Short-Term Autonomic and Cardiovascular Effects of Mindfulness Body Scan Meditation

Blaine Ditto, Ph.D., Marie Eclache, B.A., and Natalie Goldman, B.A.
Department of Psychology
McGill University

ABSTRACT

Background: *Recent research suggests that the Mindfulness-Based Stress Reduction program has positive effects on health, but little is known about the immediate physiological effects of different components of the program.* ***Purpose:*** *To examine the short-term autonomic and cardiovascular effects of one of the techniques employed in mindfulness meditation training, a basic body scan meditation.* ***Methods:*** *In Study 1, 32 healthy young adults (23 women, 9 men) were assigned randomly to either a meditation, progressive muscular relaxation or wait-list control group. Each participated in two laboratory sessions 4 weeks apart in which they practiced their assigned technique. In Study 2, using a within-subjects design, 30 healthy young adults (15 women, 15 men) participated in two laboratory sessions in which they practiced meditation or listened to an audiotape of a popular novel in counterbalanced order. Heart rate, cardiac respiratory sinus arrhythmia (RSA), and blood pressure were measured in both studies. Additional measures derived from impedance cardiography were obtained in Study 2.* ***Results:*** *In both studies, participants displayed significantly greater increases in RSA while meditating than while engaging in other relaxing activities. A significant decrease in cardiac pre-ejection period was observed while participants meditated in Study 2. This suggests that simultaneous increases in cardiac parasympathetic and sympathetic activity may explain the lack of an effect on heart rate. Female participants in Study 2 exhibited a significantly larger decrease in diastolic blood pressure during meditation than the novel, whereas men had greater increases in cardiac output during meditation compared to the novel.* ***Conclusions:*** *The results indicate both similarities and differences in the physiological responses to body scan meditation and other relaxing activities.*

(**Ann Behav Med** 2006, *32*(3):227–234)

INTRODUCTION

In recent years, the Mindfulness-Based Stress Reduction (MBSR) program has become a popular clinical stress reduction technique (1). It has been used widely in the treatment of medical problems such as chronic pain and cancer as well as psychiatric problems such as anxiety, depression, and panic (2,3) and is finding increasing use in other areas such as cardiovascular disease. That said, the research to date has emphasized clinical trials of the effectiveness of MBSR with diverse medical conditions, as opposed to research on its physiological effects. One important question that has not been studied in detail is whether the physiological effects of this program are any larger or different compared to those of other popular relaxation and stress reduction techniques (4–6). Although the clinical value of MBSR does not hinge on this issue—the specific practices and underlying emphasis on patience, being nonjudgmental, and accepting (1) appeal to many people and may encourage continuation of the program—it is interesting and potentially important to examine the physiological effects of different aspects of MBSR. For example, although there are many similarities in the physiological effects of various forms of meditation, differences have also been observed (e.g., 7). These differences may suggest that some techniques are better suited to certain clinical populations than others. Studies of the physiological effects of different aspects of the MBSR program may also indicate beneficial or less useful components. The study presented here focuses on the short-term effects of an MBSR body scan meditation.

Overall, there is an extensive literature examining the physiological effects of different forms of meditation. The effects of Transcendental Meditation (TM) have been most heavily studied (8–17), but other meditative techniques derived from various Asian traditions have been investigated, as well as the physiological correlates of prayer (7,18–25). Lehrer, Sasaki, and Saito (19) observed a significant decrease in respiration rate and a significant increase in heart rate variability associated with respiration (respiratory sinus arrhythmia, or RSA), as well as a general increase in heart rate variability, among Rinzai and Soto Zen practitioners while they were meditating. Rinzai practitioners breathed more slowly before and during meditation. Bernardi et al. (18) observed similar changes in mantra-based yoga and rosary prayer and an increase in baroreflex sensitivity during these activities. Given the importance of parasympathetic activity (indexed by RSA) an increase in blood-pressure-buffering baroreflex activity might be expected. Peng et al. (7) observed both similarities and differences in the physiological effects of three forms of meditation, two of which involved specific manipulations of breathing patterns. The one that did not specifically attempt to alter respiration still produced a significant decrease in respiration rate, an increase in RSA, and a decrease in the frequency within the heart rate variability spectrum where RSA was observed. Perhaps most interesting, the authors argue that the pattern of heart rate variability results support the idea meditation involves active, arousal-promoting processes as well as relaxing processes (23,26).

This research was supported by a grant from the Heart and Stroke Foundation of Québec.

Reprint Address: B. Ditto, Ph.D., Department of Psychology, McGill University, 1205 Dr. Penfield Avenue, Montreal, QC H3A 1B1, Canada. E-mail: blaine.ditto@mcgill.ca

In this article we describe two studies that examined the short-term autonomic and cardiovascular effects of one technique commonly used in Mindfulness Meditation training, body scan meditation. The focus was on (a) whether body scan meditation produces any reliable physiological changes, (b) whether these changes are any different from those produced by a comparable period of just sitting quietly, and (c) whether these changes are any different from those produced by other relaxing activities such as progressive muscular relaxation or listening to a story. Although Study 1 examined the effects of body scan meditation over 1 month, the possible impact of meditation on physiological activity when one is not meditating was not studied in depth. That is, this research should not be viewed as a randomized controlled trial. Further, it is important to emphasize that only one small part of the MBSR program that was easy to operationalize was studied in our research. On the other hand, a number of results concerning the physiological correlates of body scan meditation are presented.

STUDY 1

Method

Participants. Thirty-two healthy young adults who were interested in learning stress reduction techniques were randomly assigned to either a body scan meditation group (BSM; *n* = 10; 7 women, 3 men), a progressive muscular relaxation group (PMR; *n* = 10; 7 women, 3 men), or a wait-list control group that just sat quietly during the sessions (SIT; *n* = 12; 9 women, 3 men). There were no significant differences between groups in age (*M* = 21.6 ± 2.2 years). None of the participants had previously tried or practiced meditation. In addition to receiving training in stress reduction techniques (those assigned the PMR and SIT groups were offered training in meditation after the study), participants were reimbursed $10 for each laboratory session. They were asked to refrain from exercising and caffeine for 2 hr before the session.

Apparatus. Repeated measurements of blood pressure (in mmHg) were obtained using a Critikon 845XT Dinamap monitor (GE Healthcare, Tampa, FL). The blood pressure cuff was placed on the participant's nondominant arm. Heart rate (in beats per minute [bpm]) and heart rate variability (in log units) were assessed using electrodes attached to opposite sides of the chest, a Grass polygraph, and a Delta-Biometrics Vagal Tone Monitor-II (VTM-II; Delta Biometrics, Bethesda, MD). The vagal tone monitor quantifies RSA using a moving polynomial filter to assess beat-to-beat heart rate variability in the adult respiratory frequency band of .12 to .40 Hz. The moving polynomial reduces the impact of nonstationarity on the signal by acting as a high-pass filter before quantifying RSA. Details of the procedure can be found in Porges and Bohrer (27). Respiratory sinus arrhythmia is a widely used indicator of parasympathetic nervous system activity directed at the heart, that is, vagal tone. Respiration-related variation in heart rate is largely attributable to respiratory modulation of outflow of the vagus nerve (28).

Participants who practiced mindfulness meditation listened to the first portion of the first audiotape in the series used by patients in the Mindfulness-Based Stress Reduction Clinic at the Center for Mindfulness, University of Massachusetts (www.mindfulnesstapes.com). The tape is a guided body scan. Listeners are asked to attend to various parts of their body and their breathing, gently observing these areas and allowing other thoughts to recede. In contrast, participants who practiced progressive muscular relaxation listened to instructions included with Bernstein and Borkovec's manual (29). This classic relaxation technique involves tensing and relaxing of different muscle groups.

Procedure. Individuals participated in two identical laboratory sessions scheduled at the same time of day 4 weeks apart. After attachment of the physiological recording apparatus, they were asked to sit quietly in a comfortable chair for 15 min The experimenter was in a separate room, and the lights were dimmed. Afterward, the BSM group listened to the meditation tape, and the PMR group listened to the PMR tape for 20 min and practiced the techniques. The SIT group was asked to sit quietly for an equal period of time. After 20 min, members of all groups were asked to stop what they were doing, stand up, and stand quietly for 5 min Afterward, they were asked to bend their knees and squat for 3 min These postural changes influence venous return to the heart and baroreflex stimulation and, as a result, can provide a rough estimate of baroreflex sensitivity (30,31).

In the 1-month interval between sessions, participants in the meditation group were given some readings (e.g., sections from Full Catastrophe Living [1]), asked to practice the techniques daily, and asked to attend two group practice/discussion sessions. They were also asked to record their home practice in a daily log. Participants in the PMR group were asked to practice muscle relaxation daily, attend two group practice/discussion sections, and record their practice.

Data analysis. For each session, four means were calculated for each individual's systolic and diastolic blood pressure, heart rate, and RSA measures: baseline (mean for the first 15 min of sitting quietly), treatment (mean for the 20 min they were practicing BSM, PMR, or just sitting), standing, and squatting. To examine the short- and long-term effects of meditation and progressive muscular relaxation, 3 Group (BSM, PMR, SIT) × 2 Time (baseline vs. treatment) × 2 Session (Session 1 vs. Session 2) analyses of variance (ANOVAs) were conducted. The effects of the treatment conditions on response to the postural changes were examined using change scores calculated by subtracting the treatment value from the standing and squatting values. These change scores were then analyzed using 3 Group (BSM, PMR, SIT) × 2 Posture (standing vs. squatting) × 2 Session ANOVAs.

Results

Responses to relaxation. The 3 Group × 2 Time × 2 Session ANOVAs of systolic and diastolic blood pressure values produced no significant effects. There were no group differences in baseline blood pressure. None of the interventions—meditation, progressive muscular relaxation, or just sitting—reduced blood pressure either immediately or over the 1-month period. The only significant effect in the ANOVA of heart rate values was a significant effect of Time, *F*(1, 29) = 14.28, *p* < .001. Heart rate decreased significantly during the 20-min treatment/sitting periods in Session 1 (*M* = –1.8 bpm) and Session 2 (*M* = –2.2 bpm), but the magnitude of change did not vary by group or session.

In contrast, the ANOVA of RSA values produced significant Group × Time, *F*(2, 29) = 4.77, *p* = .016, and Session × Time, *F*(1, 29) = 10.05, *p* = .004, interactions. Although there were no group differences in baseline RSA, planned comparisons revealed that individuals who practiced mindfulness meditation displayed significantly larger baseline to treatment increases in RSA than participants in both the sitting quietly and progressive muscular relaxation conditions in both sessions (Figure 1). The effect did not require extensive practice, that is, it appeared in Session 1 although the results also indicate that BSM produced larger increases in RSA during Session 2, *t*(9) = 2.53, *p* = .032. Similarly, people who practiced PMR, who did not increase RSA during Session 1, exhibited a significant increase in RSA during Session 2, a significantly greater increase than in Session 1, *t*(9) = 4.48, *p* = .002.

Responses to postural change. Although the ANOVAs revealed expected effects of the postural changes on physiological change scores (e.g., increased heart rate and decreased RSA upon standing and decreased heart rate and increased RSA upon squatting), none produced any significant effects involving treatment group. The heart rate ANOVA produced an interesting Session × Posture interaction effect, *F*(1, 27) = 8.06, *p* = .009. This was due to generally greater heart rate responses to the postural changes during the apparently more relaxing Session 2. That is, heart rate increased more upon standing (*M* = 16.3 vs. 13.6 bpm) and decreased more upon squatting (*M* = –12.2 vs. –5.2 bpm) during Session 2.

STUDY 2

In Study 1, respiratory sinus arrhythmia increased significantly during the practice of a mindfulness meditation exercise, more than during comparable periods of sitting quietly and progressive muscular relaxation. Thus, body scan meditation appears to have enhanced an important aspect of parasympathetic nervous system activity more than just sitting quietly and even another popular relaxation procedure. On the other hand, the differences between groups in this study were not widespread. This may have been related to the between-subjects design as well as the modest sample size. As a result, a second study was conducted in which participants served as their own controls. A wider array of autonomic and cardiovascular variables were also assessed via impedance cardiography, and a more balanced group of men and women was recruited.

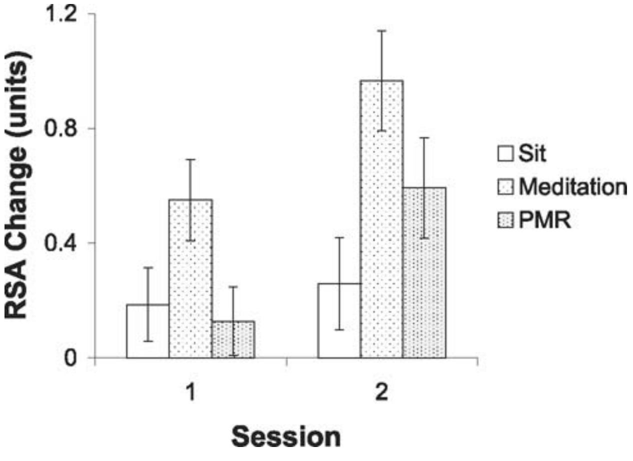

FIGURE 1 Respiratory sinus arrhythmia changes during Study 1 sessions.

Method

Participants. Thirty healthy young adults participated in two laboratory sessions at the same time of day. Fifteen (8 women, 7 men) practiced mindfulness meditation during the first session and listened to a control audiotape during the second session, whereas 15 (7 women, 8 men) sat and listened quietly to the control audiotape during the first session and practiced meditation during the second. The two groups were comparable in age (*M* = 19.2 ± 2.1 years). None of the participants had previously tried or practiced meditation. In addition to receiving training in mindfulness meditation, participants were reimbursed $10 for each laboratory session. They were asked to refrain from exercising and caffeine for 2 hr before the session.

Apparatus. Repeated measurements of blood pressure were obtained using a Critikon 845XT Dinamap monitor. The blood pressure cuff was placed on the participant's nondominant arm. Additional autonomic and cardiovascular measures were obtained using an Ambulatory Impedance Monitor (AIM-8F; Bio-Impedance Technology, Chapel Hill, NC). To assess changes in cardiac stroke volume, the AIM uses a tetrapolar combination of spot and band electrodes. One spot current electrode is placed behind the right ear over the base of the mastoid process. The other spot current electrode is placed over the lower right rib cage below the lower recording band electrode, which encircles the thorax over the tip of the xiphoid process. The other recording band electrode encircles the base of the neck. A third spot electrode is placed over the lower left rib cage. This electrode, along with the two other spot electrodes is used to obtain the ECG signal for the AIM. Cardiac output (CO, in l/min) was calculated as stroke volume × heart rate and total peripheral resistance (TPR, in dyne-sec/cm^5) was calculated as (mean arterial blood pressure / CO) × 80. Impedance-based measures were based on values that were ensemble averaged over 55-sec intervals. Post hoc editing was done using the COPWORKS program.

The AIM also measures cardiac pre-ejection period (PEP). PEP is the cardiac time interval during which the left ventricle contracts while the aortic and mitral valves are closed, measured by the time between ventricular depolarization in the ECG and the upswing in the impedance signal, indicating release of blood into the aorta. PEP is a particularly informative measure as it reflects cardiac contractility and is perhaps the best noninvasive measure of cardiac sympathetic activity (32–35).

During the meditation sessions, virtually identical to those of Study 1, participants listened to the same 20-min segment of meditation instructions. On the other hand, in contrast to the PMR tape used in Study 1, the control audiotape used in Study 2 did not ask participants to practice any form of relaxation. Rather, we were interested in comparing the effects of meditation to those of an activity that was similar in many respects but did not require any form of active participation. Because meditation involved listening to an audiotape of a person speaking in a pleasant, friendly voice, it was decided to have participants listen to a segment of a pleasant audio novel during the control session. As a result, participants listened to the first 20 min of a commercially available tape of J.K. Rowling's *Harry Potter and the Sorcerer's Stone* (36). This section sets the stage for the story and holds the listener's attention but is not one of the more exciting portions.

Procedure. Each individual participated in two laboratory sessions scheduled at the same time of day within 1 week. After attachment of the physiological recording apparatus, they were asked to sit quietly in a comfortable chair for 10 min. The experimenter was in a separate room, and the lights were dimmed. Afterward, people listened to either the Harry Potter (HP) tape or the meditation tape, following instructions. After 20 min of passive listening or practicing meditation, the participants were asked to stop what they were doing and to stand quietly for 3 min. (The standing data in Study 2 were generally uninformative and are not presented.)

Data analysis. For each session, a baseline value was calculated for each dependent measure by averaging values obtained during the second 5 min of the initial 10-min rest period. To examine possible changes in the dependent measures across time somewhat more carefully than in Study 1, four additional values for each measure were calculated reflecting the average values for each 5-min interval during the meditation/listening period.

Several dependent measures were calculated off-line using sequential interbeat intervals measured by the AIM. For consistency with the results from Study 1, estimates of RSA were calculated in the same manner using the VTM-II and averaged as noted earlier. In addition to these values of high-frequency (.12 to .40 Hz) heart rate variability, estimates of low-frequency (.06 to .10 Hz) heart rate variability were also obtained using the VTM-II. Low-frequency heart rate variability is often used as an index of cardiac sympathetic activity. That said, the autonomic origins of low-frequency heart rate variability are more ambiguous, including both sympathetic and parasympathetic activity (37,38), than high-frequency heart rate variability, which is a relatively pure index of cardiac parasympathetic activity.

The heart rate variability data were also used to assess respiration rate. Although direct measures of respiration were not obtained, respiration rate can be assessed using the heart rate variability spectrum (39). Because, by definition, breathing in and out produces variations in heart rate (RSA), the central frequency associated with heart rate variability in the respiratory range reflects the frequency of the phenomenon—respiration—which creates this variability. To identify these frequencies, separate spectral analyses of heart rate variability data within each of the ten 5-min blocks in the study (the 5-min baseline and four 5-min meditation/listening blocks on each day) were conducted with the widely used algorithms recommended by the Task Force of the European Society of Cardiology and the North American Society of Pacing Electrophysiology (40).

Finally, respiration rates obtained during these periods were used for additional analyses of RSA data. A number of researchers have noted that the magnitude of RSA is influenced by not only outgoing vagal activity but variables such as respiratory frequency, depth, and stimulation of oxygen- and carbon-dioxide-sensitive chemoreceptors (28,41,42). In fact, under some conditions the association between RSA and vagal activity can be significantly reduced or entirely obscured (42). Although this occurs to a greater degree under experimental (e.g., exercise) or participant (e.g., hyperventilation) conditions that accentuate changes in these other variables and some investigators have argued that RSA is a good index of vagal activity under most non-stressful conditions (28), the possibility of respiratory changes during meditation suggested an additional analysis of RSA controlling for respiration rate. Following Grossman and Taylor's (41) recommendation that RSA should be corrected for respiration on an idiographic basis, a regression equation for each participant was calculated predicting their RSA values in the ten 5-min blocks from their respiration rates. Respiration-corrected residual RSA scores were then analyzed similar to the other variables.

The effects of meditation and listening were assessed using a series of 2 Session (BSM vs. HP) × 4 Time (5-min block) × 2 Gender ANOVAs of change scores calculated by subtracting the baseline value from the meditation/listening values. The criterion for statistical significance was $p < .05$. Greenhouse-Geisser corrected degrees of freedom were used in repeated measures ANOVAs.

Results

There were no significant effects in the ANOVAs of systolic blood pressure and total peripheral resistance, although systolic blood pressure decreased significantly in the 20-min test periods relative to baseline ($M = 2.2$ mmHg), $t(29) = 3.31$, $p = .002$. The only significant effect in the heart rate ANOVA was a main effect of Time, $F(3, 84) = 41.15$, $p < .001$, indicating continuing heart rate deceleration while people continued to sit quietly meditating or listening to HP. In contrast, as in Study 1, the high-frequency heart rate variability (RSA) ANOVA produced a significant main effect of Session, $F(1, 26) = 11.42$, $p = .002$. Participants displayed greater increases in RSA while they were meditating than listening to HP (Figure 2).

Similarly, the ANOVA of respiration rate produced a significant main effect of Session, $F(1, 27) = 9.92$, $p = .004$, although in the opposite direction. There was no change in respiration rate as participants sat quietly and listened to HP. However, the

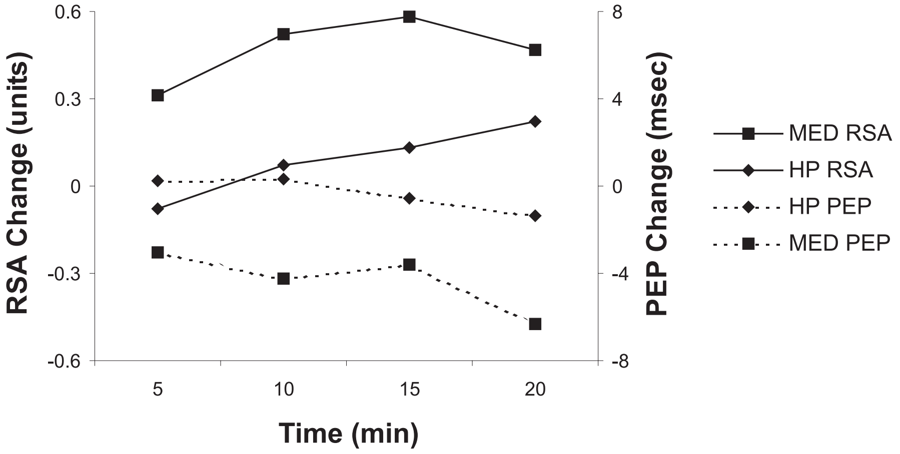

FIGURE 2 Study 2: Respiratory sinus arrhythmia and pre-ejection period changes during Harry Potter (HP) and meditation (MED).

rate decreased significantly during meditation, from a mean of .283 Hz (17.0 breaths/min) during the baseline period to .258 Hz (15.5 breaths/min) during meditation. On the other hand, the ANOVA of the respiration-corrected RSA values indicates that the increases in RSA during meditation cannot be explained entirely by slowed respiration. The ANOVA of respiration-corrected RSA values also produced a significant main effect of Session, *F*(1, 24) = 4.38, *p* = .047, suggesting more vagal activity (higher respiration-corrected RSA) during meditation.

In addition to more high-frequency heart rate variability during meditation, the ANOVA of low-frequency heart rate variability produced a significant main effect of Session, *F*(1, 26) = 8.28, *p* = .008. Participants had greater increases in low-frequency heart rate variability while they were meditating. Interestingly, the PEP also produced a significant main effect of Session, *F*(1, 28) = 6.66, *p* = .015, but in the opposite direction (Figure 2). That is, participants displayed greater decreases in PEP while they were meditating than listening to HP.

Finally, results from the ANOVAs of diastolic blood pressure and cardiac output change scores suggest that some of the effects of meditation may be gender specific. The diastolic blood pressure ANOVA produced a significant Gender × Session interaction, *F*(1, 28) = 6.87, *p* = .014. This was due to significantly greater decreases in diastolic blood pressure among women when they practiced meditation as compared to listening to HP (Figure 3). The ANOVA of cardiac output change scores also produced a significant Gender × Session × Time interaction, *F*(3, 78) = 4.37, *p* = .015. Separate analyses of data from men and women revealed no significant effects among women. However, men displayed a significant increase in CO during the last 5 min of meditation compared to decreased values while listening to HP. An identical pattern of results was obtained in analyses of cardiac output change scores expressed as a percentage premeditation/listening baseline values, which are displayed in Figure 4 for easier comparison with previous results (13,17).

DISCUSSION

These results indicate that a number of physiological changes occur during the practice of body scan meditation. In

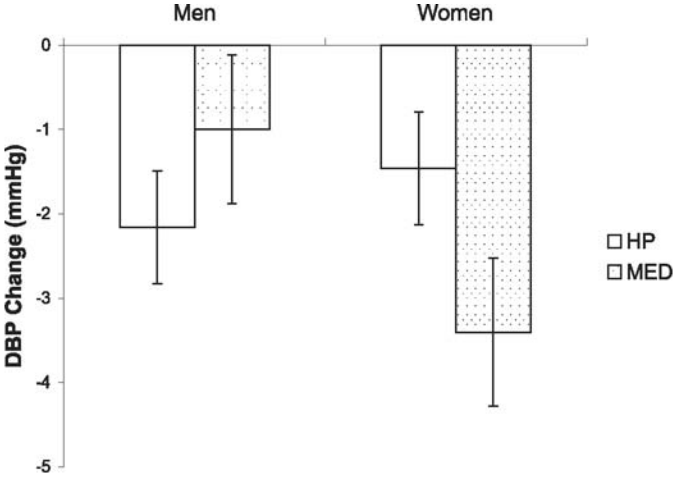

FIGURE 3 Study 2: Diastolic blood pressure changes during Harry Potter (HP) and meditation (MED).

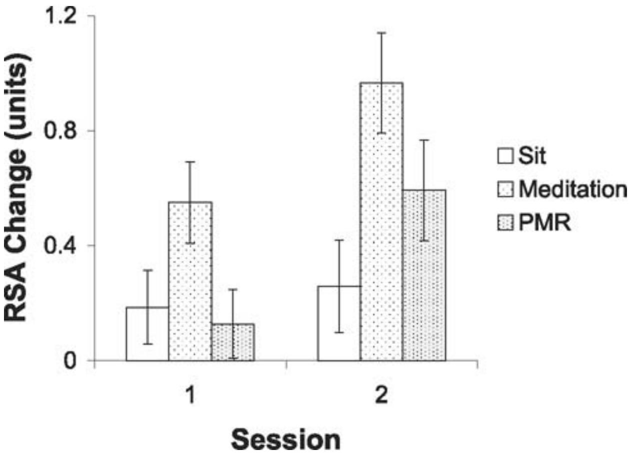

FIGURE 4 Study 2: Cardiac output changes in men during Harry Potter (HP) and meditation (MED).

some cases (e.g., heart rate), the changes were no larger than those produced by other relaxing activities, although significant decreases in these measures were observed. However, the overall pattern of physiological activity produced by this form of meditation is consistent with other forms of meditation, and at least somewhat distinct from the patterns produced by other forms of relaxation.

Consistent with the results of several studies examining changes in heart rate variability associated with meditation (7,18,19,24,25), large (at least in relation to the other interventions) and reliable increases in cardiac respiratory sinus arrhythmia were observed. Participants who practiced meditation in Study 1 displayed significantly greater increases in RSA in Session 1 compared to those who sat quietly *and* those who practiced the classic relaxation technique of progressive muscular relaxation. The effect was replicated in Study 2. Although additional training and practice in meditation between the first and second sessions of Study 1 were modest, participants displayed significantly greater increases in RSA after 1 month. This appears to have been related to practicing meditation or relaxation. Participants in the PMR group also showed greater increases in RSA in Session 2 than Session 1, although not as large as those in the BSM group. These differences cannot be attributed to participants feeling more at ease during Session 2 than Session 1 because the no-treatment control participants did not show greater increases in RSA during Session 2. These results suggest that meditation might be particularly beneficial vis-à-vis progressive muscle relaxation for hypertensives and cardiac patients, who often display reduced cardiac vagal activity (43–46). In fact, although they used TM rather than the MBSR program, Schneider and colleagues have observed significantly greater decreases in blood pressure in hypertensives who were taught TM versus progressive muscle relaxation in several studies (11,47). Furthermore, in a recent follow-up study combining the results from two randomized controlled trials, they observed a significant reduction in cardiovascular mortality in those who learned TM (48). The belief that meditation produced an impact on vagal activity in our research is strengthened by the fact that a significant effect of meditation on RSA was observed even after correction for respiration rate. Using similar statistical procedures, Grossman et al. (42) observed close correspondence across a number of experimental conditions between changes in respiration-corrected RSA values and changes in heart rate following beta-adrenergic blockade.

Of all the results, the PEP findings are probably the most distinctive. Although the reductions in PEP during meditation might seem to suggest greater relaxation, increases in cardiac sympathetic activity produce *decreases* in PEP (32–35). Several previous studies have noted signs of increased arousal in some peripheral measures during meditation, but this has usually been linked to more "transcendent" periods of meditation or more meditation experience. For example, Kubota et al. (25) observed increases in both cardiac parasympathetic and sympathetic activity in Zen meditation during periods of high frontal midline theta EEG activity. Peng et al. (7) found a significant increase in low-frequency heart rate variability in experienced practitioners of Kundalini yoga during meditation. The PEP data complement and help clarify the meaning of the low-frequency heart rate variability results. As noted before, low-frequency heart rate variability reflects parasympathetic as well as sympathetic activity in most nonmeditative states (36,37) and is probably even more confounded during meditation due to a decrease in respiration rate that shifts parasympathetically mediated RSA to a lower frequency (7,19), although this issue may not have been as severe in our research given the modest reduction in breathing during meditation, which still left respiration rate (.258 Hz) well within typical respiratory frequencies. Nevertheless, the PEP findings provide additional evidence suggesting that meditation may sometimes produce an increase in cardiac sympathetic activity. This is further supported by the observation of increased cardiac output among men during meditation in Study 2. Similar effects on cardiac output have been observed during TM (13,17). PEP is associated with cardiac contractility. Thus, increased cardiac sympathetic activity might increase cardiac output even in the absence of an effect of meditation on heart rate. An increase in cardiac sympathetic activity may also explain the absence of an effect of meditation on heart rate in our research, consistent with the findings of a number of investigators (7,13,17,19). That is, increased cardiac sympathetic activity may buffer the impact of the effect of meditation on cardiac parasympathetic activity, reducing the likelihood of heart rate change. This would not negate potential therapeutic effects of meditation, although it points to the complexity of the issue and the importance of not viewing meditation as simply a state of rest (49).

Clearly, one important limitation of this research was the absence of direct measures of respiration. This was related in part to our desire to employ an ambulatory impedance monitor in Study 2. However, although not optimal, assessment of respiration rate using heart rate variability is theoretically sound and has some empirical justification. For example, Thayer and colleagues (38) recently observed high correlations between measures of respiration rate obtained via analyses of heart rate variability and more conventional strain gauge measures. Nevertheless, more direct and detailed assessment of respiration in future research will help clarify the autonomic and other physiological changes produced by meditation. The research was also limited by modest samples in both Studies 1 and 2. The reduction in power probably limited the ability to detect treatment effects in both studies. For example, although Study 1 was not conceptualized as a randomized controlled trial, it is possible that larger groups might have revealed significant effects of the practice of meditation over time. In a recent study using a similar beginning technique of the MBSR program, Barnes et al. (50) observed relative reductions in resting and ambulatory blood pressure among 34 middle-school students who practiced meditation at school and at home for 3 months compared to 39 students in a control group. Although the within-subjects methodology may have reduced the impact of the modest sample size in Study 2, this was offset to some degree by the presentation of the two conditions on different days. Within-subjects variability in the physiological measures could have arisen from many sources, including variability inherent in the impedance methodology due to electrode placement, skin characteristics, and so forth (51).

Another limitation of the research is that the participants did not include experienced meditators. It is likely that some of the physiological effects of meditation are accentuated by practice and others that are not observed in beginners become manifest. This belief is consistent with the results of Study 1, where greater increases in RSA were observed in the BSM and PMR groups after a month. On the other hand, most medical patients who are enrolled in MBSR programs have no prior experience with meditation. The results we present are encouraging in that they suggest certain immediate physiological effects and hold promise for further change (although the fact that the participants were young, healthy nonmeditators requires, in turn, further qualification of the results—the question of whether these results generalize to older, less healthy individuals awaits future research). Finally, it is important to emphasize once again that only one small part of the MBSR program that was easy to operationalize was studied in our research. We cannot comment on the short- or long-term physiological effects of other aspects of the program. Indeed, there is some reason to suspect that our results may not be entirely generalizable to the rest of the program. The body scan technique requires focus on a specific object, which differs from other MBSR techniques like insight mindfulness meditation. This may have increased the likelihood of observing a pattern of physiological activity that is generally consistent with that observed during other forms of meditation involving a relaxed focus such as TM. Regardless, our results suggest that an interesting pattern of physiological activity is produced by body scan meditation that is somewhat distinct from changes produced by nonmeditation relaxation. Studies of the short- and long-term physiological effects of different aspects of the MBSR program may inform and contribute to the literature on its clinical effects.

REFERENCES

(1) Kabat-Zinn J: *Full Catastrophe Living: Using the Wisdom of Your Body and Mind to Face Stress, Pain and Illness*. New York: Delacourt, 1990.

(2) Bishop SR: What do we really know about mindfulness-based stress reduction? *Psychosomatic Medicine*. 2002, *64:*71–83.

(3) Grossman P, Niemann L, Schmidt S, Walach H: Mindfulness-based stress reduction and health benefits. A meta-analysis. *Journal of Psychosomatic Research.* 2004, *57:*35–43.

(4) Robert McComb JJ, Tacon A, Randolph P, Caldera Y: A pilot study to examine the effects of a mindfulness-based stress-reduction and relaxation program on levels of stress hormones, physical functioning, and submaximal exercise responses. *Journal of Alternative and Complementary Medicine.* 2004, *10:*819–827.

(5) Carlson LE, Speca M, Patel KD, Goodey E: Mindfulness-based stress reduction in relation to quality of life, mood, symptoms of stress and levels of cortisol, dehydroepiandrosterone sulfate (DHEAS) and melatonin in breast and prostate cancer outpatients. *Psychoneuroendocrinology.* 2004, *29:*448–474.

(6) Robinson FP, Mathews HL, Witek-Janusek L: Psycho-endocrine-immune response to mindfulness-based stress reduction in individuals infected with the human immunodeficiency virus: A quasiexperimental study. *Journal of Alternative and Complementary Medicine.* 2003, *9:*683–694.

(7) Peng CK, Henry IC, Mietus JE, et al.: Heart rate dynamics during three forms of meditation. *International Journal of Cardiology.* 2004, *95:*19–27.

(8) Delmonte MM: Physiological responses during meditation and rest. *Biofeedback and Self-Regulation.* 1984, *9:*181–200.

(9) Barnes VA, Treiber FA, Davis H: Impact of Transcendental Meditation on cardiovascular function at rest and during acute stress in adolescents with high normal blood pressure. *Journal of Psychosomatic Research.* 2001, *51:*597–605.

(10) Barnes VA, Treiber FA, Johnson MH: Impact of transcendental meditation on ambulatory blood pressure in African-American adolescents. *American Journal of Hypertension.* 2004, *17:*366–369.

(11) Schneider RH, Alexander CN, Staggers F, et al.: A randomized controlled trial of stress reduction in African Americans treated for hypertension for over one year. *American Journal of Hypertension.* 2005, *18:*88–98.

(12) Travis F, Olson T, Egenes T, Gupta HK: Physiological patterns during practice of the Transcendental Meditation technique compared with patterns while reading Sanskrit and a modern language. *International Journal of Neuroscience.* 2001, *109:*71–80.

(13) Barnes VA, Treiber FA, Turner JR, Davis H, Strong WB: Acute effects of transcendental meditation on hemodynamic functioning in middle-aged adults. *Psychosomatic Medicine.* 1999, *61:*525–531.

(14) Throll DA: Transcendental meditation and progressive relaxation: Their physiological effects. *Journal of Clinical Psychology.* 1982, *38:*522–530.

(15) Wallace RK: Physiological effects of transcendental meditation. *Science.* 1970, *167:*1751–1754.

(16) Woolfolk RL: Psychophysiological correlates of meditation. *Archives of General Psychiatry.* 1975, *32:*1326–1333.

(17) Jevning R, Wilson AF, Smith WR, Morton ME: Redistribution of blood flow in acute hypometabolic behavior. *American Journal of Physiology.* 1978, *235:*R89–R92.

(18) Bernardi L, Sleight P, Bandinelli G, et al.: Effect of rosary prayer and yoga mantras on autonomic cardiovascular rhythms: Comparative study. *British Medical Journal.* 2001, *323:*1446–1449.

(19) Lehrer P, Sasaki Y, Saito Y: Zazen and cardiac variability. *Psychosomatic Medicine.* 1999, *61:*812–821.

(20) Arambula P, Peper E, Kawakami M, Gibney KH: The physiological correlates of Kundalini Yoga meditation: A study of a yoga master. *Applied Psychophysiology and Biofeedback.* 2001, *26:*147–153.

(21) Lee MS, Kim BG, Huh HJ, et al.: Effect of Qi-training on blood pressure, heart rate and respiration rate. *Clinical Physiology.* 2000, *20:*173–176.

(22) Schmidt T, Wijga A, Von Zur Muhlen A, Brabant G, Wagner TO: Changes in cardiovascular risk factors and hormones during a comprehensive residential three month kriya yoga training and vegetarian nutrition. *Acta Physiologica Scandanavica.* 1997, *640*(Suppl.):158–162.

(23) Corby JC, Roth WT, Zarcone Jr. VP, Kopell BS: Psychophysiological correlates of the practice of Tantric Yoga meditation. *Archives of General Psychiatry.* 1978, *35:*571–577.

(24) Takahashi T, Murata T, Hamada T, et al.: Changes in EEG and autonomic nervous activity during meditation and their association with personality traits. *International Journal of Psychophysiology.* 2005, *55:*199–207.

(25) Kubota Y, Sato W, Toichi M, et al.: Frontal midline theta rhythm is correlated with cardiac autonomic activities during the performance of an attention demanding meditation procedure. *Cognitive Brain Research.* 2001, *11:*281–287.

(26) Jevning R, Wallace RK, Beidebach M: The physiology of meditation: A review. A wakeful hypometabolic integrated response. *Neuroscience and Biobehavioral Reviews.* 1992, *16:*415–424.

(27) Porges SW, Bohrer RE: The analysis of periodic processes in psychophysiological research. In Cacioppo JT, Tassinary IG (eds), *Principles of Psychophysiology.* Cambridge, UK: Cambridge University Press, 1990, 708–753.

(28) Houtveen JH, Rietveld S, de Geus EJ: Contribution of tonic vagal modulation of heart rate, central respiratory drive, respiratory depth, and respiratory frequency to respiratory sinus arrhythmia during mental stress and physical exercise. *Psychophysiology.* 2002, *39:*427–436.

(29) Bernstein D, Borkovec, TD: *Progressive Relaxation Training: A Manual for the Helping Professions*. Champaign, IL: Research Press, 1973.

(30) Rickards CA, Newman DG: A comparative assessment of two techniques for investigating initial cardiovascular reflexes under acute orthostatic stress. *European Journal of Applied Physiology.* 2003, *90:*449–457.

(31) Hanson P, Slane PR, Rueckert PA, Clark SV: Squatting revisited: Comparison of haemodynamic responses in normal individuals and heart transplantation recipients. *British Heart Journal.* 1995, *74:*154–158.

(32) Burgess HJ, Penev PD, Schneider R, Van Cauter E: Estimating cardiac autonomic activity during sleep: Impedance cardiography, spectral analysis, and Poincare plots. *Clinical Neurophysiology.* 2004, *115:*19–28.

(33) Newlin DB, Levenson RW: Pre-ejection period: Measuring beta-adrenergic influences upon the heart. *Psychophysiology.* 1979, *16:*546–553.

(34) Sherwood A, Allen MT, Obrist PA, Langer AW: Evaluation of beta-adrenergic influences on cardiovascular and metabolic adjustments to physical and psychological stress. *Psychophysiology.* 1986, *23:*89–104.

(35) Berntson GG, Cacioppo JT, Binkley PF, et al.: Autonomic cardiac control. III. Psychological stress and cardiac response in autonomic space as revealed by pharmacological blockades. *Psychophysiology.* 1994, *31:*599–608.

(36) Rowling JK: *Harry Potter and the Sorcerer's Stone* [audiotape]. New York: Listening Library, 1999.

(37) Akselrod S, Gordon D, Ubel FA, et al.: Power spectrum analysis of heart rate fluctuation: A quantitative probe of beat-to-beat cardiovascular control. *Science.* 1981, *213:*220–222.

(38) Appel ML, Berger RD, Saul JP, Smith JM, Cohen RJ: Beat to beat variability in cardiovascular variables: Noise or music? *Journal of the American College of Cardiology.* 1989, *14:*1139–1148.

(39) Thayer JF, Sollers III JJ, Ruiz-Padial E, Vila J: Estimating respiratory frequency from autoregressive spectral analysis of heart period. *IEEE Engineering in Medicine and Biology Magazine.* 2002, *21:*41–45.

(40) Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology: Heart rate variability: Standards of measurement, physiological interpretation and clinical use. *Circulation.* 1996, *93:*1043–1065.

(41) Grossman P, Taylor EW: Toward undersanding respiratory sinus arrhythmia: Relations to cardiac vagal tone, evolution and biobehavioral functions. *Biological Psychology.* 2006, in press.

(42) Grossman P, Karemaker J, Wieling W: Prediction of tonic parasympathetic cardiac control using respiratory sinus arrhythmia: The need for respiratory control. *Psychophysiology.* 1991, *28:*201–216.

(43) Blumenthal JA, Sherwood A, Babyak MA, et al.: Effects of exercise and stress management training on markers of cardiovascular risk in patients with ischemic heart disease: A randomized controlled trial. *Journal of the American Medical Association.* 2005, *293:*1626–1634.

(44) La Rovere MT, Bigger Jr. JT, Marcus FI, Mortara A, Schwartz PJ: Baroreflex sensitivity and heart-rate variability in prediction of total cardiac mortality after myocardial infarction. ATRAMI (Autonomic Tone and Reflexes After Myocardial Infarction) Investigators. *Lancet.* 1998, *351:*478–484.

(45) Liao D, Cai J, Barnes RW, et al.: Association of cardiac autonomic function and the development of hypertension: The ARIC study. *American Journal of Hypertension.* 1996, *9:*1147–1156.

(46) Singh JP, Larson MG, Tsuji H, et al.: Reduced heart rate variability and new-onset hypertension: Insights into pathogenesis of hypertension: The Framingham Heart Study. *Hypertension.* 1998, *32:*293–297.

(47) Schneider RH, Staggers F, Alexander CN, et al.: A randomised controlled trial of stress reduction for hypertension in older African Americans. *Hypertension.* 1995, *26:*820–827.

(48) Schneider RH, Alexander CN, Staggers F, et al.: Long-term effects of stress reduction on mortality in persons ≥55 years of age with systemic hypertension. *American Journal of Cardiology.* 2005, *95:*1060–1064.

(49) Holmes DS, Solomon S, Cappo BM, Greenberg JL: Effect of Transcendental Meditation versus resting on physiological and subjective arousal. *Journal of Personality and Social Psychology.* 1983, *44:*1245–1252.

(50) Barnes VA, Davis HC, Murzynowski JB, Treiber FA: Impact of meditation on resting and ambulatory blood pressure and heart rate in youth. *Psychosomatic Medicine.* 2004, *66:*909–914.

(51) Barnes VA, Johnson MH, Treiber FA: Temporal stability of twenty-four-hour ambulatory hemodynamic bioimpedance measures in African American adolescents. *Blood Pressure Monitoring.* 2004, *9:*173–177.