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Enhanced Response Inhibition During Intensive Meditation Training Predicts Improvements in Self-Reported Adaptive Socioemotional Functioning

Baljinder K. Sahdra, Katherine A. MacLean, Emilio Ferrer, Phillip R. Shaver, Erika L. Rosenberg, Tonya L. Jacobs, Anthony P. Zanesco, Brandon G. King, and Stephen R. Aichele
University of California, Davis

David A. Bridwell
University of California, Irvine

George R. Mangun
University of California, Davis

Shiri Lavy
Ariel University Center, Israel

B. Alan Wallace
Santa Barbara Institute for Consciousness Studies

Clifford D. Saron
University of California, Davis

We examined the impact of training-induced improvements in self-regulation, operationalized in terms of response inhibition, on longitudinal changes in self-reported adaptive socioemotional functioning. Data were collected from participants undergoing 3 months of intensive meditation training in an isolated retreat setting (Retreat 1) and a wait-list control group that later underwent identical training (Retreat 2). A 32-min response inhibition task (RIT) was designed to assess sustained self-regulatory control. Adaptive functioning (AF) was operationalized as a single latent factor underlying self-report measures of anxious and avoidant attachment, mindfulness, ego resilience, empathy, the five major personality traits (extroversion, agreeableness, conscientiousness, neuroticism, and openness to experience), difficulties in emotion regulation, depression, anxiety, and psychological well-being. Participants in Retreat 1 improved in RIT performance and AF over time whereas the controls did not. The control participants later also improved on both dimensions during their own retreat (Retreat 2). These improved levels of RIT performance and AF were sustained in follow-up assessments conducted approximately 5 months after the training. Longitudinal dynamic models with combined data from both retreats showed that improvement in RIT performance during training influenced the change in AF over time, which is consistent with a key claim in the Buddhist literature that enhanced capacity for self-regulation is an important precursor of changes in emotional well-being.

Keywords: meditation, response inhibition, self-regulation of emotion and behavior, adaptive functioning, dynamic modeling

A growing body of Western psychological research has drawn on meditative traditions to better understand compassion (Lutz, Greischar, Perlman, & Davidson, 2009), self-compassion (Leary, Tate, Adams, Batts Allen, & Hancock, 2007; Neff, 2003), mindfulness (Baer, Smith, Hopkins, Krietemeyer, & Toney, 2006), loving-kindness (Fredrickson, Cohn, Coffey, Pek, & Finkel, 2008), accep-

Baljinder K. Sahdra, Katherine A. MacLean, Emilio Ferrer, Phillip R. Shaver, Stephen R. Aichele, and George R. Mangun, Department of Psychology, University of California, Davis; Baljinder K. Sahdra, Katherine A. MacLean, Erika L. Rosenberg, Tonya L. Jacobs, Anthony P. Zanesco, Brandon G. King, and Clifford D. Saron, Center for Mind and Brain, University of California, Davis; David A. Bridwell, Department of Cognitive Science, University of California, Irvine; George R. Mangun, Department of Neurology, University of California, Davis; Shiri Lavy, Ariel University Center, Samaria, Samaria, Israel; B. Alan Wallace, Santa Barbara Institute for Consciousness Studies; Clifford D. Saron, The M.I.N.D. Institute, University of California at Davis Medical Center.

Katherine A. MacLean is now at the Johns Hopkins University School of Medicine.

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Correspondence concerning this article should be addressed to Baljinder K. Sahdra, 267 Cousteau Place, Center for Mind and Brain, Davis, CA 95618. E-mail: bksahdra@gmail.com

tance (Hayes, Luoma, Bond, Masuda, & Lillis, 2006), and "nonattachment" or release from mental fixations (Sahdra, Shaver, & Brown, 2010). Moreover, mindfulness meditation shows promise in the treatment of depression (Kuyken et al., 2008), eating disorders (Kristeller & Hallett, 1999), substance abuse (Bowen et al., 2006), and stress-related physical disease (e.g., psoriasis; Kabat-Zinn et al., 1998). Overall, the literature suggests that meditative practices may enhance well-being and promote health (Ekman, Davidson, Ricard, & Wallace, 2005; Fredrickson et al., 2008; Wallace & Shapiro, 2006), but the cognitive and behavioral mechanisms underlying such effects remain largely unknown.

The benefits of certain kinds of meditation may stem in part from their emphasis on using attentional skills to regulate emotions and actions. A key feature of various kinds of meditation is observing one's experiences (e.g., thoughts, emotions, or behavioral inclinations) while refraining from either obsessively following them or actively pushing them away (e.g., Asanga, 4th to 5th century BCE/1950; Bodhi, 2000; Lingpa, unknown publication date, as referenced in Wallace, 2006; Padmasambhava, 9th century BCE/1997; Shantideva, 7th century BCE/2006). These ideas are quite compatible with Western psychology's emphasis on the detrimental effects of rumination (Nolen-Hoeksema, Wilco, & Lyubomirsky, 2008), which increases the likelihood of anxiety and depression, and difficulties caused by defensive suppression of emotion (Gross, 1998; Mikulincer, Dolev, & Shaver, 2004), which can negatively affect a person's health (Gross, 2006; Mikulincer, Florian, & Welle, 1993). Training in recognizing and inhibiting one's automatic tendencies during meditation (such as not scratching an itch, not wiggling, and not following a trail of anxious or depressing rumination) is thought to increase emotional balance in daily life (Wallace & Shapiro, 2006) and enhance one's general capacity to direct attention at will to one's goals, values, and aspirations without being distracted or derailed by life's ups and downs (Chödrön, 2006; Wallace, 2006).

Attention allows a person to prioritize and focus on one among several competing stimuli, thoughts, or actions in a given situation, thereby influencing behavior and performance. Attention can be automatically drawn to stimuli and actions (because of momentary salience or well-established habits) or voluntarily guided in line with personal goals, prior knowledge, or explicit instructions (Posner & Cohen, 1984). Posner and Petersen (1990) proposed a functionally distinct *executive* component of attention that prioritizes and selects among competing stimuli and actions. This executive component of attention, also known as *executive control* (Fan & Posner, 2004), exerts voluntary, goal-directed control over which stimuli, thoughts, emotions, and actions are selected despite habitual and/or prepotent tendencies. Furthermore, the ability to control attention and habitual behavioral responses in the laboratory has been shown to predict successful executive control outside the laboratory, especially in tasks involving *response inhibition*, the voluntary withholding of a habitual or impulsive response. For instance, response inhibition errors in the laboratory predict attentional lapses and action slips in everyday life (Robertson, Manly, Andrade, Baddeley, & Yiend, 1997).

In the literature on personality and social psychology, there is a related concept, "metacognitive monitoring," which can be measured, for example, with the Adult Attachment Interview (reviewed by Hesse, 2008) and interview-based measures of "reflective functioning" (Fonagy, Gergely, & Target, 2008). The mental skill of monitoring one's cognitions has been related in numerous studies to better parenting, especially regulation of one's feelings in challenging parental situations (Hesse, 2008). This emphasis is evident in clinical psychology as well, where the concept of "mindfulness," originally borrowed from the Buddhist tradition (Kabat-Zinn, 1990), has proven to be an important part of adaptive functioning and an important goal for psychotherapy (Germer, Siegel, & Fulton, 2005). Recent diary studies of participants attempting to control bad habits in daily life shows that "vigilant monitoring" (thinking "don't do it" or carefully watching for slipups in daily life) helped in controlling unhealthy habits by increasing inhibitory cognitive control (Quinn et al., 2010).

There is also a growing consensus in cognitive neuroscience that executive control allows a person to successfully meet the socioemotional demands of a situation by monitoring and modulating emotion and behavior (see review by Berger, Kofman, Livneh, & Henik, 2007). The effort associated with selectively orienting toward or away from particular stimuli, or inhibiting a dominant (i.e., habitual or prepotent) response, depends on executive control (Posner & Rothbart, 2000; Rueda, Rothbart, McCandliss, Saccomanno, & Posner, 2005). Furthermore, research on preschoolers shows that effortful control involved in resolving attentional conflicts is negatively correlated with emotional reactivity, suggesting that executive control may help a person regulate negative emotions (Gerardi-Caulton, 2000). Also, children who refrain from immediate gratification during the preschool years show better cognitive and self-regulatory competencies in adolescence (Shoda, Mischel, & Peake, 1990).

There is preliminary evidence that meditation induces such changes in attentional control. Jha, Krompinger, and Baime (2007) reported that experienced meditators, compared to a meditation-naïve comparison group, had superior executive control, as indexed by less interference from irrelevant distracting stimuli (on the executive component of the Attention Network Task; Fan, McCandliss, Sommer, Raz, & Posner, 2002). Also, Chambers, Lo, and Allen (2008) found that training-related improvements in executive control, as indexed by an attentional switching task that required keeping a mental count of different categories of words, correlated with increases in self-reported mindfulness and fewer depressive symptoms after meditation training. So the existing data, although limited, point to a potential attentional mechanism underlying the benefits of meditation training for well-being.

Based on an integration of this diverse literature, we hypothesize that meditation practice benefits socioemotional functioning by enhancing executive control, which can be indexed, at least in part, by laboratory assessments of the ability to inhibit undesired responses. To test the hypothesis that meditation-induced changes in response inhibition affect changes in adaptive socioemotional functioning, we collected longitudinal data from adults engaged in 3 months of intensive meditation training in an isolated retreat setting (Retreat 1) and from a wait-list control group that later engaged in identical training (Retreat 2). The training involved meditation techniques designed to improve sustained attention, and attentional and emotional regulation (Wallace, 2006). We tracked changes in response inhibition using a task that required participants to respond quickly to frequently occurring stimuli (90% probability) and not to respond to infrequently occurring stimuli (10% probability).

Despite the seemingly simple nature of the task, errors in responding to the infrequent stimulus are common (Helton, 2009). The task places high processing demands on executive attention, requiring a person to monitor his or her performance to avoid making the habitual motor response when the low-frequency stimulus appears. Further, the task implicitly involves making behavioral adjustments (via increased executive control) when response errors occur (Carter, Botvinick, & Cohen, 1999; Ridderinkhof, van den Wildenberg, Segalowitz, & Carter, 2004). When people perform response inhibition tasks for extended periods (e.g., > 30 min), accuracy notably decreases over time (Grier et al., 2003; Helton et al., 2005), and people find the task stressful (Grier et al., 2003). Informed by these findings, we designed a 32-min sustained response inhibition task (RIT) that combined the effort associated with sustained performance (see review in Warm, Parasuraman, & Matthews, 2008) and the challenge of avoiding impulsive behavioral responses.

We operationalized "socioemotional functioning" with an omnibus measure of *adaptive functioning* (AF), a single latent variable based on self-report measures of several psychosocial constructs: anxious and avoidant attachment, mindfulness, ego resilience, empathy, five broadband personality traits, difficulties in emotion regulation, depression, anxiety, and psychological well-being. We expected the Retreat 1 group, compared to the wait-list control group, to improve on the RIT and on AF, and we expected the wait-list control group to show similar improvements during Retreat 2. In line with the literature reviewed above, we hypothesized that participants' enhanced ability to inhibit responses in the RIT, which we used as an index of executive attention, would predict their subjective changes in AF.

Method

Participants

We recruited participants by advertising in various Buddhist magazines, websites, and meditation centers in the United States. The advertisement indicated that we were investigating "the relation between meditation and well-being," and that the meditation practices taught in the study retreats would be "drawn from the Theravada and Mahayana Buddhist traditions." Interested individuals were invited to apply.

Sixty applicants were selected (~50% acceptance rate) based on the following inclusion criteria: They were between 21 and 70 years of age; they agreed to refrain from smoking and consuming recreational drugs 3 months prior to the retreat; they also agreed to refrain from smoking, drinking, and consuming recreational drugs during the retreat; they were available for testing at all time points; they were available to attend either Retreat 1 or Retreat 2 (the retreat attended by participants who served as the waitlist control group for Retreat 1); they did not have a serious medical or psychological illness, as assessed with the Mini International Neuropsychiatric Interview screen (Sheehan et al., 1998) conducted by a licensed clinical psychologist on the project research team; and they had participated in at least three 5- to 10-day meditation retreats in the previous 10 years, including at least one led by Dr. Alan Wallace, the meditation teacher in Retreats 1 and 2. Previous retreat experience was mandatory, because it indicated that participants were familiar with the emotional rigors of retreat experience, and were likely to adhere to the intensive training schedule and complete the retreat.

The participants were assigned to an initial training group ($n = 30$) or a waitlist control group ($n = 30$) through stratified matched assignment; the two groups were matched on age ($M = 48$ years, range $= 22$ to 69), sex (28 men, 32 women), and years of meditation experience ($M = 13$). In addition, the control and retreat groups did not differ in mean education level, marital status, or annual household income, all Fs < 1.

The composition of the two groups was as follows: 70% were from the United States, 10% from Mexico, and 3% each from England, Italy, and Canada (with the remaining 11% coming from various other countries in Europe, Asia, and South America). Sixty-four percent were European American, 14% European, 12% Hispanic, and 3% Asian American; the remaining 4% were of mixed ethnicity. On average, they were well educated: 53% held graduate or professional degrees, 14% had some graduate or professional training, 23% had graduated from college, 8% had some college education, and 2% had less than a completed high school education. They varied in socioeconomic status, from a household income of "$10,000 or less" to a household income of "$100,000 or more" (the median category was $60,000 to $70,000). Regarding civil status, 41% were married, 19% single, 15% dating, 12% divorced, 6% cohabiting, 5% engaged, and 2% widowed.

Only one participant dropped out of the study (due to a family emergency). Participants paid approximately $5,300 to participate in the retreat but were compensated for participating in data collection at a rate of $20/hr. Travel expenses were paid for wait-list control participants who were flown to the retreat center to be tested at the three assessment points during Retreat 1.

Meditation Training

Under the guidance of Dr. Wallace, participants practiced meditation for 6 to 10 hr a day for 3 months in an isolated retreat setting (the Shambhala Mountain Center in Red Feather Lakes, Colorado). The training included the following seven practices (described in Wallace, 2006): (1) *mindfulness of breathing* to induce relaxation of body and mind, and facilitate calming of compulsive thinking and sensory distraction; (2) *observing mental events* ("settling the mind in its natural state") to enhance attentional stability and vividness; (3) *observing the nature of consciousness* ("awareness of awareness") to increase the stability and vividness of attention; (4) *loving-kindness* to arouse a heartfelt wish that self and others will experience genuine happiness and its causes, replacing resentment and hatred with a spirit of forgiveness; (5) *compassion* to arouse a heartfelt wish that self and others will be free of suffering and its causes, thereby overcoming apathy and aloof indifference; (6) *empathetic joy* to arouse delight in one's own and others' successes, joys, and virtues, thus countering inclinations toward envy; and (7) *equanimity* to arouse an impartial, unconditional sense of affectionate concern for all beings, regardless of their closeness to or distance from oneself. Participants were encouraged to spend most of their time on one or two of the first three practices specifically designed to improve sustained attention and attention regulation. They were also advised to devote some time each day to the remaining complementary practices designed to generate positive and balanced aspirations about their own and others' well-being. On average, they practiced about

6 hr a day on their own (see Table 1 for details of solitary practice time for all practices), and congregated twice a day for 30 min to practice meditation guided by Dr. Wallace. The evening session was often followed by a talk by Dr. Wallace and period of question and answers. Participants also met with Dr. Wallace privately once a week for individual advice, clarification, and guidance.

Laboratory Testing Sessions

Two identical field laboratories were constructed in the building in which participants lived and practiced meditation. Each laboratory included a sound-attenuated, darkened testing room located next to a room where stimulus presentation and data acquisition were controlled. *Presentation* software (Neurobehavioral Systems, http://www.neurobs.com) was used to deliver all stimuli on an LCD monitor (Viewsonic VX-922). Laboratory assessments were conducted at pre-, mid-, and postretreat in both Retreats 1 and 2. In Retreat 1, the waitlist control participants were flown to the retreat setting so that they could be assessed in the same setting as, and immediately after, the retreat participants. Because the study was conducted at relatively high altitude (2500 m), the control participants arrived 3 days (range = 65 to 75 hr) before the beginning of testing for acclimatization. Participants in the first retreat group completed 3 on-site testing sessions; those in the second retreat group completed 6 on-site testing sessions including testing as controls.

Response Inhibition Task (RIT)

RIT threshold. At the beginning of Retreat 1 (preretreat), participants first completed a threshold procedure (duration = 10 min) to calibrate task difficulty for each individual (see MacLean et al., 2009; MacLean et al., 2010). Participants saw single gray vertical lines appear one at a time at the center of the monitor screen against a black background (stimulus duration = 150 ms; variable intervals between stimuli, M = 1850 ms, range = 1550 to 2150 ms). Instructions emphasized speed and accuracy in making responses with the left mouse button (right index finger) to frequent long lines (70% of stimuli) while inhibiting responses to rare short lines (30% of stimuli). Participants received sound feedback indicating (a) correct inhibitions of responses to short lines ("ding"), (b) accidental responses to short lines ("whoosh"), and (c) missed responses to long lines ("whoosh"). The procedure determined the length of the short line required for each participant to perform at 85% overall accuracy.

RIT accuracy. Immediately after the threshold procedure, participants performed the sustained *response inhibition task* (RIT; duration = 32 min) with the short line set to his or her individual threshold. The RIT instructions, stimuli, and timing were identical to the threshold procedure except that it did not include sound feedback, line lengths were fixed, and the short line occurred less frequently (10% of stimuli).

Response inhibition performance can be quantified as overall error rate, or the rate of accidental responses to the rare target. However, error rate does not take into account the tendency to respond (or not respond) during the task (i.e., response bias). For example, a participant could achieve many correct inhibitions using a strategy of responding to fewer trials overall. Thus, we chose a dependent measure of accuracy that captured how well a participant could correctly inhibit responses to short lines while also correctly responding to long lines. Specifically, we calculated the nonparametric index of perceptual sensitivity, A', using correct and incorrect inhibition rates (see formula in Stanislaw & Todorov, 1999; in applying this formula, we defined correct inhibitions as hits and incorrect inhibitions as false alarms). Because we were interested in how accuracy changed across the task, we calculated A' for each of eight contiguous blocks of trials (120 trials, 4 min each) within the RIT at each assessment. Thus, our dependent measures of RIT performance were (1) average A' and (2) the slope of A' across blocks.

Some participants unexpectedly did not show large declines in accuracy at preretreat. To keep task demands high for all individuals across multiple sessions, we increased the overall difficulty level of the task by setting target threshold at 75% accuracy at all subsequent assessments in both retreats. To compare Retreat 1 preassessment performance (set at 85% threshold level) to all other assessments (set at 75% threshold level), we adjusted A' for each individual at each block at preassessment to compute performance at 75% [adjusted A' = (original A' × .75)/.85].

Self-Report Measures

Retreat 1 questionnaires. At the beginning and end of Retreat 1, participants completed identical packets of questionnaires including the scales detailed below. To minimize the testing burden, the questionnaires were not administered at the midpoint.

Attachment insecurities. Attachment anxiety (fear of rejection or abandonment) and avoidance (avoidance of intimacy and interdependence) were assessed with the 36-item Experiences in Close Relationships scale (ECR; Brennan, Clark, & Shaver, 1998),

Table 1
Average Daily Solitary Practice Time (in Hours) of Different Meditation Practices in Retreat 1 and Retreat 2

	Total average daily practice	Daily average for attention practices				Daily average for balancing practices				
		1	2	3	Total of 1 to 3	4	5	6	7	Total of 4 to 7
Retreat 1	6.35 (1.34)	2.25 (2.05)	1.71 (2.15)	1.75 (1.93)	5.67 (1.31)	.15 (.09)	.27 (.15)	.08 (.06)	.09 (.04)	.68 (.30)
Retreat 2	6.00 (1.54)	3.01 (1.80)	1.20 (1.35)	1.02 (1.08)	5.20 (1.43)	.14 (.08)	.35 (.22)	.10 (.06)	.08 (.06)	.80 (.38)

Note. 1 = mindfulness of breathing; 2 = observing mental events; 3 = observing the nature of consciousness; 4 = compassion; 5 = loving-kindness; 6 = empathetic joy; 7 = equanimity. Standard deviations are in parentheses. In addition to solitary practice hours reported here, participants congregated twice a day for 30 min (1 hr total) to practice meditation guided by Dr. Wallace.

which included 18 items assessing *attachment anxiety* (e.g., "I worry about being rejected or abandoned") and 18 assessing *avoidant attachment* (e.g., "I don't feel comfortable opening up to others"). Participants rated their degree of agreement with each of the items on a scale ranging from 1 (*Disagree Strongly*) to 7 (*Agree Strongly*). Cronbach's alpha reliability coefficients for the two scales averaged above .90 across the two assessments (at the beginning and end of the retreat).

Mindfulness. Participants completed the Five Facet Mindfulness Questionnaire (FFMQ; Baer, et al., 2006), which assesses five aspects of mindfulness: (1) *observing or noticing experience* (e.g., "I pay attention to sensations, such as the wind in my hair or sun on my face"); (2) *acting with awareness or avoiding automatic pilot* (e.g., "When I'm doing something, I'm only focused on what I'm doing, nothing else"); (3) *describing or labeling feelings* (e.g., "I'm good at finding the words to describe my feelings"); (4) *nonjudging of experience* (e.g., a reverse-scored item, "I criticize myself for having irrational or inappropriate emotions"); and (5) *nonreactivity to internal experience* (e.g., "I perceive my feelings and emotion without having to react to them"). Participants responded to each item on a 1-to-7 scale ranging from 1 (*Disagree Strongly*) to 7 (*Agree Strongly*). Alphas for these scales ranged from .80 to .93, and alpha for the entire scale averaged .95 across the pre- and postretreat assessments. The scores on the subscales were intercorrelated, with Pearson *r*s ranging from .24 to .59. A principal components analysis indicated that a single factor accounted for 55% of the variance in the five subscale scores, with the scales loading on the principal component as follows: *Observing*, .65; *Describing*, .68; *Acting with Awareness*, .77; *Nonjudgment*, .75; and *Nonreactivity*, .84. We therefore computed a single mindfulness score at each time point by averaging all of the item scores for each participant.

Depression. We used the Center for Epidemiologic Studies Depression Scale (CES-D), which was designed to measure depressive symptoms in a general (i.e., nonclinical) population (Radloff, 1977). The 20-item scale measures depressive mood, feelings of guilt and worthlessness, psychomotor retardation, loss of appetite, and sleep disturbance (e.g., "I felt fearful," "My sleep was restless," "I had crying spells"). Participants indicated the frequency with which they felt or behaved in certain ways over the past several weeks, using a scale ranging from 1 (*Rarely or never: 1 or fewer days per week*) to 7 (*Most or all the time: 7 days per week*). The alpha for the scale averaged .83 across the two assessments.

Anxiety. We employed the 20-item State Trait Anxiety Inventory (STAI; Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983). Participants indicated the frequency with which they experienced various anxiety symptoms (e.g., "I have disturbing thoughts," "I feel inadequate," "I wish I could be as happy as others seem to be") on a 4-point scale: 1 (*Almost never*), 2 (*Sometimes*), 3 (*Often*), and 4 (*Almost always*). Alpha for this scale averaged .92 across the two assessments.

Ego-resiliency. Ego-resiliency is defined as the ability to "bounce back" from negative emotional experiences (Block & Kremen, 1996). An ego-resilient individual is conceptualized as someone who can "be as undercontrolled as possible and as overcontrolled as necessary" (p. 351). Participants responded to the items (e.g., "I enjoy dealing with new and unusual situations," "I get over my anger at someone reasonably quickly") by indicating their degree of agreement on a scale ranging from 1 (*Disagree Strongly*) to 7 (*Agree Strongly*). The average alpha for this scale was .79.

Empathy. The Interpersonal Reactivity Index (IRI) assesses cognitive and affective dimensions of empathy (Davis, 1983); the 21-item IRI contains three subscales: *Personal distress*, the tendency to experience distress in response to extreme distress in others (e.g., "In emergency situations I feel apprehensive and ill at ease"); *Empathic concern*, the tendency to experience feelings of sympathy and compassion for others in need (e.g., "I often have tender, concerned feelings for people less fortunate than me"); and *Perspective taking*, the degree to which an individual spontaneously takes the point of view of other people in everyday life (e.g., "I try to look at everybody's side of a disagreement before I make a decision"). The items were rated on a scale ranging from 1 (*Disagree Strongly*) to 7 (*Agree Strongly*). The average alphas for the three scales were .83 for *Personal distress*, .80 for *Empathic concern*, and .84 for *Perspective taking*, and overall scale was .87. *Personal distress* was negatively correlated with *Perspective taking* ($r = -.33$) and *Empathic concern* ($r = -.44$); perspective taking and empathic concern were positively related ($r = .65$). A principal components analysis indicated that a single factor accounted for 55% of the variance in the three subscale scores, with the scales loading on the principal component as follows: *Personal distress*, −.58; *Empathic concern*, .81; and *Perspective taking*, .82. We reverse-scored personal distress and then averaged the three subscales to create a composite empathy score for each participant at each time point.

Personality traits. We employed the 44-item Big Five Inventory (BFI; John, Donahue, & Kentle, 1991; John & Srivastava, 1999) to measure the following broadband traits: *Extraversion*, encompassing such traits such as talkative, energetic, and assertive; *Agreeableness*, being sympathetic, kind, and affectionate; *Conscientiousness*, being organized, thorough, and reliable; *Neuroticism*, being tense, moody, and anxious; and *Openness to experience*, having wide interests and being imaginative and insightful. Items were rated on a scale ranging from 1 (*Disagree Strongly*) to 7 (*Agree Strongly*). The average alphas for the five scales ranged from .78 for *Openness* to .86 for *Neuroticism*.

Difficulties in emotion regulation. The 36-item Difficulties in Emotion Regulation Scale (DERS), developed by Gratz and Roemer (2004), is based on an "integrative conceptualization of emotion regulation as involving not just the modulation of emotional arousal, but also the awareness, understanding, and acceptance of emotions, and the ability to act in desired ways regardless of emotional state" (p. 41). The scale contains six subscales: (1) *Nonacceptance of one's own feelings* (e.g., "When I'm upset, I become embarrassed for feeling that way"); (2) *Difficulties in fulfilling one's goals* (e.g., "When I'm upset, I have difficulty getting work done"); (3) *Impulsiveness* (e.g., "When I'm upset, I become out of control"); (4) *Lack of emotional awareness* (e.g., a reverse-scored item, "When I'm upset, I acknowledge my emotions"); (5) *Lack of strategies in recovering from negative emotions* (e.g., "When I'm upset, I believe that I will remain that way for a long time"); and (6) *Lack of clarity* (e.g., "I have difficulty making sense of my feelings"). Items were rated on the usual 1 to 7 scale. Alphas for these subscales ranged from .77 to .92, and the subscales were intercorrelated, with *r*s ranged from .35 to .73. A factor analysis indicated that a single factor accounted for 62% of the variance in the six subscales, and all of them loaded above .70

on that factor. We therefore computed a composite DERS score by averaging all of the items scores (average $\alpha = .95$).

Psychological well-being. Participants completed a 54-item well-being scale (Ryff, 1989) tapping the following six constructs: (1) *Autonomy* (e.g., "People rarely talk me into doing things I don't want to do"); (2) *Environmental mastery* (e.g., "I am quite good at managing the many responsibilities of my daily life"); (3) *Personal growth* (e.g., "I think it is important to have new experiences that challenge how you think about yourself and the world"); (4) *Positive relations with others* (e.g., "I know that I can trust my friends, and they know they can trust me"); 5) *Purpose in life* (e.g., "I have a sense of direction and purpose in life"); and 6) *Self-acceptance* (e.g., "When I look at the story of my life, I am pleased with how things have turned out"). Items were rated on the usual 7-point scale. Average alphas ranged from .65 to .83, and the subscales were intercorrelated (*r*s ranged from .30 to .76). A principal components analysis yielded a single factor that accounted for 58% of the variance in the six subscales, which loaded from .63 to .84 on that factor. We therefore computed a composite psychological well-being score (average $\alpha = .92$).

Retreat 2 questionnaires. We administered all of the measures used in Retreat 1 (listed above) again at the end of Retreat 2. However, to minimize participants' testing burden, we administered only two randomly selected measures from Retreat 1 at the beginning of Retreat 2: the Five Facet Mindfulness Questionnaire (FFMQ) and the Ego Resiliency Scale. Participants' responses to these measures at the end of Retreat 1 and at the beginning of Retreat 2 (a temporal gap of 3 months) were highly correlated (FFMQ $r = .86$; Ego Resiliency $r = .77$) and did not differ significantly as a function of time (FFMQ $t(28) = -.69$, $p = .50$; Ego Resiliency $t(28) = -.64$, $p = .53$). We therefore treated the control participants' Retreat 1 postretreat data as a proxy for their Retreat 2 preretreat data.

The alphas of all measures at the end of Retreat 2 were as follows: (1) *Avoidant attachment*, .87; (2) *Anxious attachment*, .91; (3) *Mindfulness* overall, .96, with alphas for the subscales ranging from .71 for *Observing* to .94 for *Nonjudgment*; (4) *Depression*, .75; (5) *Anxiety*, .93; (6) *Ego-resiliency*, .75; (7) *Empathy* overall, .84, with alphas for the subscales ranging from .56 for *Empathic concern* to .90 for *Personal distress*; (8) *Big Five personality traits* (alphas ranged from .76 for *Agreeableness* to .88 for *Extroversion*); (9) *Difficulties in Emotion Regulation*, .96, with alphas ranging from .56 for *Lack of emotional awareness* to .93 for *Nonacceptance*; and (10) *Psychological well-being* overall, .93, with subscale alphas ranging from .69 for *Personal growth* to .85 for *Self-acceptance*.

Follow-up assessment. Participants completed a *follow-up* assessment of RIT and of all the self-report measures listed above approximately 5 months after the completion of their respective retreat. Laptop computers, headphones, and questionnaire packets were shipped to participants' homes along with detailed instructions for setting viewing distance and ambient lighting. The RIT was administered using *Presentation*. Stimuli and timing parameters matched those used in the retreat laboratory assessments detailed above. In addition, the laptop version of the task included onscreen instructions to guide participants through practice, the threshold procedure, and the 32-min RIT. Because participants had completed the task at least 3 times before, they were familiar with it. Even so, they were asked to call our research team if they needed help in setting up the laptop. Participants were compensated at a rate of $20/hr, and all shipping costs were covered.

Results[1]

Response Inhibition Task (RIT):

Retreat 1. Of the 60 participants in the period that included Retreat 1 ($n = 30$ in each group), three participants were left-handed (1 retreat participant and 2 waitlist control participants). Separate analyses including and excluding these participants yielded virtually identical results. Thus left-handed participants are included in the analyses reported below. We removed participants who were outliers (3 *SD* below the grand mean) in change in accuracy ($M = .07$, $SD = .07$) on the RIT. One retreat participant was an outlier on change in accuracy. Thus, the RIT analyses included 59 individuals.

RIT threshold. As mentioned before, the purpose of the threshold procedure at the beginning of the RIT was to keep task difficulty constant across participants and across testing times. Calibrating task difficulty in this way allowed us to interpret any training-related changes in RIT accuracy. First, to determine if threshold itself changed over the course of training, we used analysis of variance (ANOVA) to test the between-subjects effect of *group* (retreat v. control) and the within-subjects effect of *assessment* (pre-, mid- and postretreat) on threshold. A main effect of assessment ($F(2, 56) = 45.0$, $p < .0001$, $\eta_p^2 = .62$) revealed that thresholds decreased (i.e., improved) across assessments in both groups (Retreat: $M = 1.0°$ at preretreat, 0.71° at midretreat, and 0.65° at postretreat; Control: $M = 1.2°$ at preretreat, 0.87° at midretreat, and 0.76° at postretreat). The main effect of group was also significant ($F(1, 57) = 4.25$, $p = .04$, $\eta_p^2 = .07$). Importantly, there were no group differences in threshold at preretreat, $t(57) = 1.55$, $p = .12$, indicating that the groups were matched at the beginning of training. Although thresholds were significantly lower in the retreat group at midretreat, $t(57) = 2.06$, $p = .04$, the group difference was not significant at postretreat, $t(57) = 1.60$, $p = .11$ and the interaction between group and assessment was not significant ($p = .75$, $\eta_p^2 = .01$). Taken together, these findings are consistent with general practice effects and not with training-related change. Because we set the length of the target line in the RIT to the threshold value obtained at each assessment for each individual, individual differences in threshold change may have influenced RIT performance. Thus, we statistically controlled for the influence of threshold in all models of RIT performance reported next.

RIT accuracy. We modeled changes in RIT performance during Retreat 1 using hierarchical linear regression. Analyses were conducted in SAS using the proc mixed function (Singer, 1998). We first tested a baseline model with fixed effects of *block* (centered to the first block), *assessment* (preretreat, midretreat and postretreat centered to the first assessment), *group* (retreat and control; retreat group membership was coded as 1 and control group membership as 0) and *threshold* (centered to the grand

[1] Preliminary analyses including gender showed that gender did not moderate the effects of retreat on AF or RIT. Gender was therefore excluded from the reported analyses.

mean). We included random effects on the intercept to allow for individual differences in initial performance (A' during the first block). This model revealed a significant effect of block ($\beta = -.009$, $p < .0001$), a significant effect of threshold ($\beta = -.044$, $p = < .0001$) and a nonsignificant effect of group ($p = .52$). Importantly, the effect of assessment was significant ($\beta = .046$, $p < .0001$), indicating increases in average accuracy. To test the prediction that increases in accuracy would be greater for retreat participants, we next tested a model that included the interaction between group and assessment. This model also included the interaction between threshold and assessment, to control for individual differences in threshold change. Consistent with our prediction, the interaction between group and assessment was significant ($\beta = .011$, $p = .02$). Moreover, the Bayesan Information Criterion (BIC; smaller values indicate a better model fit) indicated that this model fit the data better (BIC = −3092) than the baseline model (BIC = −3049). Finally, the addition of 2-way and 3-way interaction effects (e.g., the interaction between block and assessment) did not improve the model fit. Thus, the findings demonstrate training-related increases in average response inhibition accuracy.

Retreat 2

RIT threshold. In the model of RIT performance in Retreat 1, we found that individual differences in threshold improvement influenced accuracy on the RIT ($p < .0001$). In Retreat 2, we addressed this issue by fixing the length of the target line for each participant to the threshold achieved at the beginning of training. A repeated-measures ANOVA across four assessments (postretreat 1, preretreat 2, midretreat 2 and postretreat 2) confirmed that thresholds did not change significantly after the end of Retreat 1 ($F(3, 26) = 1.06$, $p = .38$, $\eta_p^2 = .11$).

RIT accuracy. As in Retreat 1, we modeled RIT performance using hierarchical linear regression. We tested the fixed effects of block, assessment (preretreat, midretreat and postretreat), and the interaction between block and assessment. We again included random effects on the intercept to allow for individual differences in initial accuracy. This model revealed a significant effect of block ($\beta = -.011$, $p < .0001$), a significant effect of assessment ($\beta = .011$, $p = .02$), and a significant interaction between assessment and block ($\beta = .003$, $p = .02$). The significant effect of assessment confirmed the result from Retreat 1 of improvements in average response inhibition accuracy with training. Further, the significant interaction between block and assessment demonstrated that training led to improvements in sustained response inhibition accuracy (i.e., a more positive slope across blocks) when task difficulty and target parameters were held constant.

AF: Retreat 1

Factorial structure of AF. We conducted a confirmatory factor analysis to determine the factor structure underlying the self-report measures at both the beginning and end of the retreat. We tested a model of a single factor that might be expected to improve as a result of meditation training. The one-factor model fit better than a two-factor model separating negative and positive constructs. We then examined factorial invariance across groups (i.e., retreat and control) for each of the measurement occasions (i.e., pre- and postretreat). The fit of these models is described in Table 2. The results indicated that all measures loaded substantially on a single latent construct, which we labeled "Adaptive Functioning" (AF; note that participants' scores on the measures assessing maladaptive functioning, such as anxiety and difficult emotion regulation, were reversed such that all scores indicated positive functioning). The results also indicated that assumptions of strong factorial invariance (i.e., equal factor loadings and intercepts) and strict factorial invariance (i.e., equal factor loadings, intercepts, and unique variances) across groups were reasonable for the pre- and postretreat, respectively. In other words, the AF factor had an equivalent structure across groups for both occasions; thus, between-groups differences in the factor means were interpretable.

In the next step, based on the previous results, we pooled the data from both groups and examined factorial invariance over

Table 2
Goodness-of-Fit Indices of the Factorial Invariance Models of AF

Model	χ^2	*df*	# pars	BIC	$\chi^2/\Delta df$
Pre-Retreat (Groups = Retreat and Control)					
CFA_1 Initial confirmatory analysis	366	155	83	1832	—
CFA_2 Weak factorial invariance ($\lambda^=$)	389	168	70	1802	23/13
CFA_3 Strong factorial invariance ($\lambda + \tau^=$)	403	182	56	1759	13/14
CFA_4 Strict factorial invariance ($\lambda + \tau + \Theta^=$)	440	196	42	1739	$37/14^{<.01}$
CFA_5 Unequal Factor Means ($\alpha^{\neq}$)	439	195	43	1742	1/1
Post-Retreat (Groups = Retreat and Control)					
CFA_1 Initial confirmatory analysis	300	155	83	1725	—
CFA_2 Weak factorial invariance ($\lambda^=$)	321	168	70	1693	21/13
CFA_3 Strong factorial invariance ($\lambda + \tau^=$)	343	182	56	1658	22/14
CFA_4 Strict factorial invariance ($\lambda + \tau + \Theta^=$)	363	196	42	1621	20/14
CFA_5 Unequal Factor Means ($\alpha^{\neq}$)	351	195	43	1613	$12/1^{<.01}$
Longitudinal Invariance (Pooled Sample)					
CFA_1 Initial confirmatory analysis	656	336	98	2812	—
CFA_2 Weak factorial invariance ($\lambda^=$)	675	350	84	2777	19/14
CFA_3 Strong factorial invariance ($\lambda + \tau^=$)	685	362	72	2734	10/12
CFA_4 Strict factorial invariance ($\lambda + \tau + \Theta^=$)	711	376	58	2703	$26/14^{<.05}$

Note. λ = factor loadings; τ = observed variables intercepts; Θ = unique variances; $^=$ equality constraint in a given parameter across groups.

time. That is, we determined whether the same factor was being measured on both occasions. The results, shown in Table 2, indicate that, as before, the AF factor had an equivalent structure for both the pre- and postretreat assessments. Given the equivalence of the factor across occasions and groups, it was reasonable to examine differences in the factor means over time.

Changes in AF. In the next set of analyses we tested our general hypothesis that the retreat group would improve on the AF factor from preretreat to postretreat but the control group would not. For this purpose, we assessed change in the latent factor for the retreat group and the waitlist control group using second-order latent difference score (2LDS) models (Ferrer, Balluerka, & Widaman, 2008; McArdle, 2001; McArdle & Hamagami, 2001; McArdle & Nesselroade, 1994). Following the approach of Ferrer et al. (2008), we imposed a standardized metric for the latent variable by fixing the variance and the mean of the latent variable at unity and zero respectively on the first occasion and then estimating all factor loadings and intercepts while constraining factor loadings and intercepts to invariance on the second occasion. This approach allowed interpretations of change in the latent variable in standardized terms (i.e., in standard deviation units) rather than the unit of an arbitrarily selected manifest variable.

The results are shown in Table 3, including factor loadings, means on the AF factor at preretreat, the latent change factor, and their respective variances. The factor loadings show that most of the variables contribute substantially to the factor and only one, Openness to Experience, has a factor loading smaller than the conventional .40. Of these variables, some show particularly large loadings (>.70), indicating that they are strong indicators of our adaptive socioemotional functioning construct. These variables are Attachment Anxiety, Difficulties in Emotional Regulation, Mindfulness, Conscientiousness, Agreeableness, and Psychological Well-Being. Other parameter estimates reported in Table 3 indicate that the retreat participants improved on the latent dimension but the control participants did not. The estimate of the mean change in AF in the retreat group was .526, indicating a change of half a standard deviation over the course of the retreat. For the control group, in contrast, that estimate was −.007 ($p > .05$), indicating that from pre- to post retreat there was no change in AF (see the left panel of Figure 1). In addition to the differences in means, the estimates of the variances indicate discrepancies in the variability of the changes between the groups, with the retreat group showing more differences in change across individuals. Specifically, preretreat levels of AF were negatively correlated with change in AF in the retreat group, indicating that higher levels of adaptive functioning at the beginning of training were associated with less change in adaptive functioning. This correlation was not significant for the control group ($p > .05$). Finally, a model that constrained factor means, variances, and correlations to be equal over time resulted in a significantly worse fit.

Table 3
Parameter Estimates From 2LDS Models of AF in Retreat 1

	Retreat	Control
Factor loadings $\lambda^{=}$		
Avoidant attachment	1.000 (=)	1.000 (=)
Attachment anxiety	.954 (.111)	.954 (.111)
Depression	.444 (.072)	.444 (.072)
Anxiety	.477 (.049)	.477 (.049)
Neuroticism	1.008 (.125)	1.008 (.125)
Difficulties in emotional regulation	.848 (.094)	.848 (.094)
Mindfulness	.897 (.097)	.897 (.097)
Ego resiliency	.511 (.079)	.511 (.079)
Empathy	.577 (.085)	.577 (.085)
Extroversion	.450 (.104)	.450 (.104)
Agreeableness	.705 (.099)	.705 (.099)
Conscientiousness	.706 (.118)	.706 (.118)
Openness to experience	.363 (.100)	.363 (.100)
Psychological well-being	.705 (.070)	.705 (.070)
Means μ	2.049 (.725)	1.976 (.447)
Factor at time 1	.000 (=)	.000 (=)
Change	.526 (.082)	−.007 (.051)^{ns}
Variances σ^2	2.049 (.725)	1.976 (.447)
Factor at time 1	1.000 (=)	1.000 (=)
Change	.154 (.055)	.051 (.023)
Correlation ($\rho_{factor,change}$)	−.562 (.174)	−.444 (.242)^{ns}

Note. Values in parentheses indicate standard errors. All values are maximum likelihood estimates. "=" indicates a parameter constraint. "ns" indicates a parameter whose 95% confidence interval includes zero.

Changes in individual variables. We conducted univariate mixed model ANOVA on each of the measures that contributed to the latent construct, with time (pre vs. post retreat) as a within-subjects variable and group (retreat vs. waitlist control) as a between-subjects variable. All measures except depression and attachment anxiety showed the predicted pattern to a significant degree ($p < .05$), indicating broad improvement in adaptive functioning due to training.

AF: Retreat 2

Changes in AF. The data were analyzed in a second-order latent difference score (2LDS) model similar to the one for Retreat 1 except that there was no control group. The factor loadings were constrained to be identical to those in Retreat 1 so that we could assess change in the latent factor from pre- to postretreat. The mean of the slope was 0.618 ($SE = 0.106$). Because the mean and standard deviation of the latent variable at preretreat were set to zero and unity respectively, this slope indicates a change of over half a standard deviation (see the right panel of Figure 1).

Changes in individual variables. We also conducted paired *t* tests on individual measures. All measures except depression yielded significant differences in the predicted directions ($p < .05$). Because the participants were prescreened for psychopathology, it is not surprising that the low mean depression scores did not get lower as a result of either retreat.

Dynamics of RIT and AF Among Participants in Both Retreats

We found significant training-related improvements in overall response inhibition accuracy (A') in both retreats, and an examination of the observed performance trajectories confirmed that increases in accuracy were evident throughout the 32-min task (see Figure 2 for combined data from both retreats). Thus, we used overall A' as an index of RIT performance at each assessment. We combined the RIT and AF data from both retreats ($N = 58$) and tested dynamic models based on latent difference score (LDS) models to test our main hypothesis that training-related improvements in RIT would predict improve-

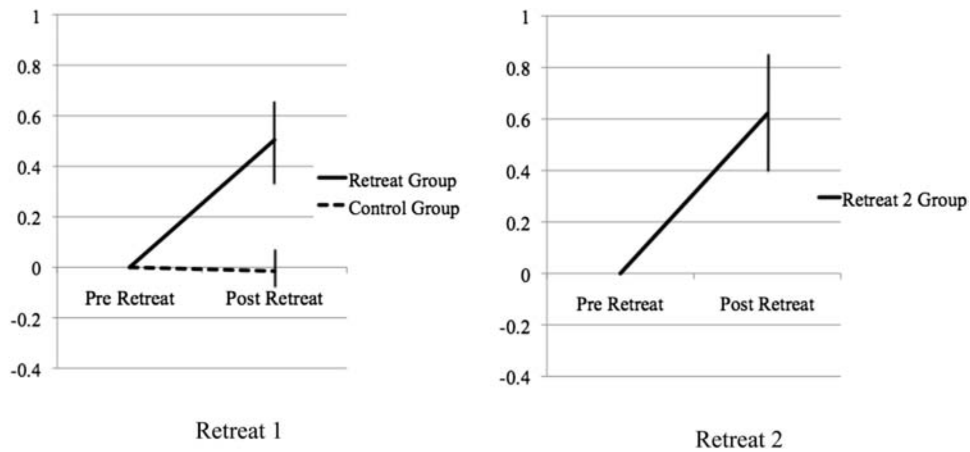

Figure 1. Slopes of the latent variable, AF, by group and time in Retreat 1 (left panel), and by time in Retreat 2 (right panel). The means and standard deviations of the latent factor at preretreat were set to zero and unity respectively to allow interpretations of the changes in means in standard deviation units.

ments in AF. See the Appendix for the RIT and AF equations in our 2LDS model and Figure 3 depicting the model.

The results reported in Table 4 indicate that changes in RIT were a function of a constant slope and a dampening effect of RIT at the previous occasion. Changes in AF, on the other hand, were a function of a small inertia from AF at the previous occasion and, mainly, scores on RIT at the previous occasion. This model provided a very good fit to the data. Moreover, a model with a slope parameter for AF yielded a nonsignificant coefficient and did not improve the fit.

As Table 5 shows, all the estimated means and covariances are close to the observed means and covariances, indicating that the model accounts for the observed data very well. Figure 4 represents the expected trajectories of RIT and AF based on the results from the dynamic system (thick lines) and 20 randomly generated individual trajectories (thin lines).

Follow-up assessments. We combined the data from both groups to compare the levels of RIT and AF at follow-up to the respective levels of these variables at the end of training ($N = 53$ with complete data during retreat and at follow-up). Follow-up

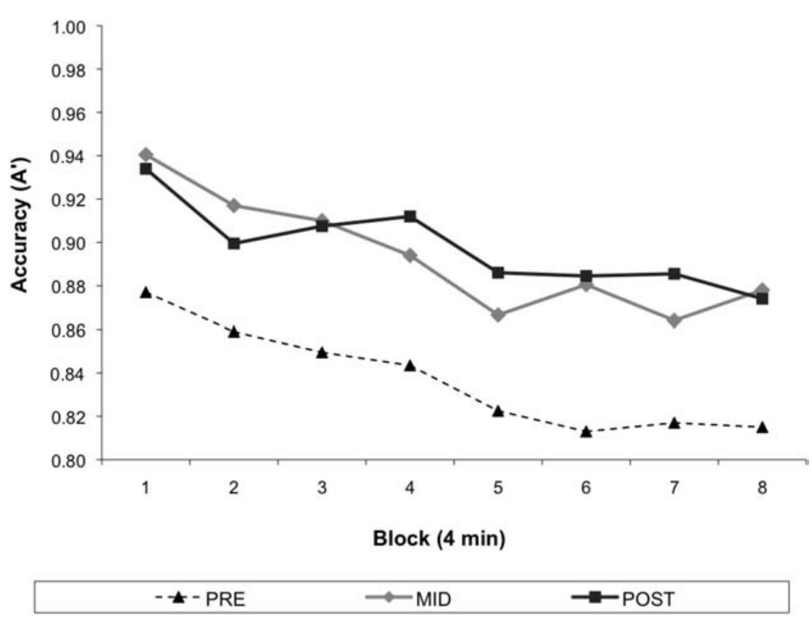

Figure 2. Accuracy performance during the 32-min RIT. Response inhibition accuracy (A') plotted as a function of time on task (eight 4-min blocks) for each of three testing points (pre-, mid-, and postretreat) during training. Data shown for participants in both retreats ($N = 58$) during their respective training periods. Overall response inhibition accuracy increased significantly from preretreat to midretreat ($M = .837$ at preretreat vs. .894 at midretreat, $F(1, 57) = 68.9$, $p < .001$, $\eta_p^2 = .55$) and from preretreat to postretreat ($M = .837$ at preretreat vs. .898 at postretreat, $F(1, 57) = 72.3$, $p < .001$, $\eta_p^2 = .56$).

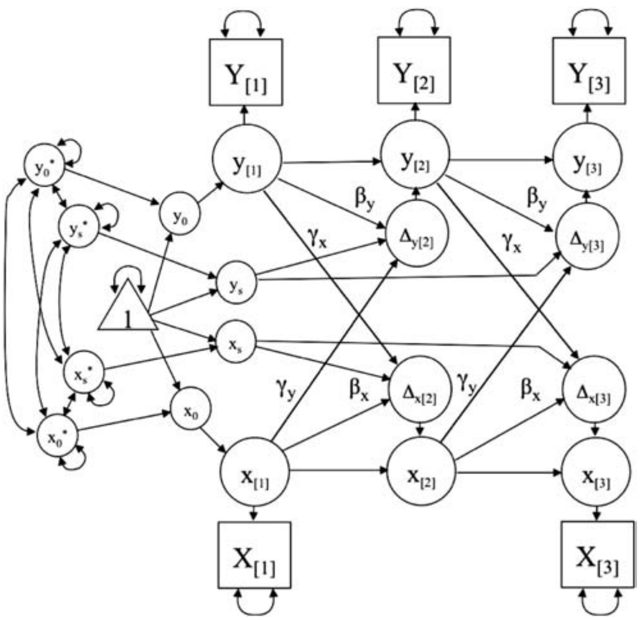

Figure 3. Bivariate LDS model in which Y represents scores on the RIT and X represents scores on AF.

assessments occurred approximately 5 months after the completion of each retreat, although there was considerable individual variability in the amount of time that passed between the end of retreat and the follow-up assessment (M = 25 weeks, range = 18 to 49 weeks).

The levels of RIT at follow-up were not significantly different from the postretreat levels (RIT: M = .890, SD = .07 at follow-up vs. M = .898, SD = .06 at postretreat, $F < 1$). To examine whether the effects in AF persisted after the meditation retreat, we tested

Table 4
Estimates From Bivariate LDS Models Between RIT and AF

Parameter	RIT	AF
Fixed parameters		
Initial mean μ_0	.837 (.009)	.064 (.090)
Slope mean μ_s	.818 (.107)	—
Proportion β	−.908 (.124)	−.022 (.042)
Coupling γ	−.005 (.011)	.319 (.031)
Random parameters		
Initial variance σ_0^2	.003 (.001)	.399 (.088)
Slope variance σ_s^2	.002 (.001)	—
Error variance σ_e^2	.002 (.001)	.075 (=)
Covariances		
$\sigma_{y0,ys}$	.002 (.001)	
$\sigma_{y0,x0}$	−.007 (.006)	
Model fit		
χ^2/df (p)		1.69/7 (.98)
# Parameters		13
CFI		1.00
RMSEA (p < .05)		.0000 (.98)

Note. Standard errors are in parentheses. Number of subjects (N_s = 58). Number of data points (N_d = 290). All parameters are full maximum likelihood estimates. "—" indicates a parameter what was not estimated. "=" indicates a fixed parameter (to the shown value).

Table 5
Observed and Estimated Means and Covariances for RIT and AF

	RIT1	RIT2	RIT3	AF1	AF3
			Observed		
Means	0.837	0.894	0.898	0.065	0.607
Covariances					
RIT1	0.004				
RIT2	0.003	0.004			
RIT3	0.003	0.002	0.004		
AF1	−0.007	−0.002	−0.005	0.473	
AF2	−0.005	−0.001	−0.001	0.381	0.433
			Estimated		
Means	0.837	0.894	0.898	0.064	0.607
Covariances					
RIT1	0.004				
RIT2	0.003	0.004			
RIT3	0.003	0.002	0.004		
AF1	−0.007	−0.003	−0.002	0.474	
AF2	−0.005	−0.001	−0.001	0.379	0.436

for changes in AF after the retreat. We examined a model comparing the mean values of the AF factor before the retreat (i.e., pretest), immediately after (i.e., posttest), and after about 5 months (i.e., follow-up), for all participants. Setting the initial AF factor mean to zero for scaling purposes, we found the mean values to be as follows: Pre Retreat M = 0, Post Retreat M = .547, and Follow-up M = .419. However, when we tested a model in which the means for posttest and follow-up were constrained to be equal, the model fit did not increase significantly ($\Delta\chi^2/1df$ = 2.9 /1, $p >$ .05), indicating that these two means were not significantly different from each other. In other words, there was an increase in AF from the beginning to the end of the retreat, and this level was sustained for 5 months after the end of the retreat. These results indicate that the improvements in executive function and psychological changes that participants experienced as a result of retreat endured several months after the completion of training.

Discussion

In a longitudinal study, we examined whether intensive meditation training would produce measurable changes in attentional control (as assessed with a response inhibition task) and whether these changes would predict improvements in adaptive functioning (assessed with a variety of interrelated self-report measures). The study involved two retreats, each 3 months long. Data from the first retreat allowed comparisons between a wait-list control group and a retreat group. The retreat group improved on the response inhibition task and reported better adaptive functioning, but the control group did neither. When the control participants engaged in their own retreat, they also improved on the response inhibition task and reported functioning more adaptively, replicating the findings from the first retreat. We combined the data from the two retreats to achieve greater statistical power to test our central hypothesis that improvements in response inhibition would influence positive changes in adaptive functioning. Using dynamic linear modeling, we found response inhibition to be a statistically reliable indicator of participants' reported increases in adaptive

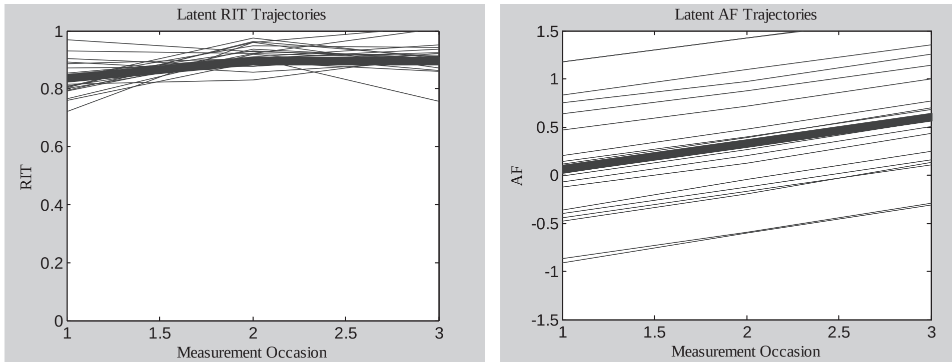

Figure 4. Latent trajectories of retreat participants' performance on RIT (left panel) and their self-reported AF (right panel) as a function of time in training. These graphs represent the expected trajectories of RIT and AF based on the results from the dynamic system of bivariate LDS model of the data of retreat participants of both retreats ($N = 58$). The thick line represents the expected group trajectory and the thin lines represent 20 randomly generated individual trajectories. Measurement occasions 1, 2, and 3 represent preretreat, midretreat, and postretreat respectively.

functioning over the course of training. Follow-up assessments showed that the improvements in RIT performance and AF persisted several months after completion of training.

The sustained response inhibition task used in the present study is not the only way to index changes in attentional control with training. They might also be measured by tasks that tap selective attention and conflict monitoring (e.g., the Attention Network Task used by Jha et al., 2007). In addition, changes in other dimensions of executive control such as working memory capacity and task switching may also change with meditation training and relate to psychological function. Indeed, results from a recent study of mindfulness meditation suggest that changes in working memory capacity during training mediated reductions in negative affect (Jha, Stanley, Kiyonaga, Wong, & Gelfand, 2010). Future studies of meditation training will benefit from using multiple outcome measures of response inhibition and attentional control to provide converging evidence to existing reports and to examine how different measures of attentional control relate to specific dimensions of emotion regulation and psychological wellbeing. Moreover, a challenge for future research will be to identify training-outcome measures that have ecological validity and relate to executive-control skills used in daily life.

Previous laboratory research on untrained participants has shown that self-control is an exhaustible resource (Baumeister, Bratslavsky, Muraven, & Tice, 1998). For example, participants' initial efforts on tests of response inhibition or working memory temporarily deplete their executive-control resources and undermine their subsequent performance on different tasks involving self-regulation (Schmeichel, 2007). The results of such experiments are interpreted as supporting a limited resource model of self-control. Our research suggests that at least one aspect of self-regulation, executive control of response inhibition, can be enhanced through meditation training. An intensive 3-month training experience improved response inhibition capacity, and the effect persisted several months after completion of training. To our knowledge, this is the first study to demonstrate that the capacity of self-regulation can be enhanced in a lasting manner.

It will require further research to identify the mediating processes that link improved attentional and behavioral self-regulation with overall socioemotional adaptation. As mentioned in the Introduction, improved metacognitive monitoring might reduce a person's tendency to ruminate on negative experiences or interpretations of experiences. Greater attentional control might allow a person to keep positive goals for social behavior in mind, making it easier to avoid unnecessary conflicts and hurt feelings. Such attentional control and metacognitive monitoring might also make it easier to reappraise situations and experiences in ways conducive to positive rather than negative emotions, and beneficial rather than harmful responses to other people. Finally, this kind of self-regulation might make it easier for a person to focus on, and remember, prosocial norms and goals. These are all previously studied approaches to emotion-regulation (Gross, 2006) and pro-social behavior (Mikulincer & Shaver, 2009), so it should be possible to use existing measures in future studies to identify the active mediators in the kind of situation we studied.

Although our findings support our hypothesis that improved attentional control contributes to desirable changes in adaptive functioning, we should consider how other features of the training environment may have contributed to the findings. One factor might be the social support that retreat participants received from their peers during the 3 months of training. Although participants mostly practiced alone and in silence, they also practiced as a group twice a day and occasionally conversed with their peers. Although social connectedness has been shown to increase psychological and physical well-being (DeVries, Glasper, & Detillion, 2003; Lee & Robbins, 1998), it seems unlikely to have contributed equally to both improvement on the response inhibition task and increases in psychological well-being. There might also have been effects of the peaceful natural surroundings and the weekly meetings with a committed teacher. It is also conceivable that participants' idiosyncratic preferences for different combinations of the seven meditation methods taught in the retreats might have had some effect on their training. Some of the techniques were explicitly oriented toward the regulation of attention, and these were the most frequently used, but others fostered kindness and compassion, which might have had unique effects on psychosocial adaptation. Moreover, some of the techniques may have had stronger effects on AF than others (e.g., empathetic joy and compassion training may have had greater effects on empathy and emotion regulation). However, these claims are speculative because the sample size was not large enough to decompose the different possible effects. It should be noted that other complex training programs (e.g., Acceptance and Commitment Therapy, Mindfulness-Based Stress Reduction) also have these limitations. Further research is needed to compare different meditation techniques with relevant control treatments (e.g., relaxation vs. meditation; Jain et al., 2007) taught by the same teachers in the same environment. Such research should also include measures of possible mediating processes informed by the results of our study.

Despite these limitations, our results are among the first to suggest that increased attentional control brought about through meditation training can enhance well-being. We hope our methods and findings will spur further research on the mechanisms by which meditation training benefits psychological functioning.

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Appendix

Specifications of the Latent Difference Score Model

Extensive details are available elsewhere concerning the LDS modeling procedure's mathematical and statistical properties (McArdle, 2001; McArdle & Hamagami, 2001), its applications to developmental data (Ferrer & McArdle, 2004; Ferrer et al., 2007), and comparisons between LDS models and other models of change (Ferrer & McArdle, 2003). In short, LDS models are based on true scores, as distinguished from measurement error. Thus, the observed scores of two variables Y and X for person i at time t are conceptualized as consisting of true scores y, x and error e_y, e_x:

$$Y_{it} = y_{it} + e_{yit}$$

and

$$X_{it} = x_{it} + e_{xit}. \quad (1)$$

The true scores can be used to describe the current state of each variable as a function of its previous value plus change:

$$y_{it} = y_{it-1} + \Delta y_{it}$$

and

$$x_{it} = x_{it-1} + \Delta x_{it}. \quad (2)$$

Using this notation, the trajectory for each variable can be written as a linear accumulation of latent changes up to time t:

$$Y_{it} = y_{i0} + \left(\sum_{k=1}^{t} \Delta_{yki}\right) + e_{yit}$$

and

$$X_{it} = x_{i0} + \left(\sum_{k=1}^{t} \Delta_{xki}\right) + e_{xit} \quad (3)$$

and the equations describing the latent changes in the two variables can be expressed as

$$\Delta y_{it} = \alpha_y \cdot y_{is} + \beta_y \cdot y_{it-1} + \gamma_y \cdot x_{it-1}$$

and

$$\Delta x_{it} = \alpha_x \cdot x_{is} + \beta_x \cdot x_{it-1} + \gamma_x \cdot y_{it-1} \quad (4)$$

where α is the coefficient associated with the constant slopes y_{is} and x_{is}, β is a self-feedback coefficient representing the effect of the same variable at the previous state on the change, and γ is the coupling coefficient, representing the effect of the other variable in the system at the previous time point on the change. According to this model, changes in the true scores of each variable Δy_t and Δx_t are a function of three components: (a) a constant slope α, (b) the scores on the same variable at the previous occasion β, and (c) the scores on the other variable at the previous occasion γ. This last component, the coupling parameter, represents forces from one variable at time t that lead to changes in another variable at $t + 1$.

Based on the results reported in Table 4, the equations for RIT and AF in our 2LDS model can be written as

$$\mathrm{RIT}_{it} = .837 \pm [.055] + \left(\sum_{k=1}^{t} \Delta_{yki}\right) + .002,$$

and

$$\mathrm{AF}_{it} = .064 \pm [.627] + \left(\sum_{k=1}^{t} \Delta_{xki}\right) + .075, \quad (5)$$

and the Equations of Change as

$$\Delta \mathrm{RIT}_{it} = .818 \pm [.045] - .908\, RIT_{it.1} - .005\, AF_{it-1},$$

and

$$\Delta AF_{it} = -.022\, AF_{it-1} + .319\, RIT_{it-1}, \quad (6)$$

where the numbers in brackets represent standard deviations.

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