstein, 1983). It was administered in the Divorce, Cancer, and Mediation sample; no measure of stress was available in the Aging sample.

Fatigue. Fatigue was assessed in the Divorce, Aging, and Cancer samples using the four-item fatigue subscale of the 36-Item Short Form Health Survey (Ware & Sherbourne, 1992). No

assessment of fatigue was available in the Meditation sample.

Loneliness. The UCLA Loneliness Scale was administered in the Divorce and Meditation samples (Russell, Peplau, & Ferguson, 1978). The National Institutes of Health (NIH) loneliness scale was used in the Aging sample (Cyranowski et al., 2013). No measure of loneliness was included in the Cancer sample.

Overall Negative Emotionality. An exploratory factor analysis (EFA) found that scores on all these scales could be well-represented by a single summary factor ($RMSE = 0.06$, $TLI = 0.878$, r of scores with factors = 0.95). To create a composite measure, the scale scores were Z-scored and averaged. This overall variable presents the best single test of the hypothesis that sighing is associated with negative emotionality. The full results of the one-factor EFA are available in the Supplementary Materials.

Coding of Sighing. Research assistants indicated whether the participant audibly sighed in each sound file. In the coding systems, a sigh was defined as an exaggerated exhalation of breath (Keefe & Block, 1982). In the Cancer, Divorce, and Meditation sample, all sound files were independently double-coded; in the Aging sample, a subset of sound files were double-coded to establish reliability. The codings were aggregated across all of a participant's compliant (i.e. deemed wearing the EAR) and waking (i.e. deemed not sleeping) sound files to yield the percentage of a participant's valid waking sound file in which a sigh occurred. Intercoder reliability, computed on the aggregated measure for each coder as $ICC[1,2]$, was $ICC = .93$ in the Cancer sample, $ICC = .80$ in the Divorce sample, $ICC = .66$ in the Meditation sample, and $ICC = .57$ in the Aging sample. Note that an ICC of .60 has traditionally been considered "good" for behavioral coding in psychology, so even our least reliable sample meets traditional requirements of the field (Cicchetti, 1994). Based on prior experience working with EAR data,

our research group has found that relatively rare events—such as sighing—tend to have lower reliability values. More details of the EAR coding system can be found online, at the EAR study repository (<https://osf.io/n2ufd/>).

In one prior study, sighing was assessed using both auditory cues and behavior (Keefe & Block, 1982). In videos, sighing could sometimes be better recognized in a movement of the shoulder and cheeks, as opposed to in auditory cues. To address concerns over whether the acoustically-derived measure of sighing we used was reliable, we conducted secondary coding of existing video of social interactions in a lab study. Two coders were provided with audio and visual channels, while two other coders were provided only audio channels. Emulating the EAR method, videos were divided into 50-second segments, creating a total of 81 segments to be coded. This is roughly equivalent to a full day's worth of EAR recordings. Inter-coder agreement among the two audio coders was slightly higher ($ICC = .79$) than agreement among audio plus visual coders ($ICC = .64$). This secondary coding exercise indicated that having access to the additional visual coding channel did not give audio-visual coders any reliability advantage, and that adding visual information may have actually distracted from accurate coding.

Analysis. Due to the non-normality of many of the variables involved, we chose to present results both in terms of the traditional Pearson's correlation coefficient as well as Kendall's τ -b as measures of association. Kendall's τ -b is a measure of correlation that, like Spearman's ρ , is computed on the rank order of variables, which makes it a more robust estimator of association when analyzing non-normal variables. Bayes factors can easily be computed in favor of the null hypothesis for Kendall's τ -b, which is why we opted for it over Spearman's ρ . The Bayes factors presented (BF_{01}) represent the relative odds that the data are

observed under the null hypothesis, so higher numbers indicate that the data favor the null. We follow the “rule of thumb” interpretation of Bayes factors that values from 1 to 3 indicate “anecdotal evidence,” 3 to 10 indicate “moderate evidence,” and 10 to 30 indicate “strong evidence” in favor of the (null) model (Lee & Wagenmakers, 2013). Cases where the Bayes factor was below 1 indicate that the alternative model is favored (the data support the existence of a non-zero correlation); in these cases we calculated BF_{10} to provide evidence in favor of the alternative that was on the same scale as the evidence reported in favor of the null.

We used uninformative or “default” priors in all analyses. The uninformative prior was identical to that used in Study 1, to which we were comparing our results. The decision to use the same priors allowed for a more precise comparison. Additionally, the original study we were replicating consisted of 13 women who had arthritis, which we considered a negligible sample in comparison to the 510 individuals included in this sample. Although Pearson’s r is provided as a comparison point for our analyses, due to the non-normal distribution of the variables we considered Kendall’s τ -b to be the critical test of our hypothesis. All analyses were conducted in JASP.

Results

Correlations between daily sighing and each of the self-reported negative emotionality outcomes were calculated from three data sets: one with participants who indicated male as gender ($N = 190$), one with participants who indicated female as gender ($N = 319$), and one with all participants ($N = 510$). We estimated associations for gender separately because the previous published EAR study by Robbins and colleagues (2011) only included female participants, so the

effect estimates by gender are important comparison points for previous research. Descriptive statistics for sighing and negative emotionality variables are presented in Table 3³.

Table 3: Descriptive Statistics

Variable	Cancer Sample			Divorce Sample			Meditation Sample			Aging Sample		
	N	M (SD)	α	N	M (SD)	α	N	M (SD)	α	N	M (SD)	α
Sighing	52	4.3 (5.8)	.	112	3.4 (3.5)	.	186	3.3 (2.9)	.	107	1.9 (2.6)	.
Overall Negative Emotionality	51	30 (13)	0.81	122	34 (13)	0.85	188	19 (10)	0.79	107	23 (15)	0.7
Neuroticism	51	34 (16)	0.86	120	38 (16)	0.8	182	30 (15)	0.84	107	16 (16)	0.64
Depression	41	17 (13)	0.85	122	20 (11)	0.91	188	7 (9)	0.89	107	9 (8)	0.83
Anxiety	.	.	.	120	30 (15)	0.92	188	5 (6)	0.86	.	.	.
Stress	51	33 (15)	0.83	121	47 (18)	0.7	185	33 (15)	0.36	.	.	.
Fatigue	51	38 (18)	0.95	120	37 (21)	0.92	.	.	.	72	29 (15)	0.88
Loneliness	.	.	.	121	33 (22)	0.87	186	22 (15)	0.91	46	22 (13)	0.91

Note: Sighing is in a proportion of time metric. The Cancer sample percentages are for the dataset that included a combination of both patients and caregivers. All self-report variables are on a percentage of maximum possible (POMP) metric. α is Cronbach's alpha.

Was there an association between daily sighing and overall negative emotionality?

Among all participants the association between daily sighing and overall negative emotionality was almost exactly zero ($\tau = .026$, 95% CI [-.062, .026]), and there was strong evidence in favor of the null model (BF_{01} for $\tau = 11.60$). Bayes factors indicated moderate to strong evidence in favor of the null model for almost all indicators of negative emotionality (except fatigue, see

³ For consistency with prior literature on the EAR, sighing is reported and analyzed here in the proportion of files with sighs metric. If sighs per hour were to be used, the average values for each sample would be: Cancer, 3.1 sighs per hour; Divorce, 4.1 sighs per hour; Meditation, 3.2 sighs per hour; Aging, 2.3 sighs per hour.

below). Data are presented in Table 4.

Was daily sighing associated with any specific negative emotionality construct? To find the strongest associations of sighing and negativity in our sample, we calculated BF_{10} , which gave evidence in favor of the alternative model. Note that BF_{10} is interpreted as the “opposite” of the BF_{01} (where higher values indicate stronger evidence in favor of the null). Only the association of sighing and fatigue ($BF_{10} = 2.74$) had a BF_{10} above 1, indicating that the alternative was favored. The strength of this evidence was just below the category of “moderate.” Data are presented in Table 4.

Were any associations between daily sighing and the negative emotionality constructs gender-specific? The BF_{01} for daily sighing and the negative emotionality constructs among female participants indicated strong evidence in favor of the null, except for the association between daily sighing and fatigue. Calculating the BF_{10} for these variables, we found that the Bayes factors suggested “moderate” evidence that sighing was positively associated with fatigue among women ($BF_{10} = 3.05$). For male participants, the BF_{01} values were lower, indicating “anecdotal” to “moderate” support for the null hypothesis. The exception was the association between daily sighing and loneliness, which was below 1 and therefore indicated support for the alternative model. To characterize the strength of evidence in favor of the alternative model, BF_{10} was calculated. This calculation provided moderate evidence that sighing was negatively associated with loneliness ($BF_{10} = 2.66$) among men. However, there was moderate evidence that sighing and fatigue were not associated in men—which is different from the association observed among women and in the combined data. Data are presented in Table 4.

Table 4: Correlations and Bayes Factors for Daily Sighing and Negative Emotionality

Variable	n	Pearson's r	95% CI	BF ₀₁	Kendall's τ	95% CI	BF ₀₁
All Participants							
Overall Negative Emotionality	510	.025	[-.062, .111]	15.39	.026	[-.032, .084]	11.60
Neuroticism	502	.028	[-.059, .115]	14.68	.067	[.008, .125]	1.37
Depression	510	-.001	[-.094, .079]	17.78	.005	[-.053, .063]	16.94
Anxiety	296	-.024	[-.137, .090]	12.65	-.047	[-.122, .030]	6.44
Stress	399	-.004	[-.102, .094]	15.90	-.022	[-.088, .043]	12.21
Loneliness	341	-.034	[-.139, .072]	12.17	-.056	[-.127, .015]	4.23
Fatigue	287	0.129	[.013, .24]	1.28	.106	[.028, .182]	0.37
Female Participants							
Overall Negative Emotionality	319	.059	[-.051, .167]	8.24	.053	[-.021, .125]	5.09
Neuroticism	316	.023	[-.087, .132]	13.10	.057	[-.017, .130]	4.34
Depression	319	.025	[-.085, .134]	12.93	.047	[-.027, .120]	6.17
Anxiety	199	.036	[-.103, .173]	9.917	.005	[-.088, .097]	10.72
Stress	261	.020	[-.101, .14]	12.28	.012	[-.069, .093]	11.84
Loneliness	220	.052	[-.08, .182]	8.83	.010	[-.079, .097]	11.07
Fatigue	176	.188	[.04, .324]	0.484	.133	[.033, .229]	0.328
Male Participants							
Overall Negative Emotionality	190	-.033	[-.174, .109]	9.93	-.015	[-.110, .079]	10.04
Neuroticism	185	.033	[-.111, .175]	9.84	.090	[-.008, .184]	2.01
Depression	190	-.058	[-.197, .084]	8.04	-.065	[-.159, .031]	4.38
Anxiety	96	-.163	[-.347, .038]	2.26	-.135	[-.264, .002]	1.16
Stress	137	-.039	[-.203, .128]	8.45	-.098	[-.207, .016]	2.17
Loneliness	120	-.201	[-.363, -.022]	0.81	-.155	[-.270, -.033]	0.38

Fatigue	111	.017	[-.168, 0.2]	8.30	.053	[-.073, .175]	5.79
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Note: 95% CI indicates 95% Bayesian Credible Interval. BF_{01} indicates evidence in favor of the null model. Values above 1 are in favor of the null model, and below 1 are in favor of the alternate model.

Figure 1: Correlations of Sighing with Negativity Variable

Note: Values represent point estimate and error bars represent 95% Credible Interval.

Discussion

Contrary to prior literature and strong lay assumptions (Study 1), we did not find a reliable

association between how frequently people sigh in daily life and their level of overall negative emotionality. Bayes factors provided strong evidence in favor of the null hypothesis that daily sighing is not related to overall negative emotionality, using an index of six negative emotionality constructs. Prior research has also suggested that frequent sighing might be a marker of depression symptoms (Robbins et al., 2011). Using a larger, more diverse sample, we did not find a significant association between daily sighing and symptoms of depression or anxiety. In fact, among men, more frequent sighing was associated with slightly lower depressive symptoms—although there was only moderate evidence in favor of this association. Similarly, frequent sighing did not emerge as a reliable indicator of loneliness or experienced stress, and in fact was associated with slightly less loneliness in men. Our results therefore indicate that people who sigh frequently do not experience more symptoms of psychological disorders or discomfort than those who do not.

There was some evidence that people who sigh more frequently report being more fatigued, a result in line with intuition. This result was strong in women and not present in men, but data do not yet support an unambiguous conclusion. As more data are collected using the EAR or other observational methods, we propose that the association between frequent sighing and fatigue should be re-evaluated. It is both intuitive and plausible given the current state of evidence that we might ultimately find that, compared to people who sigh less, those who sigh more also feel more tired.

General Discussion

Sighing frequently is often taken as an indicator that someone is tired, stressed, overwhelmed, or

depressed. In Study 1, we documented the lay assumption that people think of those who sigh more frequently as being higher in negative emotionality. The effect was consistent for every single measure of negative emotionality we used. Previously published evidence, based on the very small sample size of 13 participants, supported this intuitive association between people's sighing frequency and negative emotionality (Robbins et al., 2011). The new evidence we provide in Study 2, however, provides a much more comprehensive and robust empirical test of this strong perceived association. Pooling data across four studies that unobtrusively recorded participants throughout their daily lives, we found no association between daily sighing and overall negative emotionality. The original study establishing a significant negative correlation used a small sample of patients with rheumatoid arthritis, and so represented an unusual, highly specific sample. The present study does include a patient sample (i.e., individuals with cancer) but includes nonpatient samples as well. It therefore represents a more general test but cannot provide a replication estimate for a sample that is comparable to the original study. Because we are using a substantially larger and considerably more representative sample, we can be more confident in the representativeness of our results: counter to common lay beliefs, frequent sighing is not a reliable indicator of negative affect, including levels of depressive symptoms, trait anxiety, loneliness, or experienced stress.

One result stands out as counter-intuitive, and worthy of further exploration: men who sighed more reported being less lonely. This result may indicate a more general phenomenon, such that men who are more expressive in their non-verbal behavior are better able to connect with others. In this explanation, sighing would be taken as a general indicator of expressiveness in men. The effect might be constrained to men due to gender roles, and the general expectation that men are less expressive. Those who can act counter to this stereotype may reap social

benefits. Of course, this is speculation based on seeing these results, and an independent test would be needed to confirm it.

Limitations and Future Directions. One limitation of our study is that we did not continuously record participants, but instead made records from a sample of sounds during the day. It is therefore likely that some sighs were missed. Theoretically, this should only negatively impact our results if this sampling procedure biases our estimate of sighing in some way. The fact that the studies analyzed here used several different sampling schemes, all of which yielded similar overall rates of sighing (1.9% to 4.3%), suggests that there was little bias in these results. However, more definitive research is needed on this question.

One critical limitation of our study is that we examined negative affect exclusively at the trait level rather than at both the between-person and the within-person, that is moment-to-moment, level. Prior research had addressed sighing at the between-person level, reporting on people who sighed more or less frequently. There was good reason to expect that sighing frequently would be associated with negative emotionality (as indicated by the general expectation we documented in Study 1). However, our analyses cannot speak to the hypothesis that, in *times* when individuals experience more negative affect than usual (e.g., momentary sadness, stress, or loneliness), they also tend to sigh more than usual. These between-person and within-person questions are, of course, conceptually and empirically independent (Molenaar & Campbell, 2009).

To address this second theoretically important question we would need a large study that collects two parallel and synchronized time-series: one of naturalistic observations, to determine the objective presence and timing of sighs, and one of subjective negative emotionality (e.g.

surveys at the time of each sigh). Such multi-modal, intensive, ambulatory assessment data are difficult to obtain. However, one study of 52 participants comparing physiological measurement in the lab to physiological measurement found results broadly in line with ours: individuals with panic disorder did not differ from those without this anxiety condition in the breathing variables measured (Pfaltz, Michael, Grossman, Blechert, & Wilhelm, 2009). Multi-modal, intensive longitudinal studies should become more feasible as mobile sensing research advances in its ability to passively and automatically detect objective behaviors and optimizes user interfaces for smartphone-based tracking of subjective experience (Harari et al., 2016; Spathis et al., 2019). We expect that a null association will generalize to further studies examining frequency of sighing in daily life in populations drawn from the U.S., but samples from different cultures or using different methods may identify boundary conditions of this effect.

It is important for creating trustworthy, unbiased scientific literature that all results of hypothesis-testing are reported, including null-findings (Simmons, Nelson, & Simonsohn, 2012). This is particularly true when we have large samples that can give more precise estimates of effect sizes. Although our current results are inconsistent with those previously published, our use of larger, more diverse samples to explore the association between sighing and negative emotionality allows for more confidence in the generalizability of our results. These results help define the scientific boundaries for applying these intuitions and suggest the need for further refinement of key hypotheses, including the association between sighing and fatigue.

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