How Positive Emotions Build Physical Health:
Perceived Positive Social Connections Account for the Upward Spiral
Between Positive Emotions and Vagal Tone

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Abstract

The mechanisms underlying the association between positive emotions and physical health remain a mystery. We hypothesize that an upward spiral dynamic continually reinforces the tie between positive emotions and physical health, mediated by people's perceptions of their positive social connections. We tested this overarching hypothesis in a longitudinal field experiment where participants were randomly assigned to self-generate positive emotions via loving-kindness meditation, or to a monitoring waitlist control group. Intervention participants increased in positive emotions relative to control participants, an effect moderated by baseline vagal tone, a proxy index of physical health. Increased positive emotions, in turn, produced increases in vagal tone, mediated by increased perceptions of social connections. This experimental evidence identifies one mechanism –perceptions of social connections – through which positive emotions build physical health, indexed as vagal tone. Results suggest that positive emotions, positive social connections, and physical health influence one another in a self-sustaining upward spiral dynamic.

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People who experience warm, upbeat emotions live longer and healthier lives. Indeed, prospective evidence connecting positive emotions to physical health and longevity has steadily grown for a decade (for a meta-analysis linking positive emotions to objective health outcomes, see Howell, Kern, & Lyubomirsky, 2007; for one linking positive emotions to mortality, see Chida & Steptoe, 2008). Experiencing frequent positive emotions, for instance, forecasts having fewer colds (Cohen, Alper, Doyle, Treanor, & Turner, 2006), reduced inflammation (Steptoe, O'Donnell, Badrick, Kumari, & Marmot, 2007), and less cardiovascular disease (Boehm & Kubzansky, 2012). Complementing this prospective correlational evidence, a recent longitudinal field experiment designed to test Fredrickson's broaden-and-build theory of positive emotions (1998, in press) found that individuals randomly assigned to self-generate positive emotions reported experiencing fewer headaches and less chest pain, congestion, and weakness (Fredrickson, Cohn, Coffey, Pek & Finkel, 2008). These first causal data lend confidence to the conclusion suggested by prospective correlations: Positive emotions build physical health. Stronger evidence still would come from an experimental manipulation of positive emotions that influenced an objective marker of physical health. Providing such evidence is one aim of the work reported here.

Cardiac vagal tone provides our objective proxy for physical health. Indexed at rest as variability in heart rate associated with respiratory patterns, vagal tone reflects the functioning of

the vagus nerve, the Xth cranial nerve and core component of the parasympathetic nervous system, which regulates heart rate in response to signals of safety and interest (Porges, 2007). Low vagal tone has been linked to high inflammation (Thayer & Sternberg, 2006) and forecasts higher risk for myocardial infarction and decreased odds of survival after heart failure (Bibevski & Dunlap, 2011).

Intriguingly, recent prospective evidence suggests that the causal arrow between positive emotions and physical health may run in the opposite direction as well: Physical health also appears to promote positive emotions. Building on findings that high vagal tone has been associated with superior abilities to regulate one's own emotions (Fabes & Eisenberg, 1997; Thayer, Hansen, Saus-Rose, & Johnson, 2009) and with greater positive emotionality (Oveis, Cohen, Gruber, Shiota, Haidt, & Kelther, 2009), we found that people with higher vagal tone show greater gains over time in their positive emotions (Kok & Fredrickson, 2010). More strikingly, these same data also revealed that those who show greater gains in positive emotions show improvements over time in their vagal tone; in short, positive emotions and vagal tone show the reciprocal influence indicative of an upward spiral dynamic (Kok & Fredrickson, 2010). This prospective evidence not only challenges the view that, in adulthood, vagal tone is a largely stable trait-like attribute (Bornstein & Suess, 2000) but also raises the possibility that changes in habitual emotions may drive changes in vagal tone, and thereby represent one pathway through which emotional health influences physical health.

Still, the causal mechanisms that tie positive emotions specifically to vagal tone and more generally to physical health remain a mystery. We propose here that people's ability to translate their own positive emotions into positive social connections with others may hold one of the keys to solving this mystery. Three lines of evidence support our logic.

First, laboratory experiments provide ample causal evidence that positive emotions promote positive social connections. For instance, people randomly assigned to experience positive emotions show greater social engagement (Isen, 1970), social inclusiveness (Dovidio, Gaertner, Isen & Lowrance, 1995), individuating other-focus (Johnson & Fredrickson, 2005), perspective-taking (Nelson, 2009), self-disclosure (Cunningham, 1988), interpersonal trust (Dunn & Schweitzer, 2005), and compassion (Nelson, 2009). Complementing these laboratory experiments, the same longitudinal field experiment that established a causal link between people's positive emotions and their subsequent self-reported physical health established a similar causal link between positive emotions and perceived positive social connections. Plus, the more time people devoted to generating positive emotions in themselves, the more pleasant their interactions with others became (Fredrickson et al., 2008).

Second, a long-standing corpus of prospective evidence shows that having diverse and rewarding social relationships robustly forecasts physical health and longevity. Indeed, a recent meta-analytic review of 148 studies (representing more than 300,000 individuals) concluded that the influence of social integration on mortality risk is comparable to that of other well-established risk factors, such as smoking, excessive alcohol consumption, obesity, and lack of physical activity (Holt-Lunstad, Smith, & Layton, 2010). For instance, perceiving oneself as enmeshed within a variety of social relationships prospectively predicts reduced susceptibility to cardiovascular disease (e.g., Kaplan et al., 1988), cancer (e.g., Welin, Larsson, Svardsudd, Tibblin, & Tibblin, 1992) and various infections (Cohen, Doyle, Skoner, Rabin, & Gwaltney, 1997). Considerable work has also linked loneliness, or self-perceived lack of social connections, to ill-health and ill-being (for a review, see Hawkley & Cacioppo, 2010), particularly cardiovascular disease.

Third, our focus on positive social connections is further inspired by Porges' (2007) polyvagal theory, which identifies the myelinated vagus as central to the mammalian social engagement system. The vagus nerve, for instance, is anatomically linked to nerves involved in coordinating eye gaze, facial expressivity, and tuning the ear to the frequency of the human voice (Porges, 2007), each critical for social affiliative behavior. Supporting this theory, high vagal tone is associated with more prosocial behavior (Fabes, Eisenberg & Eisenbud, 1993) and social closeness (Kok & Fredrickson, 2010). Moreover, experimental evidence shows greater vagal activation in the presence of supportive versus ambivalent friendships (Holt-Lunstad, Uchino, Smith, & Hicks, 2007) and with intranasal exposure to oxytocin, a key neuropeptide that regulates social engagement (Kemp, Quintana, Kuhnert, Griffiths, Hickie & Guastella, 2012). Perceiving oneself as socially connected is critical to autonomic regulation more generally (Beckes & Coan, 2011). Moreover, consistent with Porges' polyvagal theory, the same study that demonstrated reciprocal prospective ties between positive emotions and vagal tone also demonstrated a similar pattern of reciprocal relations between perceived positive social connections and vagal tone (Kok & Fredrickson, 2010).

Looking across these three separate strands of evidence we see that positive emotions build positive social connections and that compelling data reciprocally link positive social connections both to physical health in general, and to vagal tone in particular. Integrating this evidence, we postulate that a self-sustaining upward spiral dynamic continually reinforces the tie between positive emotions and physical health. Specifically, we posit that vagal tone, by virtue of its association with superior emotion regulation, supports people's abilities to self-generate positive emotions. Positive emotions in turn promote perceived positive social connections, which in turn promote improved physical health, as indexed by increases in vagal tone.

The questions that motivated the current investigation thus include: Can people willfully harness this upward spiral dynamic to steer themselves toward greater physical health? That is, can people's efforts to self-generate positive emotions improve their vagal tone? If so, are perceived positive social connections a mechanism through which this health benefit is achieved? We designed a longitudinal field experiment, spanning more than two months, to budge the proposed upward spiral and test whether and how positive emotions build physical health, indexed objectively as vagal tone. By also including a pretest of vagal tone, we investigate whether this health marker positions people for greater success in self-generating positive emotions and securing attendant benefits.

Figure 1 portrays the conceptual model that unites the three hypotheses articulated below. Although past work has shown reciprocal links between each pair of constructs represented in this spiral model, the novel contribution of the present work is its experimental test of the causal link between positive emotions and improved vagal tone, as mediated by positive social connections.

Hypothesis 1. Individuals with higher vagal tone show greater changes in positive emotions when randomly assigned to positive emotions training.

Hypothesis 2. To the extent that random assignment to positive emotions training produces changes in positive emotions, it also produces increases in perceived positive social connections.

Hypothesis 3. To the extent that random assignment to positive emotions training increases perceived positive social connections, it increases vagal tone. Specifically, changes in positive social connections mediate the impact of experimental condition and increases in positive emotions on increases in vagal tone.

We tested these hypotheses by randomly assigning study volunteers either to learn to self-generate positive emotions through the ancient mind-training practice of *loving-kindness meditation* (LKM), or to serve in a monitoring, waitlist control group. LKM teaches individuals how to cultivate positive emotions toward themselves and others, and past research documents that it increases positive emotions, with attendant improvements in perceived positive social connections and self-reported physical health (Fredrickson et al., 2008).

Method

Participants

Participants were faculty and staff of the University of North Carolina at Chapel Hill (UNC). Recruitment materials referred to the benefits of meditation for relieving stress and pain, but did not specifically mention LKM or anticipated effects on positive emotions or social experiences.

Seventy-one UNC employees gave their consent to participate; six were ultimately excluded, five for failure to attend the meditation workshops and one whose previous meditation experience violated the exclusion criterion. Supplemental online material reports an intent-to-treat analysis incorporating all participants; it yielded a pattern of results identical to those described below.

Of our final 65 participants, 66% were female and 83% were white, with a median age of 37.5 years. Forty-eight percent were married or otherwise in a committed relationship. Chi-square and t-tests did not reveal any significant or marginally significant differences between experimental conditions in gender, race, age, education, income, or marital status.

Loving-kindness Meditation

Loving-kindness meditation (LKM) is a contemplative practice that focuses on self-generating feelings of love, compassion, and goodwill toward oneself and others. Patterning our past work (Fredrickson et al., 2008), the LKM workshop offered in this study was taught by one of the authors (MB), a licensed therapist with training in meditation instruction. Participants attended one hour-long class per week for six weeks. Each class involved guided meditation practice and discussion of how to maintain a meditative practice and how LKM could be helpful in dealing with everyday situations.

Participants were asked to practice meditation at home, ideally daily, but it was made clear that the frequency was up to them. Practice could be self-guided or guided by a recording provided by the instructor. Detailed information on the meditations and workshops is available by request from Mary Brantley (mmbrantley04@gmail.com).

Daily Assessment of Meditation Practice, Emotions, and Social Connection

Each day, for 61 consecutive days, participants reported the amount of time (in minutes) that they engaged in "meditation, prayer, or solo spiritual activity" since the last time they provided a daily report.

They then rated their most powerful experiences of 20 different emotions within the past day, using a 5-point scale (1 = *not at all* to 5 = *extremely*). These included nine positive emotions (i.e., amusement, awe, gratitude, hope, interest, joy, love, pride, and serenity) and eleven negative emotions (i.e., anger, boredom, contempt, disgust, embarrassment, fear, guilt, hatred, sadness, shame, and stress). Daily Cronbach's α coefficients for the nine positive emotion items ranged from 0.89 to 0.97 over the 61 days (mean daily $\alpha = 0.93$, $SD = 0.015$), indicating that, as in past work (Fredrickson et al., 2008), these items cohere into one factor. Accordingly, we averaged these nine items to create a daily positive emotion score ($M = 2.87$, $SE = 0.09$).

Likewise, daily Cronbach's α coefficients for the eleven negative emotion items ranged from 0.75 to 0.93 (mean daily α = 0.86, *SD* = 0.038), so we averaged these eleven items to create a daily negative emotions score (*M* = 1.74, *SE* = 0.06).

Next, participants considered the three social interactions in which they spent the most time that day. They then rated these three interactions in aggregate using 2 items adapted from Russell's UCLA Loneliness scale (1996): "During these social interactions, I felt 'in tune' with the person/s around me" and "During these social interactions, I felt close to the person/s," using a 7-point scale (1= *not at all true*, 7=*very true*). The daily Cronbach's α for these two items ranged from 0.80 to 0.98 (mean daily α = 0.94, *SD* = 0.03). Accordingly, we averaged them to create a daily social connections score (*M*= 4.89, *SE* = 0.15)

Vagal Tone

Vagal tone was assessed using spectral frequency analysis of heart rate data to obtain high-frequency heart rate variability (HF-HRV). Data were collected for two minutes at rest, with continuous recording at 1000 Hz, using disposable snap electrodes in a bipolar configuration on opposite sides of the chest. The raw HR recordings were pre-processed and manually edited to correct for artifacts. Customized software by James Long Company employed discrete Fourier transforms to extract the high frequency components of the heart rate signal (0.12-0.4 Hz) that primarily reflect vagal influences on the heart. To assess stability of measurement, the first and last 60 seconds of the recording were correlated (t1: $r = .77$ $p < .0001$, t2: $r = .90$, $p < .0001$). Analyses were also conducted using a different measure of vagal tone, one based on respiratory sinus arrhythmia (Porges, 2007), a measure that combines heart rate with respiration data. Although the pattern of results for RSA was largely similar, we favor HF-HRV here because overall fit for the hypothesized model was better for HF-HRV than for RSA. Detailed results for

models using RSA are available in online supplementary material.

Procedure

Participants visited our laboratory to provide a baseline measure of vagal tone, then were given access to a secure website daily to report time spent meditating, positive emotions and social connections for nine weeks, spanning a two-week baseline period, random assignment to conditions, the six-week meditation workshop, and one week after the end of the workshop. At the end of the nine weeks, participants made a second and final laboratory visit to provide a second measure of vagal tone.

Results

Hypothesized Model

Preliminary tests, described in supplemental material available online, demonstrated that the experimental intervention (i.e., the LKM workshop) produced increases in positive emotions, perceived social connections, and vagal tone relative to the control group. These analyses, however, do not test the mediational relationships hypothesized to underlie the causal chain among these constructs (Figure 1). A variant of a mediational, parallel process latent curve model (Cheong, MacKinnon, & Khoo, 2003) was used to test the full, hypothesized model. The model was estimated using maximum likelihood estimation and all available data.

In this model (Figure 2), both positive emotions and social connections were modeled as latent curves, with their intercept and slope factors loading on the corresponding weekly composite scores. All intercept factor loadings were fixed to 1, and slope factor loadings were fixed to week in the study, beginning with 0 for the baseline week. In addition, the residual error for each weekly rating of positive emotions was allowed to correlate with the residual error for

that week's rating of social connections, reflecting the within-week relationship between these constructs.

The model produced an RMSEA of 0.078 (CI = 0.056 - 0.098) and CFI of 0.95, placing model fit in the acceptable range. Results supported all three study hypotheses. We provide results for non-hypothesized paths in supplementary online material. Supporting Hypothesis 1, the interaction of experimental condition and baseline vagal tone significantly predicted slope of change in positive emotions (path *e*; $b = 0.043$, $z = 2.63$, $p = 0.009$), indicating that participants in the LKM group who entered the study with higher vagal tone exhibited steeper increases in positive emotions over the course of the study (Figure 3). Supporting Hypothesis 2, slope of change in positive emotions significantly and positively predicted slope of change in social connections (path *h*; $b = 1.04$, $z = 4.12$, $p < 0.001$), as illustrated by Figure 4. Finally, supporting Hypothesis 3, slope of change in social connections in turn positively predicted change in vagal tone (path *k*; $b = 4.90$, $z = 2.14$, $p = 0.03$), and as shown in Figure 5. Thus, participants who reported greater increases in positive emotions over the course of the study, who were mostly the ones randomly assigned to the LKM group, also exhibited greater increases in social connections, which were in turn associated with larger increases in vagal tone.

Alternative Models

To rule out alternative hypotheses we estimated five additional models, the statistical details of which are provided in supplemental on-line material. First, we explored whether the findings could be explained by a reduction in negative emotions rather than an increase in positive emotions. Although experimental condition significantly reduced negative emotions, this was neither predicted by baseline vagal tone, nor predictive of change in vagal tone. Thus, the negative emotions model failed to explain the impact of physical health on participants'

responsiveness to LKM, and LKM's subsequent impact on physical health. Second, we explored whether positive emotions and social connections were interchangeable in the model. Although experimental condition significantly predicted change in social connections and changes in social connections predicted changes in positive emotions, critical paths from and to vagal tone were not significant. As with the negative emotions model, the transposed model failed to link physical health to other critical variables in the model, and did not exhibit the hypothesized meditational paths. Third, we explored whether change in vagal tone might drive the changes in positive emotions and in turn social connections. Although experimental condition significantly predicted change in vagal tone, change in vagal tone did not predict change in positive emotions. Consistent with the limitations identified in the previous alternative models, the third model failed to effectively link all of the constructs as well as the hypothesized upward spiral. Fourth, we explored whether change in positive emotions was a necessary mediator. We discovered that when we prevented positive emotions from mediating, model fit was marginally significantly worse. Similarly, we explored whether change in social connections was a necessary mediator. Here we discovered that when we prevented social connections from mediating, model fit was significantly worse. Thus, models four and five support the importance of positive emotions and social connections as mediators in the model. Taken cumulatively, the alternative models exhibit isolated significant paths, however each model failed to account for the full sequence of relationships as comprehensively as our hypothesized upward spiral model, as represented conceptually in Figure 1 and statistically in Figure 2.

Discussion

These findings document not only that positive emotions build physical health, as indexed objectively as cardiac vagal tone, but also how: We found that people’s perceptions of

their positive social connections with others accounted for the causal link between positive emotions and improved vagal tone. Supporting the conceptual model depicted in Figure 1, the data suggest that positive emotions, positive social connections, and physical health forge an upward spiral dynamic. Baseline vagal tone interacted with experimental condition to predict the degree of success people had in self-generating positive emotions. Greater positive emotions in turn prompted individuals to see themselves as more socially connected. Over time, as moments of positive emotions and positive social connections increased and accrued, vagal tone also improved, building a biological resource that has been linked to numerous health benefits. This upward spiral dynamic has the potential to set individuals on self-sustaining pathways toward growth that can explain the strong empirical associations between positive social and emotional experiences and physical health. Indeed, these findings suggest that habitually-experienced positive emotions may be an essential psychological nutrient for autonomic health.

Vagal theorists have represented vagal tone as a stable, trait-like measure of autonomic regulation associated with various down-stream indicators such as cardiovascular health, social acuity, and superior regulation of cognition, emotions, and physiological systems (Porges, 2007; Thayer & Sternberg, 2006). To our knowledge, these findings the first to show that while vagal tone is largely stable, it can also be improved through sustained enhancements in an individual's emotions and social perceptions.

Strengths of this work include its experimental design, its repeated measures to assess change in targeted constructs, as well as the use of an objective marker of physical health. Limitations include the unique sample of participants motivated for self-improvement and the reliance on one technique, namely loving-kindness meditation, to self-generate positive emotions. Beyond testing how well these findings generalize across other samples, other emotion

change techniques, and other comparison groups, future work could include other objective markers of physical health, other plausible psychological mediators (e.g., broadened awareness, optimism), or objective measures of change in social or health behaviors (Kok, Waugh, & Fredrickson, in press).

Most advice dispensed about how people might improve their physical health calls for increased physical activity, improved nutritional intake, and reductions in tobacco and alcohol use. Alongside this good advice, we now have evidence to recommend efforts to self-generate positive emotions as well. Recurrent momentary experiences of positive emotions appear to serve as nutrients for the human body, increasing feelings of social belonging and giving a needed boost to parasympathetic health, which in turn opens people up to more and more rewarding positive emotional and social experiences. Over time, this self-sustaining upward spiral of growth appears to improve physical health.

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Figures and Captions

Figure 1. Conceptual model describing the relationships among vagal tone, positive emotions, and social connections.

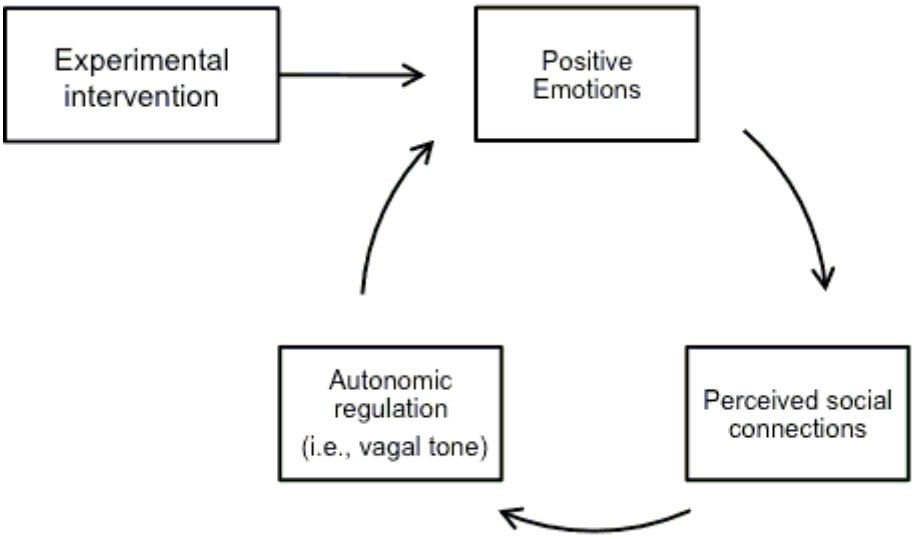

Figure 2. Parallel-process mediational model depicting impact of loving-kindness meditation on positive emotions, positive emotions on social connections, and social connections on vagal tone. Black paths represent hypotheses, solid grey paths represent anticipated significant replications of the literature, dotted grey lines represent anticipated non-significance.

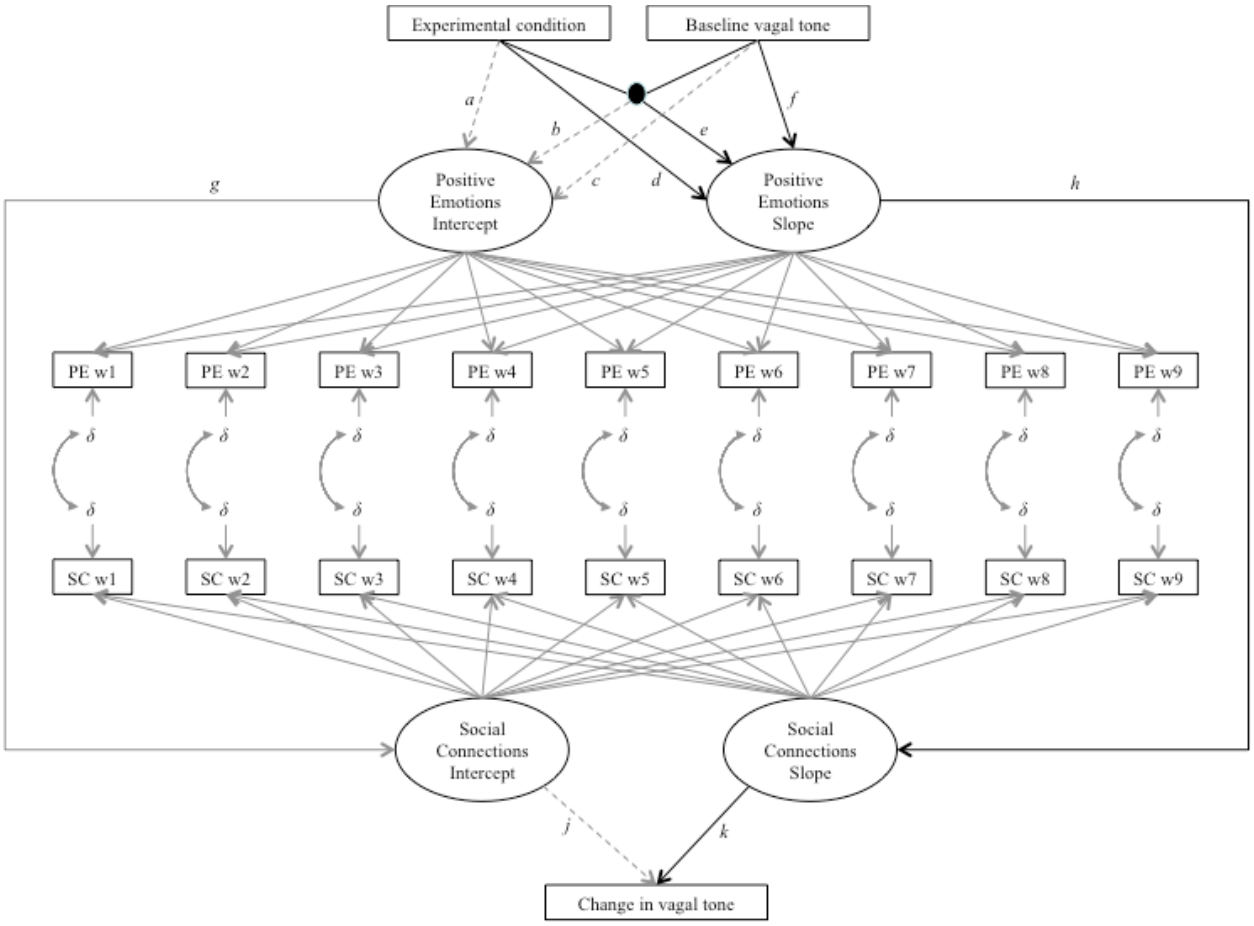

Figure 3. Relationship between baseline vagal tone and change in positive emotions for control and intervention participants. Shaded area represents 95% confidence limits for mean predicted values.

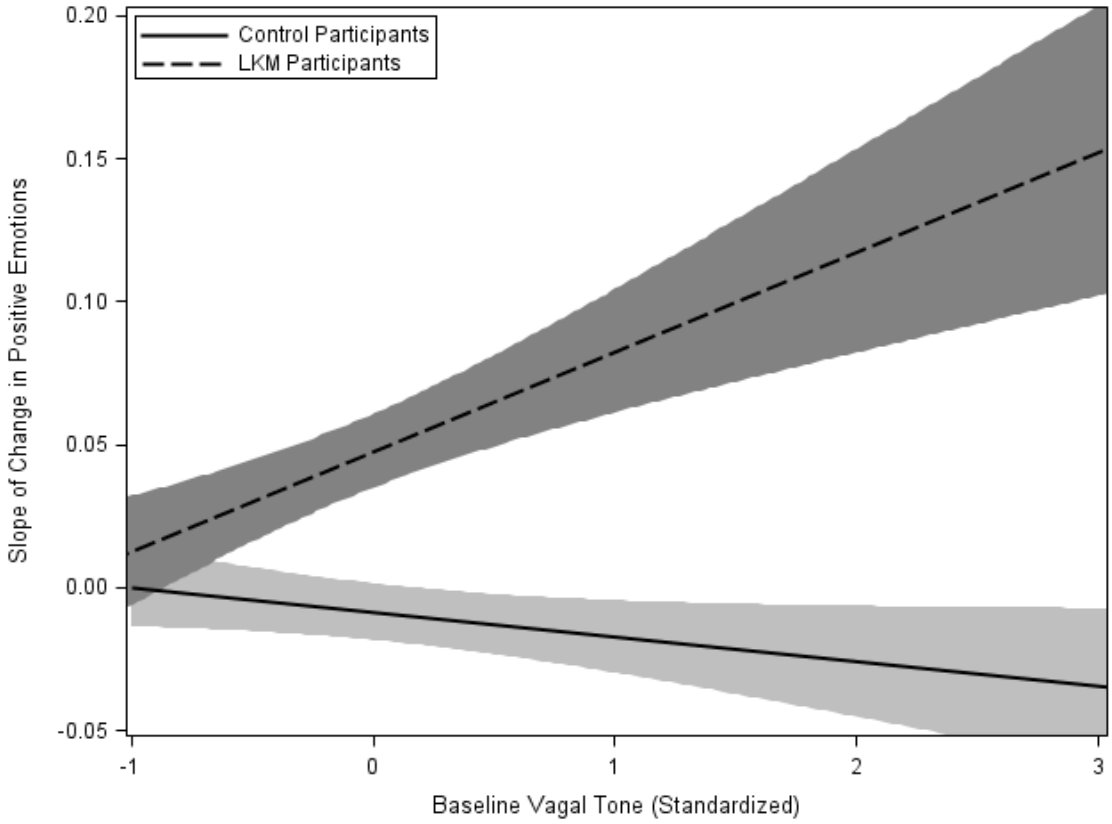

Figure 4. Relationship between change in positive emotions and change in social connections by experimental group. Quartiles represent model-derived slopes.

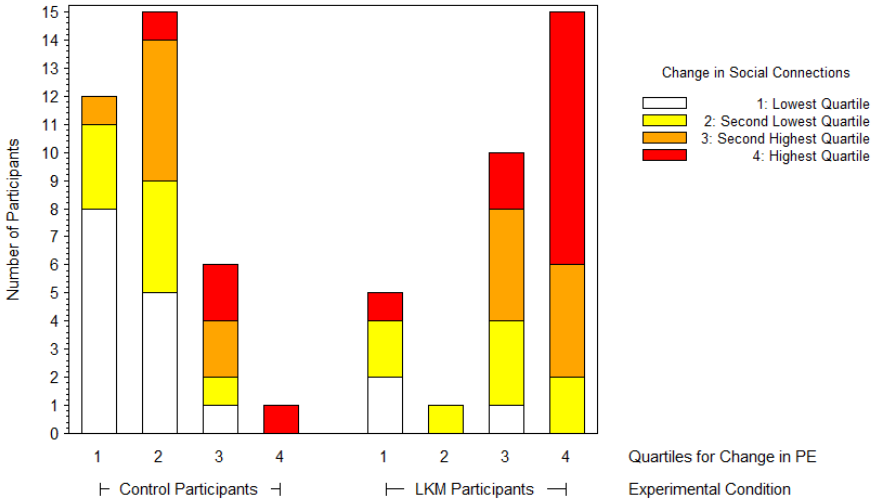

Figure 5. Relationship between change in social connections and change in vagal tone by experimental group. Quartiles represent model-derived slopes.