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Bethany E. Kok[1], Kimberly A. Coffey[1], Michael A. Cohn[2], Lahnna I. Catalino[1], Tanya Vacharkulksemsuk[1], Sara B. Algoe[1], Mary Brantley[3], and Barbara L. Fredrickson[1]

[1]Department of Psychology, University of North Carolina at Chapel Hill; [2]Osher Center for Integrative Medicine, University of California, San Francisco; and [3]Duke Integrative Medicine, Duke Center for Living Campus, Duke University

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 and that this spiral is mediated by people's perceptions of their positive social connections. We tested this overarching hypothesis in a longitudinal field experiment in which participants were randomly assigned to an intervention group that self-generated positive emotions via loving-kindness meditation or to a waiting-list control group. Participants in the intervention group increased in positive emotions relative to those in the control group, an effect moderated by baseline vagal tone, a proxy index of physical health. Increased positive emotions, in turn, produced increases in vagal tone, an effect 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.

Keywords

emotions, social interaction, health, happiness, well-being

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People who experience warmer, more 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 a meta-analysis linking positive emotions to mortality, see Chida & Steptoe, 2008). Experiencing positive emotions more frequently, for instance, forecasts having fewer colds (Cohen, Alper, Doyle, Treanor, & Turner, 2006), reduced inflammation (Steptoe, O'Donnell, Badrick, Kumari, & Marmot, 2007), and lower likelihood of cardiovascular disease (Boehm & Kubzansky, 2012). Complementing this prospective correlational evidence, a recent longitudinal field experiment designed to test Fredrickson's (1998, in press) broaden-and-build theory of positive emotions found that individuals randomly assigned to self-generate positive emotions reported experiencing fewer headaches

Corresponding Authors:

Barbara L. Fredrickson, Department of Psychology, University of North Carolina at Chapel Hill, Davie Hall CB 3270, Chapel Hill, NC 27599-3270
E-mail: blf@unc.edu

Bethany E. Kok, Department of Social Neuroscience, Max Planck Institute for Human Cognitive and Brain Sciences, Stephanstraße 1A, 04103 Leipzig, Germany
E-mail: bethkok@cbs.mpg.de

and less chest pain, congestion, and weakness compared with a control group (Fredrickson, Cohn, Coffey, Pek, & Finkel, 2008). These first causal data lend support to the conclusion suggested by prospective correlations: Positive emotions build physical health. Stronger evidence still would be to find that an experimental manipulation of positive emotions influenced an objective marker of physical health. Providing such evidence was one aim of the work reported here.

Cardiac vagal tone provided 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, which is the 10th cranial nerve and a 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 lower vagal tone forecasts greater risk for myocardial infarction and lower odds of survival after heart failure (Bibevski & Dunlap, 2011).

Intriguingly, recent prospective evidence suggests that the causal link between positive emotions and physical health may run in the opposite direction as well: Physical health 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, & Johnsen, 2009) and with positive emotionality (Oveis et al., 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 people who show greater gains in positive emotions show greater 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 vagal tone in adulthood is a largely stable, traitlike attribute (Bornstein & Suess, 2000), but also raises the possibility that changes in habitual emotions drive changes in vagal tone, and thereby constitute one pathway through which emotional health influences physical health.

Still, the causal mechanisms that tie positive emotions to vagal tone specifically and to physical health more generally remain a mystery. We propose that people's ability to translate their own positive emotions into positive social connections with others may be 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, compared with people in affectively neutral control conditions, 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 more diverse and rewarding social relationships robustly forecasts better physical health and greater 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 in magnitude 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, Svärdsudd, 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 (particularly cardiovascular disease) and ill-being (for a review, see Hawkley & Cacioppo, 2010).

Third, our focus on positive social connections is further inspired by Porges's (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, generating facial expressions, and tuning the ear to the frequency of the human voice (Porges, 2007)—functions that are critical for social affiliative behavior. Supporting this theory, studies have found that higher vagal tone is associated with more prosocial behavior (Fabes, Eisenberg, & Eisenbud, 1993) and social closeness (Kok & Fredrickson, 2010). Moreover, experimental evidence shows that vagal activation is greater in the presence of supportive, compared with ambivalent, friendships (Holt-Lunstad, Uchino, Smith, & Hicks, 2007) and that vagal activation is increased by intranasal exposure to oxytocin, a key neuropeptide that regulates social engagement (Kemp et al., 2012). Perceiving oneself as socially connected is critical to autonomic regulation more generally (Beckes & Coan, 2011). Moreover, consistent with Porges's polyvagal theory, the 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, one sees that positive emotions build positive social connections and that positive social connections are linked reciprocally to both physical health in general and 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 current investigation was motivated by the following questions: 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 2 months, to attempt 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 investigated whether a higher level of 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 we tested. 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 that it experimentally tested the causal link between positive emotions and improved vagal tone, as mediated by positive social connections.

Our hypotheses were as follows:

- 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.

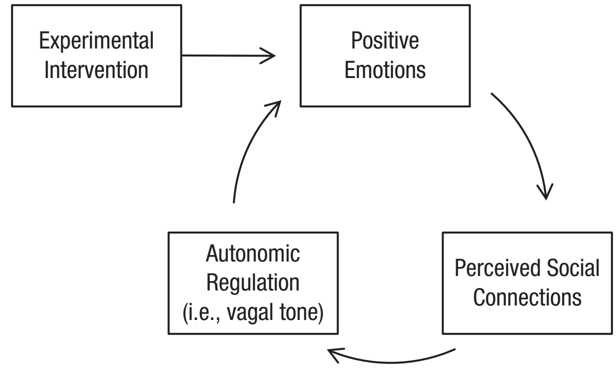

Fig. 1. Conceptual model describing the relationships among the experimental intervention, vagal tone, positive emotions, and social connections.

- 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 assignment to training and increases in positive emotions on 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 waiting-list control group. LKM teaches individuals how to cultivate positive emotions toward themselves and others, and past research has documented that it increases positive emotions, yielding 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. 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 university employees gave their consent to participate; 6 were ultimately excluded, 5 for failure to attend the meditation workshops and 1 for previous meditation experience, which violated the exclusion criterion. The Supplemental Material available online reports an intent-to-treat analysis incorporating all participants; it yielded a pattern of results identical to those described here.

Of our final 65 participants, 66% were female, and 34% were male; the majority (83%) were White. The median age of this sample was 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 the experimental conditions in gender, race, age, education, income, or marital status.

Loving-kindness meditation

LKM is a contemplative practice that focuses on self-generating feelings of love, compassion, and goodwill toward oneself and others. The LKM workshop offered in this study followed the same training as the workshops in our past work (Fredrickson et al., 2008). It was taught by one of the authors (M. B.), a licensed therapist with training in meditation instruction. Participants in the intervention condition attended one hour-long class per week for 6 weeks. Each class involved guided meditation practice, as well as discussion of how to maintain a meditative practice and how LKM can 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.[1] Participants in the control condition were told that they were on a waiting list; after the study ended, they were given the opportunity to receive meditation training from M. B.

Daily assessment of meditation practice, emotions, and social connection

Each day, for 61 consecutive days, participants in both conditions reported the amount of time (in minutes) that they had engaged in "meditation, prayer, or solo spiritual activity" since the last time they had 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*, 5 = *extremely*). These included 9 positive emotions (i.e., amusement, awe, gratitude, hope, interest, joy, love, pride, and serenity) and 11 negative emotions (i.e., anger, boredom, contempt, disgust, embarrassment, fear, guilt, hatred, sadness, shame, and stress). Daily Cronbach's α coefficients for the 9 positive-emotion items ranged from .89 to .97 over the 61 days (M = .93, SD = .015); thus, as in past work (Fredrickson et al., 2008), these items cohered into one factor. Accordingly, we averaged ratings for these 9 items to create a daily positive-emotions score (M = 2.87, SE = 0.09). Likewise, daily Cronbach's α coefficients for the 11 negative-emotion items ranged from .75 to .93 (M = .86, SD = .038), so we averaged ratings for these 11 items to create a daily negative-emotions score (M = 1.74, SE = 0.06).

Next, participants considered the three social interactions in which they had spent the most time that day. They then rated these three interactions in aggregate using two items adapted from Russell's (1996) UCLA Loneliness Scale: "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." Responses were made on a 7-point scale (1 = *not at all true*, 7 = *very true*). The daily Cronbach's α for these two items ranged from .80 to .98 (M = .94, SD = .03). Accordingly, we averaged responses to the items 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 (HR) data to obtain high-frequency heart rate variability (HF-HRV). Data were collected for 2 min 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 preprocessed and manually edited to correct for artifacts. Customized software by James Long Company (Caroga Lake, NY) employed discrete Fourier transforms to extract the high-frequency components of the HR signal (0.12–0.4 Hz) that primarily reflect vagal influences on the heart. To assess stability of measurement, we calculated the correlations between the first and last 60 s of the recording (start of study: r = .77, p < .0001; end of study: r = .90, p < .0001). Analyses were also conducted using a different measure of vagal tone, one based on respiratory sinus arrhythmia (RSA; Porges, 2007), a measure that combines HR with respiration data. Although the pattern of results was largely similar for the two measures, we report results for 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 the Supplemental Material.

Procedure

Participants visited our laboratory for a baseline measure of vagal tone. They were then given access to a secure Web site for daily reporting of time spent meditating, positive emotions, and social connections. Daily reports were made for 9 weeks, spanning a 2-week baseline period, random assignment to conditions, the 6-week meditation workshop, and 1 week after the end of the workshop. At the end of the 9 weeks, participants made a second and final laboratory visit so that we could obtain a second measure of vagal tone.

Results

Hypothesized model

Preliminary tests, described in the 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 condition. These analyses, however, did not test the mediational relationships hypothesized to underlie the causal chain among these constructs (Fig. 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 (Fig. 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 first 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, to reflect the within-week relationship between these constructs.

The model produced a root-mean-square error of approximation of 0.078 (95% confidence interval = [0.056–0.098]) and a comparative-fit index of .95, which placed model fit in the acceptable range. Results supported all

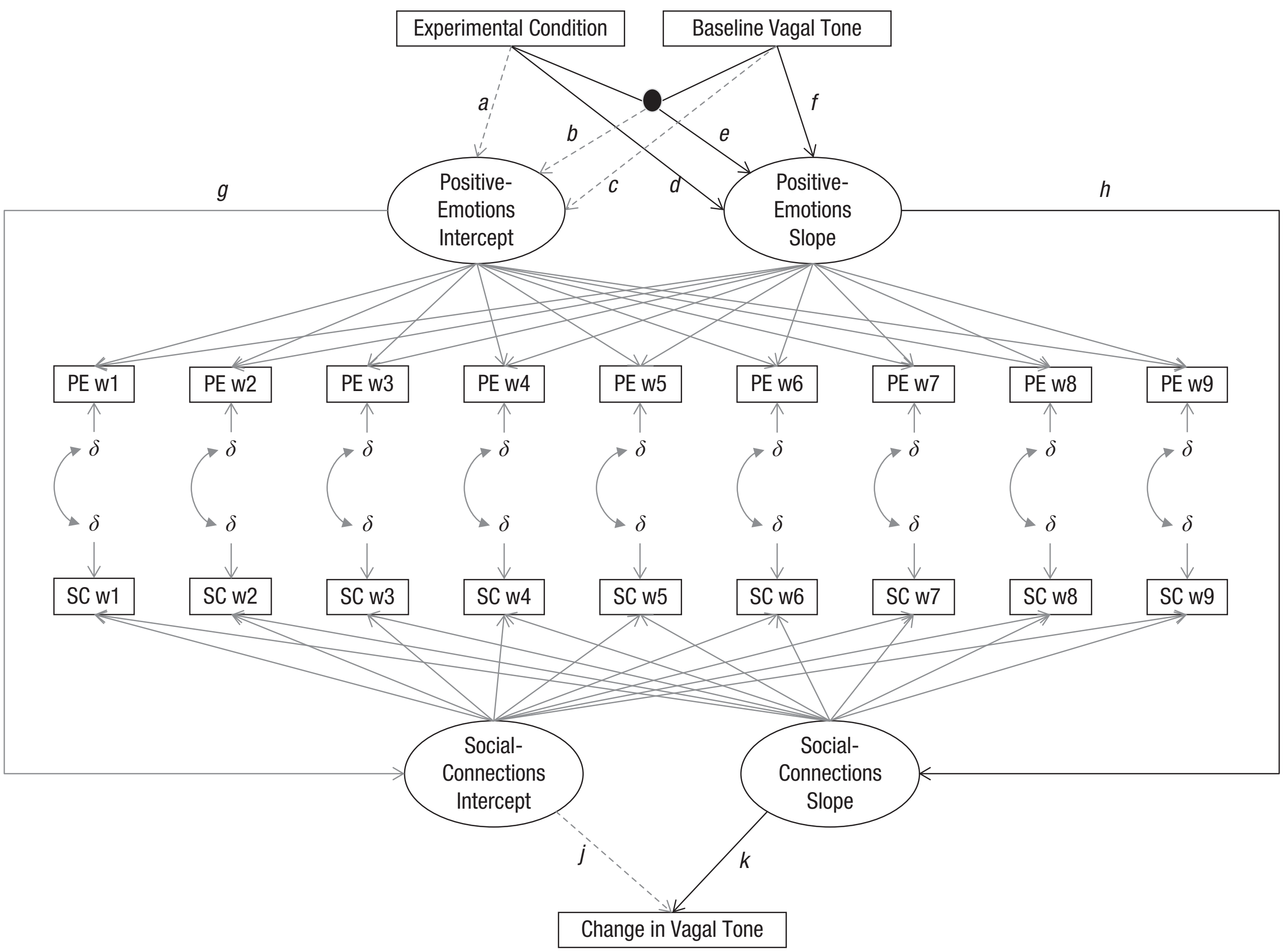

Fig. 2. Parallel-process mediational model depicting the impact of experimental condition (loving-kindness meditation vs. control condition), baseline vagal tone, and their interaction on positive emotions (PE); of PE on social connections (SC); and of SC on vagal tone. Black lines represent hypothesized relationships, solid gray lines represent anticipated significant replications of the literature, and dotted gray lines represent paths expected to be nonsignificant. The labels "w1" through "w9" refer to the 9 weeks of the study. For convenience, paths referred to in this article and in the Supplemental Material are labeled by italicized letters *a* through *j*.

three of our hypotheses. (We provide results for nonhypothesized paths in the Supplemental Material.) As predicted by Hypothesis 1, the interaction of experimental condition and baseline vagal tone significantly predicted slope of change in positive emotions (path *e* in Fig. 2; $b = 0.043$, $z = 2.63$, $p = .009$); in the LKM group, participants who entered the study with higher vagal tone exhibited steeper increases in positive emotions over the course of the study (Fig. 3). As predicted by Hypothesis 2, slope of change in positive emotions significantly and positively predicted slope of change in social connections (path *h* in Fig. 2; $b = 1.04$, $z = 4.12$, $p < .001$; see Fig. 4). Finally, as predicted by Hypothesis 3, slope of change in social connections in turn positively predicted change in vagal tone (path *k* in Fig. 2; $b = 4.90$, $z = 2.14$, $p = .03$; see Fig. 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 the Supplemental Material. First, we explored whether the findings could be explained by a reduction in negative emotions rather than an increase in positive emotions. Although assignment to the intervention condition significantly reduced negative emotions, this effect 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 change in social connections predicted change in positive emotions, critical paths from and to vagal tone were not significant. As was the case with the negative-emotions model, this transposed model failed to link physical health to other critical variables and did not exhibit the hypothesized mediational paths.

Third, we explored whether change in vagal tone might have driven 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. Thus, the third model also failed to effectively link all of the constructs or to demonstrate 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, with our fifth model, we explored whether change in social connections was a necessary mediator. We discovered that when we prevented social connections from mediating, model fit was significantly worse. Thus, the fourth and fifth models support the importance of positive emotions and social connections as mediators in the model.

Taken cumulatively, the alternative models exhibited isolated significant paths. However, none of these models accounted 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.

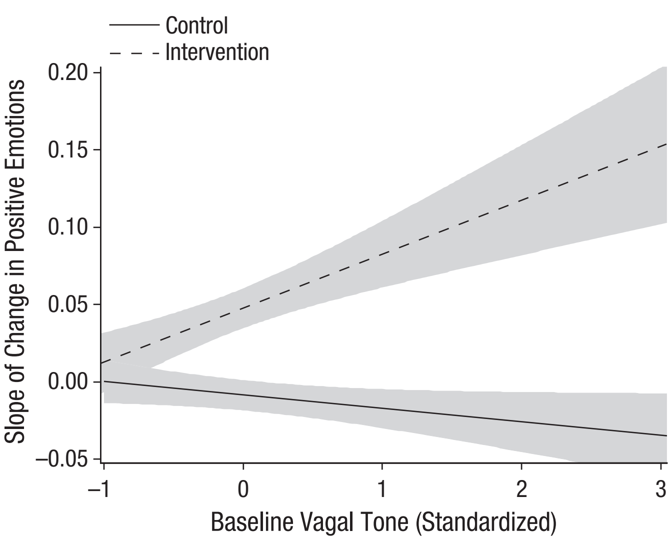

Fig. 3. Relationship between baseline vagal tone and change in positive emotions over the course of the study, for participants in the control and intervention conditions. The shaded areas represent the 95% confidence limits for mean predicted values.

Discussion

These findings document not only that positive emotions build physical health, as indexed objectively by cardiac vagal tone, but also how they do so: 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,

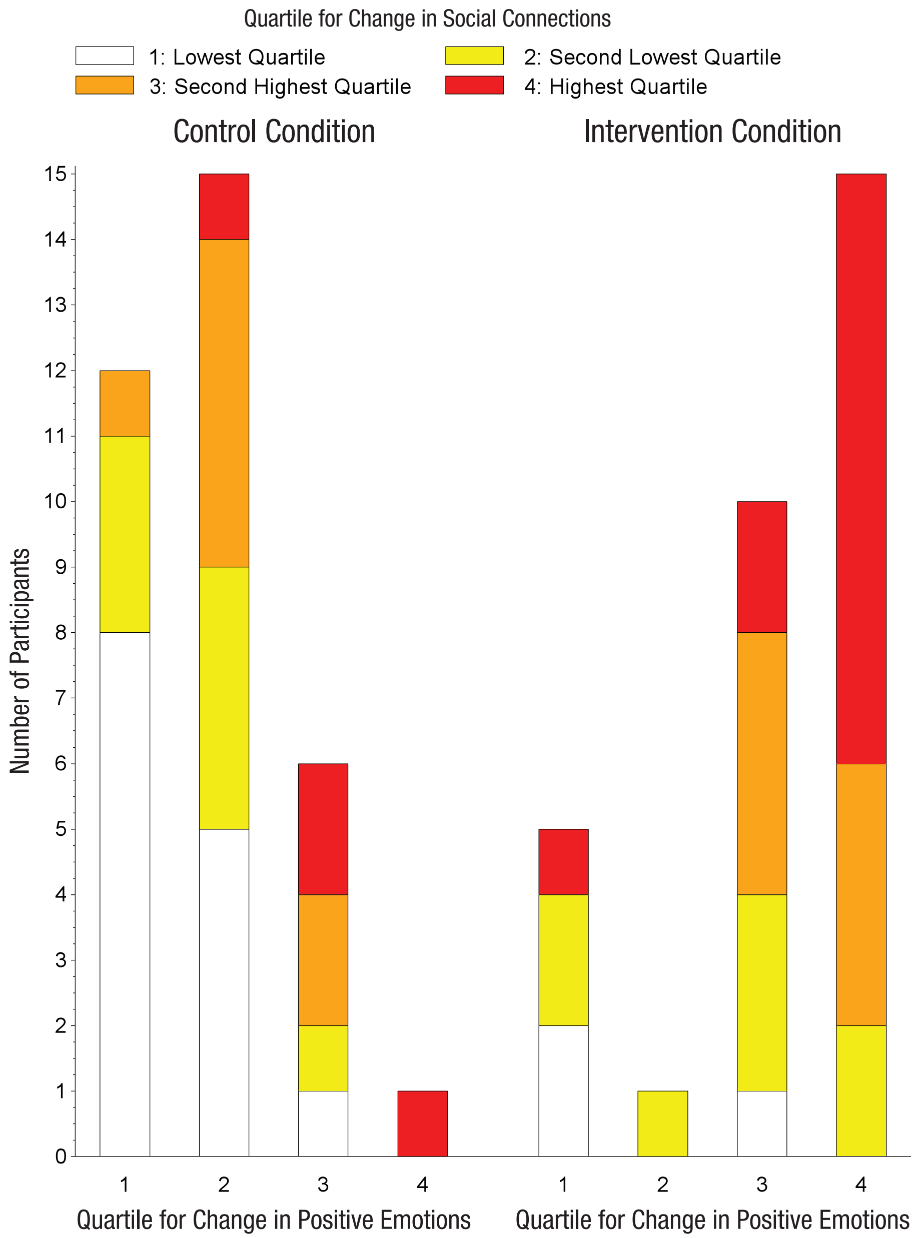

Fig. 4. Distribution of participants in the control and intervention conditions according to their quartiles for change in positive emotions and in social connections over the course of the study. Quartiles represent model-derived slopes and are numbered such that 1 represents the lowest quartile and 4 represents the highest quartile across the sample as a whole.

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, traitlike measure of autonomic regulation associated with various downstream indicators, such as cardiovascular health, social acuity, and regulation of cognition, emotions, and physiological systems (Porges, 2007; Thayer & Sternberg, 2006). To our knowledge, the present findings are the first to show that although vagal tone is largely stable, it can also be improved through sustained enhancements in an individual's emotions and social perceptions.

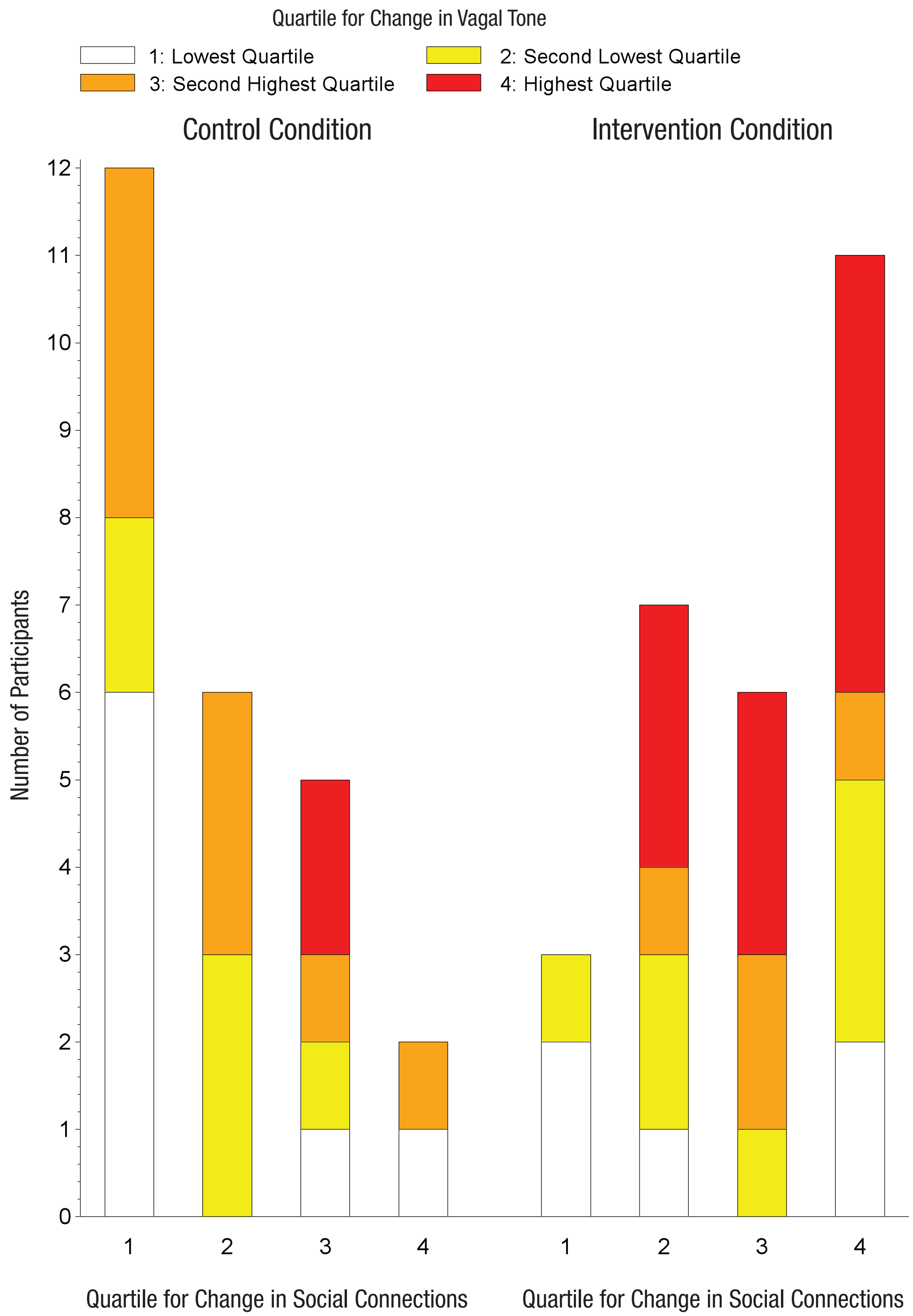

Fig. 5. Distribution of participants in the control and intervention conditions according to their quartiles for change in social connections and in vagal tone over the course of the study. Quartiles represent model-derived slopes and are numbered such that 1 represents the lowest quartile and 4 represents the highest quartile across the sample as a whole.

Strengths of this work include its experimental design, which included 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, LKM, for self-generation of 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 dispensed advice about how people might improve their physical health calls for increased physical activity, improved nutritional intake, and reductions in tobacco and alcohol use. This good advice can now be expanded to include self-generating positive emotions. 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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Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

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Supplemental Material

Additional supporting information may be found at http://pss.sagepub.com/content/by/supplemental-data

Note

1. Detailed information on the meditations and workshops is available by request from Mary Brantley (mmbrantley04@gmail.com).

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