

Research Article

Making a Life Worth Living

Neural Correlates of Well-Being

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ABSTRACT—Despite the vast literature that has implicated asymmetric activation of the prefrontal cortex in approach-withdrawal motivation and emotion, no published reports have directly explored the neural correlates of well-being. Eighty-four right-handed adults (ages 57–60) completed self-report measures of eudaimonic well-being, hedonic well-being, and positive affect prior to resting electroencephalography. As hypothesized, greater left than right superior frontal activation was associated with higher levels of both forms of well-being. Hemisphere-specific analyses documented the importance of goal-directed approach tendencies beyond those captured by approach-related positive affect for eudaimonic but not for hedonic well-being. Appropriately engaging sources of appetitive motivation, characteristic of higher left than right baseline levels of prefrontal activation, may encourage the experience of well-being.

Psychological scientists have amassed a venerable body of research investigating negative psychological processes like distorted cognitive styles, stress, and negative affect (Alloy, Reilly Harrington, Fresco, Whitehouse, & Zechmeister, 1999; Reilly Harrington, Alloy, Fresco, & Whitehouse, 1999; Watson & Clark, 1995). These processes are crucial for better understanding of their role in the development and maintenance of nearly all of the mental disorders defined in the *Diagnostic and Statistical Manual of Mental Disorders* (American Psychiatric Association, 2000). Nevertheless, the fact that positive mental processes have been much less studied underscores a mistaken assumption that the absence of negative processes connotes adaptive functioning. In fact, certain forms of psychopathology are associated with dysregulation of positive mental functions in addition to the presence of negative affective processes (e.g., Allen, Trinder, & Brennen, 1999; Watson, Clark, & Carey, 1988). Moreover, there is neuroscientific evidence for differentiation between negative and positive processes in the brain (Davidson, 2002). In their recent admonition to the field, Seligman and Csikszentmihalyi (2000) exhorted

researchers to direct efforts toward understanding the processes that enable humans to flourish, even under benign conditions. Indeed, that which makes a life worth living surely encompasses those aspects of the human condition that denote happiness, fulfillment, and enrichment—well-being.

Many conceptualizations of the nature of well-being have been formulated, as have many nomenclatures, including “psychological well-being” (PWB; Ryff, 1989; Ryff & Keyes, 1995), “subjective well-being” (SWB; Diener, 2000), “quality of life” (Frisch, Cornell, Villanueva, & Retzlaff, 1992), and “happiness” (Lyubomirsky & Lepper, 1999; Myers, 2000). According to Ryan and Deci (2001) in their recent review, the many conceptualizations of well-being stem from two broad traditions of research in the psychological literature focusing on eudaimonic well-being and hedonic well-being. On the one hand, Ryff and her colleagues’ work on PWB (e.g., Ryff, 1989) exemplifies the eudaimonic tradition. These authors describe well-being as the extent to which respondents endorse high levels of autonomy, environmental mastery, personal growth, positive relations with others, purpose in life, and self-acceptance. Hedonic well-being, on the other hand, is exemplified in the SWB work of Diener and his colleagues (Diener, 2000; Kahneman, Diener, & Schwarz, 1999). Defining SWB as people’s affective and cognitive evaluations of their lives, Diener (2000) has identified four separable components, including life satisfaction, satisfaction with important domains (e.g., work), frequent pleasant emotions, and infrequent unpleasant emotions. Hedonic well-being thus embraces positive affect as a defining feature of well-being, whereas eudaimonic well-being emphasizes that purpose, growth, and mastery may or may not be accompanied by feeling good. Recent analyses have documented that hedonic and eudaimonic well-being are related but distinct constructs, and that the likelihood of having high levels of one, both, or neither is predicted by age, educational standing, and personality characteristics (Keyes, Shmotkin, & Ryff, 2002).

Although the neural correlates of individual differences in well-being are unknown, this is an area of inquiry that may be informed at the outset by work on prefrontal activation asymmetries. Electroencephalographic (EEG) studies support the view that the prefrontal cortex (PFC) has asymmetric involvement in the experience of affect (for a recent review, see Davidson, Jackson, & Kalin, 2000). Individuals with extreme and stable levels of left greater than right frontal activation

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report greater dispositional positive and lower dispositional negative affect than individuals showing a pattern of relative right frontal activation (e.g., Tomarken, Davidson, Wheeler, & Doss, 1992). Additionally, tonic left frontal activation is associated with enhanced positive affect in response to positive films, and reduced negative affect in response to negative films (e.g., Wheeler, Davidson, & Tomarken, 1993).

Although this earlier work focused on the role of affect in explaining the right-left distinction, recent work indicates that stable individual differences in relative activation over the prefrontal regions are not actually indicative of hedonic tone (positive or negative) per se, but instead are related to the propensity to display stable approach-oriented (left hemisphere) or withdraw-oriented (right hemisphere) behavioral tendencies in the face of appropriate sources of stimulation (Harmon-Jones & Allen, 1997; Sutton & Davidson, 1997). It is our contention that appropriate engagement with goal-relevant stimuli is a prerequisite for achieving eudaimonic and hedonic well-being. Therefore, in this EEG study, we hypothesized that more left than right frontal activation at baseline would be correlated with higher levels of well-being. If positive affect has a role in both forms of well-being, the association between frontal asymmetry and well-being should in part be accounted for by approach-related positive affect. Nevertheless, we surmised that well-being requires approach-related tendencies beyond those associated with positive affect (e.g., goal-directed anticipation of future positive events), and therefore hypothesized that frontal asymmetry would continue to explain unique variance in well-being even when we statistically controlled for positive affect.

METHOD

Participants

We recruited 84 (41 females) right-handed individuals from the Wisconsin Longitudinal Study, a long-standing effort to comprehensively describe the sociodemographic and psychological trajectories of approximately 10,000 men and women who were Wisconsin high school seniors in 1957 (see <http://dpls.dacc.wisc.edu/wls> for more information about this sample). The mean (*SD*) age of our sample at the time of the EEG session was 58.49 (0.81) years, and the range was from 57 to 60 years. Informed consent was obtained, and the rights of participants were protected according to the procedures set forth by the Health Sciences Human Subjects Committee at the University of Wisconsin-Madison.

Materials and Procedure

Self-Report Measures

For the measure of eudaimonic well-being, subjects completed the Scales of Psychological Well-Being (Ryff, 1989), an 84-item self-report questionnaire with six subscales: Autonomy (Cronbach's $\alpha = .82$ in this sample), Environmental Mastery ($\alpha = .91$), Personal Growth ($\alpha = .91$), Positive Relations With Others ($\alpha = .87$), Purpose in Life ($\alpha = .91$), and Self-Acceptance ($\alpha = .92$). Responses were provided on a 6-point Likert-type scale (1 = *strongly disagree*, 6 = *strongly agree*). Subscale scores were computed by recoding relevant items so that higher scores indicate greater well-being and then summing the 14 items within each subscale. A total PWB score was computed by summing the six subscale scores ($\alpha = .97$). The PWB scales were completed as part of a mailing that occurred, for the majority of subjects, prior to the laboratory session.

We measured the life-satisfaction component of hedonic well-being at the laboratory session using the Satisfaction With Life Scale (SWLS; Diener, Emmons, Larsen, & Griffin, 1985). The SWLS is a 5-item self-report questionnaire ($\alpha = .91$) that assesses global satisfaction with life with items such as "So far I have gotten the important things I want in life." Participants responded using a 7-point Likert-type scale (1 = *strongly disagree*, 7 = *strongly agree*).

Also administered at the laboratory session, the Positive and Negative Affect Schedule (PANAS; Watson, Clark, & Tellegen, 1988) assessed participants' reported levels of dispositional positive affect. For this measure, participants are asked to describe how intensely (1 = *very slightly*, 5 = *extremely*) they generally experience 20 different feelings and emotions. The 10 positive-affect (PA) items include adjectives such as "interested," "excited," and "strong" ($\alpha = .89$). High scores on the PA scale indicate "a state of high energy, full concentration, and pleasurable engagement" (Watson, Clark, & Tellegen, 1988, p. 1063); thus, this measure reflects *approach-oriented* positive affect.

EEG Recording, Reduction, and Analysis

We recorded 29 channels of EEG activity using a stretch-lycra electrode cap (Electro-Cap International, Eaton, Ohio) in accordance with the 10-10 System (American Electroencephalographic Society, 1991). Vertical and horizontal electro-oculographic activity was recorded over the supra- and suborbit of one eye and over the external canthus of each eye, respectively (gain = 10K). Participants were also prepared for recording of other electrophysiological measures that are not reported here. We collected eight 1-min trials of resting EEG data referenced on-line to physically linked ears (gain = 20K), four with eyes open and four with eyes closed, in one of two counterbalanced orders. EEG electrode impedances were less than 5 k Ω .

After the raw EEG data were manually scored for eye movement and muscle artifact, a low-pass filter of 200 Hz was applied. We then computed alpha (8–13 Hz) power for all artifact-free 1-s epochs (overlapping by 50%) using an off-line whole-head average reference and a fast Hartley transform. The mean (*SD*) number of artifact-free 1-s epochs across the eight 1-min trials was 585.78 (136.19). Overall mean alpha power was computed by taking the simple average of eyes-closed and eyes-open power values, each weighted by the number of artifact-free epochs. We log-transformed these data to normalize the distributions and then calculated an asymmetry metric (log right – log left) for alpha power at 13 homologous electrode pairs distributed across the head. Because alpha power is inversely correlated with activation (e.g., Davidson, Chapman, Chapman, & Henriques, 1990), a positive asymmetry score, in which there is more alpha activity on the right than on the left, indicates greater left than right activation. Across the eight 1-min trials, Cronbach's alphas for the asymmetry metrics ranged from .87 to .94, with a median of .92. To index the alpha power unique to each site, we regressed mean whole-head power from the alpha power for each individual site (see Davidson, Jackson, & Larson, 2000, for description of the method). All hypotheses were examined using a one-tailed test ($p < .05$).

RESULTS

Correlations Between Frontal EEG and Self-Report Measures

Greater left than right frontal activation at the frontocentral leads (log FC4 – log FC3) was, as predicted, positively correlated with the total PWB (see Fig. 1), $r = .33$, $n = 75$, $p = .002$, and SWLS scores, $r = .30$,

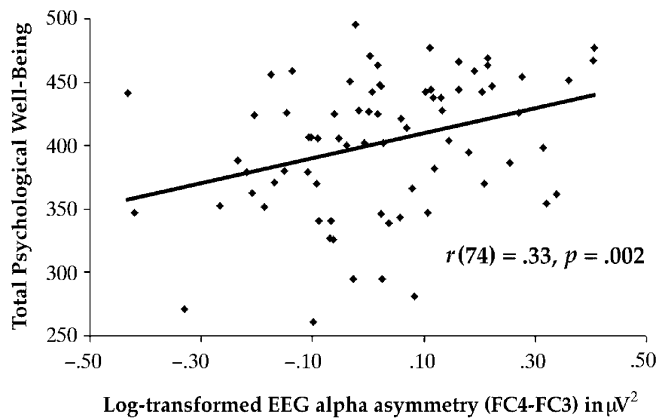


Fig. 1. Scatter plot depicting the correlation between frontal electroencephalographic (EEG) asymmetry (FC4 – FC3) and total psychological well-being. Relative left frontal asymmetry is denoted by positive values on the abscissa.

$n = 75, p = .005$. Relative left frontal activation was also associated with higher levels of reported PA, $r = .21, n = 74, p = .035$. As depicted in Figure 2, the correlations between FC4-FC3 asymmetry and well-being were focal, given the absence of significant correlations between well-being and EEG alpha power asymmetry for the other brain regions. Significant positive correlations were observed between FC4-FC3 asymmetry and five of the six PWB subscales (see Table 1). The scalp topographies of relations between asymmetry and these subscales were similar to the topography shown in Figure 2 for total PWB.

At the left frontocentral site, lower levels of alpha power (i.e., greater activation) were significantly associated with higher levels of self-acceptance, environmental mastery, personal growth, and total PWB (see Table 1). There were no significant correlations between left-sided alpha and hedonic well-being, nor between right-sided alpha and either form of well-being. Tests for differences between dependent r s (Cohen & Cohen, 1983) indicated that the correlations

between left frontal activity and PWB were significantly larger than the correlations between right frontal activity and PWB, all t s $> 2, p$ s $< .05$ (two-tailed).

Correlations Between Self-Report Measures

There was a strong association between total PWB and dispositional PA, $r = .70, n = 82, p < .001$. The PA score was also correlated with the SWLS score, $r = .26, n = 81, p = .01$, although this association was significantly weaker than that demonstrated between dispositional PA and total PWB, $t(78) = 4.61, p < .001$ (two-tailed). The total PWB and SWLS scores were also moderately correlated, $r = .47, n = 81, p < .001$.

Simultaneous and Hierarchical Regression Analyses

Multiple regression analyses revealed that the six frontal EEG asymmetry scores (FPF2-FPF1, FC4-FC3, FP2-FP1, F8-F7, F4-F3, and FC8-FC7) accounted for 27.2% of the variance in the total PWB score, $F(6, 46) = 2.86, p = .01$, and 23.3% of the variance in the SWLS score, $F(6, 46) = 2.33, p = .024$. Results of these analyses were consistent with the correlations presented earlier in this section in that FC4-FC3 was the only region with asymmetry that predicted unique variance in the total PWB, $t(46) = 3.30, p = .001$, and SWLS scores, $t(46) = 2.55, p = .007$. In line with our hypothesis that the association between frontal asymmetry and well-being would in part be accounted for by PA, introducing the PA score on the first step (i.e., controlling for PA) was associated with a 13.4% reduction in PWB variance that was explained by the six frontal asymmetry scores entered on the second step. Similarly, covarying the dispositional PA score was associated with a 9.8% reduction in SWLS variance that was accounted for by frontal asymmetry. Nevertheless, the set of six frontal asymmetry scores continued to predict unique variance in the total PWB score, $\Delta R^2 = .14, \Delta F(6, 45) = 2.62, p = .015$, but not in the SWLS score, $\Delta R^2 = .14, \Delta F(6, 45) = 1.51, p = .099$. Two additional analyses in which we instead examined whether the six frontal asymmetry

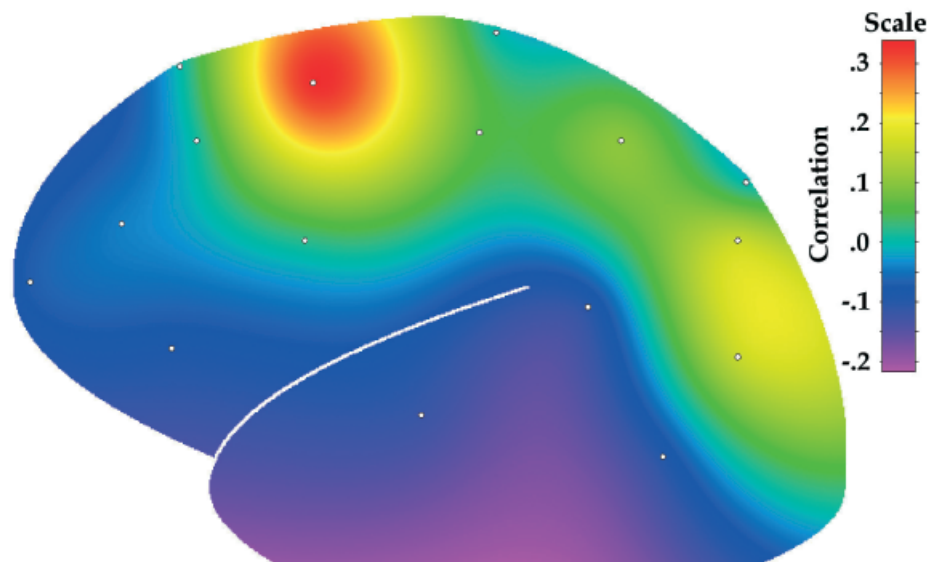


Fig. 2. A topographic representation of correlations between total psychological well-being and electroencephalographic asymmetry across the entire scalp.

TABLE 1
Correlations Between Self-Report Measures and
Electroencephalographic Alpha Power at the Frontocentral Sites

Measure	Asymmetry (FC4 – FC3)	Left hemisphere (FC3)	Right hemisphere (FC4)
Scales of PWB (total)	.33**	-.21*	.07
Self-Acceptance	.39**	-.22*	.10
Positive Relations	.36**	-.14	.14
Purpose in Life	.34**	-.18	.11
Environmental Mastery	.26*	-.19*	.03
Personal Growth	.22*	-.23*	-.02
Autonomy	.08	-.11	-.02
SWLS	.30**	-.13	.10
PA	.21*	-.10	.07
NA	-.11	.13	.05

Note. Whole-head mean alpha power was regressed out of the left and right individual sites. Across correlations, n ranged from 73 to 76. Scales of PWB = Scales of Psychological Well-Being; SWLS = Satisfaction With Life Scale; PA = dispositional positive affect; NA = dispositional negative affect (higher scores indicate more negative affect).

* $p < .05$, one-tailed. ** $p < .01$.

scores would predict variance in the PA score over and above the total PWB or SWLS score were not significant, $ps > .10$.

In the hierarchical analyses, only the FC4-FC3 region predicted unique variance in the total PWB, $\beta = .32$, $sr^2 = .07$, $t(45) = 2.85$, $p = .004$, and SWLS scores, $\beta = .30$, $sr^2 = .06$, $t(45) = 2.02$, $p = .025$, after accounting for PA and the other five frontal regions. Notably, PA did not moderate the relationship between asymmetry and either form of well-being, as six PA \times Asymmetry interaction terms entered on a third step were not significant, all $ps > .10$. However, mediation by PA was supported when Aroian's second-order test of the intervening-variable effect (Aroian, 1947; cf. MacKinnon, Lockwood, Hoffman, West, & Sheets, 2002) confirmed a significant indirect effect of FC4-FC3 asymmetry on PWB by way of dispositional PA, $z = 1.76$, $p = .04$, an effect that was not significant for satisfaction with life, $z = 1.24$, $p = .11$.

Of importance in dissociating the two forms of well-being under investigation, analyses of individual leads for this frontocentral region (FC3 and FC4) showed that when dispositional PA was partialled out, left frontocentral alpha power alone was associated with the total PWB score, $pr(72) = -.20$, $p = .046$, but not with the SWLS score, $pr(72) = -.01$, $p = .453$. Right frontocentral alpha power was not significantly associated with either the total PWB, $pr(71) = .02$, $p = .420$, or SWLS score, $pr(71) = .16$, $p = .086$.¹

Two multiple regression analyses examining the set of nonfrontal EEG asymmetry scores (C4-C3, T4-T3, T6-T5, CP4-CP3, CP6-CP5, P4-P3, and PO4-PO3) as predictors of the total PWB and SWLS scores revealed no significant effects, both $ps > .10$.

¹We tested whether the association between frontal asymmetry and well-being could be accounted for by social desirability as measured by the Marlowe-Crowne Social Desirability Scale (Crowne & Marlowe, 1960). Modeling it on the first step of the regressions did not change the pattern of results.

DISCUSSION

The Role of Left Frontal Activation in Well-Being

Greater left than right PFC activation is associated with dispositional PA (Tomarken et al., 1992), increased reactivity to positively valenced emotional stimuli (Tomarken, Davidson, & Henriques, 1990; Wheeler et al., 1993), enhanced ability to recover from negative-affective challenge (Jackson et al., 2003), and facility with voluntarily suppressing negative affect (Jackson, Burghy, Hanna, Larson, & Davidson, 2000). We believe that the association between frontal asymmetry and affect reflects a lateralized role for the PFC in the instantiation of approach and withdrawal motivational tendencies that are part and parcel of affective responses. The left PFC is active in response to appetitive stimuli that evoke the experience of PA because these stimuli induce a fundamental tendency to approach the source of stimulation.

Hypothesizing that a behavioral style notable for engagement with goal-directed stimuli should contribute to well-being, we systematically examined relations between individual differences in baseline prefrontal activation asymmetry and two widely used, validated measures of well-being. We have documented a modest but robust relationship between lateralized activation over a posterior region of the superior frontal cortex and both eudaimonic well-being, understood as purpose, mastery, strong relationships, and self-acceptance, and hedonic well-being, operationalized as the subjective sense that life is satisfying. Individuals evidencing tonic left frontal activation are more apt than individuals showing tonic right frontal activation to "organize limited resources in support of goal-approaching behaviors" (Sutton & Davidson, 1997, p. 209); thus, we believe these data underscore the importance of such behavioral engagement to achieving well-being. We suggest that taking an active role in life and appropriately engaging sources of appetitive motivation, behaviors that are characteristic of left frontal individuals, may contribute to higher levels of well-being. Although more work will be needed to understand the role played by specific brain structures within the PFC and also in other regions, at this point we know that the left frontal region is more important for well-being than the right, and that asymmetric activation over posterior cortical regions is not associated with well-being.

We have also demonstrated that approach-related PA is an important factor in understanding the predictors of well-being. This study replicated prior work in that PA was a significant independent predictor of both hedonic and eudaimonic forms of well-being. Despite the role of PA as a partial mediator of the association between asymmetry and well-being, we confirmed our prediction that frontal EEG asymmetry explains variation in well-being beyond that which is accounted for by approach-oriented PA, an effect that was significant only for eudaimonic well-being. Moreover, hemisphere-specific analyses demonstrated that left prefrontal activation was associated with eudaimonic but not hedonic well-being after the variance associated with PA was removed. Collectively, these findings suggest that goal-directed approach tendencies not captured by approach-related PA (e.g., challenging oneself and striving to achieve in the face of adversity) may be more important for attaining eudaimonic than hedonic well-being.

Strengths, Limitations, and Future Directions

We drew participants from a longitudinal study of individuals who all were high school seniors in 1957 in the state of Wisconsin. We were in

the fortunate position, therefore, of controlling well for variability due to age—all participants were mature adults of very similar ages. However, given the limited variability in age, the findings reported here are less generalizable than would have been the case if we had sampled across a broader range of ages. Additionally, there was no way to assess the extent to which there may be age-related changes in the relationship between brain activity and well-being. Indeed, studies have shown age-related changes in brain structure and function (Coffey et al., 2001; Kolev, Yordanova, Basar Eroglu, & Basar, 2002) that may have important consequences for relations between brain activity and well-being. Future studies might usefully address this issue by systematically sampling younger and older cohorts. Such studies might also investigate whether the neural circuitry that is associated with the two modes of well-being described here has downstream effects on physical health. Such effects may be present only in older groups, in which clinically significant health problems, such as cardiovascular dysfunction and cancer, are more prevalent.

It is unclear to us why our findings were limited to the frontocentral leads. This region is more posterior than the frontal regions that have revealed significant associations with affective-style measures in many studies in the past (see review by Coan & Allen, 2002), though certainly not all. At least one study has suggested that activity in this region may reflect supplementary motor area activation (Sailer, Dichgans, & Gerloff, 2000), which raises the possibility that approach-related behavioral tendencies are associated in part with tonic activation in the supplementary motor region. More definitive understanding of the sources of these signals must await systematic study of the source localization of these scalp-surface recordings.

Finally, it must be noted that our EEG data are based on recordings from a single session only. Although we confirmed with these data the very high (range = .87–.94) internal consistency reliability of the EEG asymmetry measures that we have reported in the past (Tomarken et al., 1992), it must still be emphasized that aggregating data over more than a single session would help to improve our estimates of the true trait asymmetry values of our participants. It might also be the case that measures of EEG asymmetry are more temporally stable in an older population, at least over a relatively short time interval, than in the undergraduate-student samples that have typically been studied in the past. Older individuals would be expected to exhibit regularities in daily living that would contribute to their having greater EEG asymmetry stability compared with younger student participants.

Conclusion

This work contributes to a growing body of literature on what makes a life worth living, whether such worth is measured in terms of a priori characteristics like feeling there is a purpose to one's life and exercising mastery in one's environment, or in terms of a subjective sense that life is good. Using self-report and electrophysiological methods, we have demonstrated that dispositional PA and an approach-oriented behavioral style, objectively measured using an index of asymmetric frontal function, separately contribute to two theoretically derived forms of well-being. We have further shown that left frontal activation predicts eudaimonic but not hedonic well-being when variation in dispositional PA is statistically controlled. Goal-relevant approach tendencies not captured by highly engaged PA may be more critical for attaining eudaimonic than hedonic well-being.

Acknowledgments—The research reported in this article was supported by grants from the National Institute of Mental Health (MH43454, P50-MH52354, and P50-MH61083) and by a General Clinical Research Center grant from the National Center for Research Resources at the National Institutes of Health (M01-RR03186). H.L.U., J.B.N., D.C.J., and M.A.R. were supported by T32-MH18931 (R.J.D., Director). J.B.N. was also supported by K08-MH63984, a grant from the Fetzer Institute, and a HealthEmotions Research Institute Fellowship. The authors wish to thank Brian Ostafin, Candice Koepsel, Ae Reyoung, and Jennifer Orendi for their help in collecting and processing these data.

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(RECEIVED 3/14/03; REVISION ACCEPTED 10/13/03)