Psychology and Aging
2005, Vol. 20, No. 3, 476–485

0882-7974/05/$12.00 DOI: 10.1037/0882-7974.20.3.476

Cardiovascular Intraindividual Variability in Later Life: The Influence of Social Connectedness and Positive Emotions

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Healthy normotensive men and women ($N = 33$) underwent a 60-day diary assessment of emotions and cardiovascular functioning. Individual differences in social connectedness and mood were measured in questionnaires, and positive emotions, negative emotions, systolic blood pressure (SBP), and diastolic blood pressure (DBP) were assessed daily for 60 consecutive days. Results confirmed that the cardiovascular undoing effect of positive emotions is evident primarily in the context of negative emotional arousal. The daily associations between positive emotions and cardiovascular outcomes were linked to individual differences in social connectedness. Controlling for individual differences in mood levels, multilevel regression analyses showed that social connectedness predicted extended positive emotion, diminished SBP and DBP reactivity, and more rapid SBP recovery from daily negative emotional states.

There is robust epidemiological evidence of a graded association between resting levels of blood pressure (BP) and cardiovascular morbidity and mortality across the life span (Chobanian et al., 2003; Psaty et al., 2001). Although pulse and diastolic blood pressure (DBP) are regarded as important indices of cardiovascular functioning, a growing body of empirical evidence suggests that elevated systolic blood pressure (SBP) is the primary underlying predictor of hypertension, particularly among older adults (Kannel, 2000; Pastor-Barriuso, Banegas, Damian, Appel, & Guallar, 2003; Port, Demer, Jennrich, Walter, & Garfinkel, 2000). In fact, an analysis of the Framingham Heart Study found that SBP alone correctly classified hypertensive stage in 99% of adults older than 60 years, whereas DBP correctly classified only 66% (Lloyd-Jones et al., 1999). Given that isolated systolic hypertension is the most common form of hypertension in individuals older than 65 (Izzo, Levy, & Black, 2000), it is important to understand what factors place older adults at greater or lesser risk for the development and expression of cardiovascular disorders.

One important determinant of cardiovascular risk is mood (see Kamarck et al., 1998; Räikkönen, Matthews, Flory, Owens, & Gump, 1999; Schwartz, Warren, & Pickering, 1994). The onset of negative affect (NA), for example, is linked to both heightened cardiovascular reactivity and delayed cardiovascular recovery (see Blascovich & Katkin, 1993; Krantz & Manuck, 1984), two processes that signal early signs of coronary dysregulation (Gerin & Pickering, 1995; Hocking-Schuler & O'Brien, 1997; Linden, Earle, Gerin, & Christenfeld, 1997). Social support and positive affect (PA), in turn, have been implicated in this process as important moderators of the relationship between NA and cardiovascular activation. That is, high levels of social support and PA are presumed to attenuate reactivity and speed recovery from the cardiovascular sequelae of NA (cf. Cohen, Kaplan, & Manuck, 1994; Fredrickson & Levenson, 1998).

Despite considerable research demonstrating the buffering influence of social support and PA on coronary-related morbidity and mortality (see Cohen, 1988; Fredrickson & Levenson, 1998; House, Landis, & Umberson, 1988; Kiecolt-Glaser & Newton, 2001; Seeman, 2001; Uchino, Cacioppo, & Kiecolt-Glaser, 1996), a number of important questions remain unanswered. For instance, do previous findings pertaining to the interpersonal and emotional correlates of, and contributors to, cardiovascular functioning extend to older adults (see Hawkley, Burleson, Berntson, & Cacioppo, 2003; Holt-Lunstad, Uchino, Smith, Olson-Cerny, & Nealey-Moore, 2003)? Although positive emotions have been shown to suppress the cardiovascular aftereffects of negative emotions in young adults (e.g., Fredrickson & Levenson, 1998; Fredrickson, Mancuso, Branigan, & Tugade, 2000), few studies have examined the cardiovascular effects of positive emotions in older adults. This is an especially important gap in the literature given that the health effects of emotional processes are thought to be most influential during the period surrounding late life, when biological vulnerability is greatest (Baltes, Staudinger, Lindenberger, 1999; Kiecolt-Glaser, McGuire, Robles, & Glaser, 2002). In addition, most studies linking social support to age-related changes in cardiovascular functioning have tended to focus on the physiological correlates of interpersonal conflicts (e.g., Ewart, Taylor, Kraemer, & Agras, 1991; Levenson, Carstensen, & Gottman, 1993) rather than interpersonal strengths (see Ryff & Singer, 2000; B. Singer & Ryff, 1999). The question of how social connectedness, defined as having quality ties to others (cf. Keyes,

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Partial support for this study was provided by the Association for Gerontology in Higher Education, American Association of Retired Persons Andrus Foundation Doctoral Fellowship in Gerontology, and the Wayne State University's Vice President for Research. We thank Scott Maxwell for helpful comments on an earlier version of this article, and Michael Marsiske for his contributions to the study design and data collection.

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Shmotkin, & Ryff, 2002; Ryff, 1989), is linked to cardiovascular health is of particular importance for older adults given the stability and centrality of interpersonal relationships in late life (Carstensen, 1992; Lang, 2001; Lang & Carstensen, 1994). Crucially needed, therefore, are studies that probe the emotional pathways by which the positive aspects of social relationships (e.g., affection, attachment, intimacy) contribute to cardiovascular health in later adulthood (Ryff & Singer, 2000; B. Singer & Ryff, 1999).

A related gap in the literature is the implicit assumption that cardiovascular responses detected in the laboratory generalize to cardiovascular functioning as experienced in everyday life (Krantz & Manuck, 1984; Pickering & Gerin, 1990). Relatively few studies have systematically addressed whether the physiological substrates of daily affect are temporary, resulting in slight and transient changes in BP, or whether the effects accumulate over time, increasing the level of immediate cardiovascular arousal as well as its duration (Cacioppo, 1998; Hawkley & Cacioppo, 2004). This is a particularly important gap given that sympathetically mediated hyperreactivity to everyday stressors has been posited to represent one mechanism by which negative emotions affect immune function (Cacioppo, 1994; Uchino, Berntson, Holt-Lunstad, & Cacioppo, 2001). Accumulating evidence also suggests that prolonged recovery from stress and negative emotions may indicate altered cardiovascular functioning (Gerin & Pickering, 1995; Haynes, Gannon, Orimoto, O'Brien, & Brandt, 1991; Hocking-Schuler & O'Brien, 1997) and predict subsequent hypertension (Borghi, Costa, Boschi, Mussi, & Ambrosioni, 1986). Although the foregoing studies underscore the importance of distinguishing the processes underlying cardiovascular risk, investigations of the daily physiological substrates of social connectedness and their role in promoting cardiovascular health in later life are also needed (Ryff & Singer, 2000; Ryff, Singer, Wing, & Love, 2001). As emphasized by Uchino et al. (1996), there is a need for studies that link social processes to multiple physiological systems and to track their dynamic relations through time.

The current study was designed to address these unanswered questions and further test the premise that maintenance and restoration of cardiovascular health in later adulthood result from the dynamic interplay between multiple protective factors operating at different levels of analysis. To this end, the primary aim of the study was to examine how the within-person association between daily affect and BP varied as a function of individual differences in social connectedness. In addition to investigating the boundary conditions associated with concurrent BP responses, an ancillary aim was to examine the unique ways in which social connectedness and positive emotions function to attenuate lingering autonomic activity in older adults.

It was expected that daily negative emotions would have an independent contribution to concurrent BP (Blascovich & Katkin, 1993; Krantz & Manuck, 1984). In addition, we anticipated an interaction between daily negative and positive emotions. Following previous research, we hypothesized that the cardiovascular impact of positive emotions is evident primarily in the context of negative emotional arousal (cf. Fredrickson & Levenson, 1998; Fredrickson et al., 2000). Further, social connectedness was expected to have cross-day contributions to emotion and BP (Hawkley et al., 2003; Ryff & Singer, 2000). Specifically, we predicted that, compared with less connected individuals, socially connected individuals would show extended positive emotion, diminished BP reactivity, and more rapid BP recovery from daily negative emotional arousal.

The current study combines a number of features that distinguish it from previous research in this area: the statistical control of background (i.e., age, gender, marital status) and personality (i.e., trait positive and NA) variables thought to influence BP outcomes; the modeling of short-term concurrent and lagged relationships between emotional states and BP responses; and a specific focus on the contribution of individual differences in social connectedness to the daily ebb and flow of patterns of cardiovascular activity in later life.

Method

Participants

The current study was conducted using data from 33 community-dwelling older adults (10 men and 23 women) recruited from local senior centers who completed an extensive daily assessment protocol. Participants ranged in age from 60 to 87 years ($M = 74$, $SD = 5.64$ years) and were highly educated ($M = 16$, $SD = 3.08$; range = 12–22 years). The average reported household income was \$29,000 ($SD =$ \$6,000; range = \$12,000–\$50,000+). In addition, 31 of the participants identified themselves as White and 2 participants reported their racial status as African American.

Measures

Social connectedness. Participants' perceptions of their social connectedness were measured by the Positive Relations With Others (PRWO) subscale of the Psychological Well-Being Measure (Ryff & Keyes, 1995). The scale consists of 14 items, each responded to on a 6-point Likert scale ranging from 1 (*does not apply to me at all*) to 6 (*applies very strongly*). Sample items include "Most people see me as loving and affectionate" and "I know that I can trust my friends, and they know they can trust me." The items were averaged so that higher scores were indicative of greater social connectedness ($\alpha = .92$).

PA and NA. Both trait and daily PA and NA were measured using the Positive and Negative Affect Schedule (PANAS; Watson, Clark, & Tellegen, 1988). Participants were asked to indicate the extent to which they had experienced a range of emotions. Ratings were made on a 5-point scale ranging from 1 (*very slightly* or *not at all*) to 5 (*extremely*). The PANAS consists of 10 items from the NA scale (afraid, ashamed, distressed, guilty, hostile, irritable, jittery, nervous, scared, upset) and 10 items from the PA scale (active, alert, attentive, determined, enthusiastic, excited, inspired, interested, proud, strong). Reliability data indicated alphas of .86 for both the trait NA and PA scales, respectively.

Cardiovascular functioning. In the current study, BP was used as the primary index of cardiovascular functioning. Measures of SBP and DBP were obtained using an Omron automatic digital BP monitor with IntelliSense (Omron, Schaumburg, IL), which adjusted the inflation of the occlusion cuff to the appropriate level for each individual. BP assessments were done in a seated position, using the nondominant arm after the participant had sat quietly for 5 min.

Procedure

The participants in the current study completed two testing sessions in which they were administered a large battery of psychological and physiological assessments, which included the BP, PANAS, and PRWO measures. Both testing sessions were done in groups of 4 to 10 participants and were proctored by a trained tester. After completing the two sessions, participants began the repeated-assessment portion of the study. Participants were asked to complete a daily workbook twice a day, once in the morning and once at night, for 60 consecutive days. The Daily Workbooks contained a number of measures (see Allaire & Marsiske, in press), including the PANAS and the self-assessment of BP.

Before beginning the daily assessment, each participant attended an orientation session in groups of 2 to 5 individuals where they received instructions on how to self-administer the measures in the workbook. A trained proctor guided the participants through an example workbook, thoroughly explaining the instructions for each of the measures. Participants were also given extensive practice self-administering the BP assessment, and directive feedback was provided. Participants were given four guidelines to which they were asked to adhere over the course of the study: (a) Two workbooks must be completed every day, one in the morning (within 2 hr of waking) and one at night (within 2 hr of going to bed) for 60 consecutive days; (b) workbooks were to be completed without receiving outside assistance; (c) if a workbook entry was skipped, it was to be left blank instead of making it up at a later time; (d) all workbooks were to be mailed back to the project office using envelopes with prepaid postage at the end of every week. Although each measure in the workbook was presented with instructions, participants also received a detailed daily mental exercise instructional manual, which provided additional instructions as well as a pictorial demonstration of the appropriate method for applying the BP cuff.

Although design of the current study allowed for the daily assessment of BP and affect with minimal intrusion on participants' daily lives, the self-administration of affect and BP does raise concerns regarding compliance with study protocol. Consequently, a number of quality assurance strategies were used throughout the study to minimize deviations from protocol. First, participants were asked to indicate the time a particular workbook was started and completed. On receipt of the returned workbooks, these times were reviewed to determine whether they were, in fact, being completed at the prescribed times. Participants who deviated from protocol were contacted by study staff. Second, returned workbooks were reviewed for completeness, and participants were contacted if a pattern of mistakes or skipped items or measures was found. Third, a message was stapled to the cover of two randomly selected workbooks each week instructing participants to call an answering machine and leave a message that included their identification number. The answering machine stamped their message with the date and time, and those individuals who did not call in were contacted by phone to determine whether they were facing any difficulties completing their workbooks at the appropriate time. Fourth, participants were given day and evening contact numbers for study personnel if additional questions or problems arose over the course of the daily assessment.

Preliminary Data Reduction

The analyses that follow examine the relationships among the within- and between-person variables. The within-person variables included ratings of PA and NA and assessments of SBP and DBP twice a day for 60 consecutive days. The within-day assessments were aggregated for each participant to provide 60 daily NA, PA, SBP, and DBP scores. The total number of days participants were in the study ranged from 46 to 60 ($M = 58$, $SD = 3.77$). The total number of days in the study for all participants was 1,980 (33 participants × 60 days). The total number of days of data the participants provided was 1,920 (97% complete). All within-person variables were centered within each participant to exclude the between-persons variance. The between-level variables were administered before the repeated assessment and included assessments of PA, NA, and social connectedness (PRWO). These measures constituted the trait, or between-person, variables.

Overview of Multilevel Modeling Analyses

We tested our hypotheses using multilevel modeling (MLM; Hox, 2002), also known as hierarchical linear modeling, mixed-effects modeling, and random coefficients modeling (see Raudenbush & Bryk, 2002). The flexibility of MLM provides a number of advantages. First, MLM is appropriate for diary data. In the current study, the data have a hierarchical structure with up to 60 daily observations nested within each of 33 participants. Second, MLM does not require that all individuals be measured at all occasions. Instead, through the use of full information maximum likelihood estimation (Raudenbush & Bryk, 2002), participants who have missing data for some occasions of the study or who are missing a single measure at a specific occasion are still included in the analysis. Finally, an MLM approach allows for the simultaneous estimation of within- and between-person effects. Within-person effects address questions about when and take the following form: "On days in which a person has high negative affect, do they also exhibit elevated BP?" In comparison, between-person effects ask, "Do people who score higher on social connectedness also have a lower level of average BP?" We also asked questions that assessed the interaction between our within-person variables: for example, "On days in which people have high positive affect, is there a weaker relation between daily NA and daily BP?" Finally, we assessed interactions across within- and between-person levels: for example, "Is the within-person association between daily NA and daily BP different in individuals who are low as opposed to high in social connectedness?"

We developed MLM equations predicting SBP and DBP to test our hypotheses. There were several common elements in each of our MLM analyses. First, variables that did not include a meaningful zero in the original scaling (e.g., day of study) were rescaled to include zero. Second, following recommendations by Raudenbush and Bryk (2002), each within-person variable was centered on the individuals' mean, and all between-person variables were centered on sample means. Third, we controlled for trait levels of PA and NA in the prediction of daily BP. Fourth, all lower order (i.e., within-person variables) regression parameters were modeled as random coefficients, thereby allowing individual differences in the estimated intraindividual associations.

Equation 1 describes the simplest within-person (i.e., Level 1) model, specifying that SBP for person j on day i is a function of his or her mean level of SBP (β_{0j}) and a random residual component (e_{ij}):

$$\mathrm{SBP}_{ij} = \beta_{0j} + e_{ij}. \tag{1}$$

The between-person (i.e., Level 2) model is illustrated in Equation 2. Here, individuals' Level 1 coefficients (β_{0j} or average SBP levels) are regressed on the between-person variable social connectedness (γ_{01}) and a between-persons error term (u_{0j}):

$$\beta_{0j} = \gamma_{00} + \gamma_{01}\,\text{social connectedness} + u_{0j}. \tag{2}$$

In Equation 2, (γ_{01}) can be interpreted as the effect of social connectedness on average levels of SBP.

To assess the within-person associations between NA and SBP, the Level 1 model (Equation 1) can be augmented to include time-varying predictors. Equation 3 shows daily SBP as a function of NA:

$$\mathrm{SBP}_{ij} = \beta_{0j} + \beta_{1j}\mathrm{NA}_{ij} + e_{ij}, \tag{3}$$

where SBP_{ij} represents systolic BP on day i for person j. Because we centered our within-person variables, β_{0j} represents person j's predicted level of SBP on a day of average NA; β_{1j} is the within-person slope of the NA–SBP relationship for person j, and e_{ij} is a within-person error or residual term.

Finally, to assess the moderating effects of social connectedness on the within-person associations between NA and SBP, Level 1 slopes were regressed on the Level 2 social connectedness variable. Equation 4 shows the NA–SBP association as a function of social connectedness and a between-persons error term (u_{1j}):

$$\beta_{1j} = \gamma_{10} + \gamma_{11}\,\text{social connectedness} + u_{1j}. \tag{4}$$

Table 1
Multilevel Predictors of Daily Blood Pressure

Predictor	Systolic BP Estimate	Systolic BP p	Diastolic BP Estimate	Diastolic BP p
Intercept (β_0)	131.01	0.001**	72.35	0.002**
β_0 × Average BP	1.001	0.004**	0.999	0.003**
β_0 × Trait PA	−0.001	0.84	−0.002	0.89
β_0 × Trait NA	0.054	0.34	0.023	0.81
β_0 × Social Connectedness	0.001	0.85	0.001	0.92
Negative affect (NA)	0.429	0.02*	0.346	0.04*
NA × Average BP	0.173	0.03*	0.007	0.71
NA × Trait PA	0.012	0.71	0.004	0.87
NA × Trait NA	0.365	0.007**	0.217	0.03*
NA × Social Connectedness	−0.184	0.01*	−0.128	0.02*
Positive affect (PA)	0.131	0.18	−0.053	0.16
PA × Average BP	0.008	0.28	−0.020	0.009**
PA × Trait PA	0.214	0.01*	−0.002	0.73
PA × Trait NA	0.084	0.32	0.018	0.54
PA × Social Connectedness	−0.187	0.04*	−0.005	0.24
NA × PA	−0.694	0.01*	−0.320	0.24
NA × PA × Average BP	−0.008	0.86	−0.006	0.88
NA × PA × Trait PA	0.018	0.78	−0.066	0.09
NA × PA × Trait NA	−0.031	0.61	0.341	0.06
NA × PA × Social Connectedness	−0.217	0.02*	−0.068	0.09

Note. β_0 = intercept; BP = blood pressure.
* $p < .05$. ** $p < .01$.

In Equation 4, γ_{10} can be interpreted as the predicted value of the NA–SBP association at average levels of social connectedness and γ_{11} as the partial relationship between social connectedness and the NA–SBP relationship. Following Raudenbush and Bryk (2002), the above within- and between-person equations can be solved simultaneously and expressed in a single equation as follows:

$$\text{SBP}_{ij} = \gamma_{00} + \gamma_{01}\,\text{social connectedness} + \gamma_{10}\,(\text{NA}) + \gamma_{11}(\text{NA} \times \text{social connectedness}) + u_{0j} + u_{1j} + e_{ij}. \quad (5)$$

Equation 5 illustrates how SBP for a given person and day is a function of within- and between-person variables as well as within- and between-person errors. To assess the effects of PA and its interaction with NA, as well as higher order interactions with social connectedness, Equation 5 was expanded to include the various two- and three-way interactions of NA, PA, and social connectedness. As a descriptive index, we calculated the percentage reduction of within- and between-person residual variances for each step according to the formulas provided by Bryk and Raudenbush (1992; see also Kreft & de Leeuw, 1998).

Results

Descriptive Findings

Overall, neither age nor years of education showed significant relationships with either the within- or between-person variables. Over all daily reports, moderately low intercorrelations were observed between daily NA and PA scales ($r = -.11$, $p < .001$). Daily SBP was positively associated with daily NA ($r = .22$, $p < .001$) and DBP ($r = .47$, $p < .001$), respectively.[1] Social connectedness was significantly correlated with daily PA ($r = .54$, $p < .01$) but was unrelated to daily NA ($r = -.21$, *ns*). With the exception of social connectedness, none of the key study variables differed by gender (*ps* > .20). In comparison with men (M = 42.53, SD = 11.79), women reported higher levels of social connectedness (M = 52.23, SD = 8.48), $t(31) = 7.16$, $p < .05$.

Covariates of BP

Before examining the associations among social connectedness, affect, and BP, we first examined the potential contribution of various between-person covariates (Schwartz et al., 1994). Results of this initial analysis revealed that trait PA was associated with lower levels of SBP ($b = -.19$, $SE = .06$, $p < .05$), whereas trait NA was associated with elevations in both daily SBP ($b = .37$, $SE = .08$, $p < .01$) and DBP ($b = .29$, $SE = .04$, $p < .05$), respectively (see Table 1). Finally, none of the demographic variables (i.e., age, education, gender, income) was significantly associated with the cardiovascular indexes. Subsequent MLM analyses, therefore, were conducted with trait NA and PA as between-person covariates.

The Influence of Affect and Social Connectedness on BP

We first examined how average levels of SBP and DBP each varied as a function of social connectedness. We regressed the Level 1 intercepts (i.e., average levels of SBP and DBP) on social connectedness. Inclusion of the Level 2 predictor variable resulted in a 10.7% and 7.5% decrease in residual intercept variance in

[1] Summary within-person correlations were converted to Fisher's z' equivalents (Cohen, J., & Cohen, P. 1983), which were weighted on the basis of their estimated standard errors, averaged, and evaluated for significance. Reported values reflect the reconversion of averaged Fisher's z' scores back to r values to facilitate interpretation.

daily SBP and DBP, respectively. Next, we regressed daily SBP and DBP on daily NA. Inclusion of daily NA ratings in the Level 1 model resulted in a 7.4% and 4.9% reduction of the residual within-persons variance in SBP and DBP, respectively. We then added PA and the PA × NA interaction term to the model. Inclusion of these predictors resulted in an additional 12.8% and 8.4% reduction of within-person residual variance in SBP and DBP, respectively. Finally, we examined how the Level 1 slopes (NA–BP, PA–BP, and the NA × PA interaction) varied as a function of social connectedness. Inclusion of the Level 2 predictor resulted in a 4.3% and 2.1% reduction in residual slope variance in SBP and DBP, respectively.

Concurrent effects. A key question of the current study involves whether daily affect and daily BP are concurrently related. The results of the MLM analyses predicting daily BP indicated that higher levels of daily NA were associated with higher daily SBP ($b = .43$, $SE = .04$, $p < .03$) and DBP ($b = .35$, $SE = .02$, $p < .05$) after controlling for between-person differences in trait PA and NA, respectively. In addition, daily PA interacted with daily NA to weaken its influence on SBP ($b = -.69$, $SE = .04$, $p < .02$). This interaction was decomposed by estimating the relationship between NA and SBP at 1 *SD* above and below the mean in PA (Aiken & West, 1991). The addition of the daily PA × NA interaction reduced the variance of the NA–SBP association; that is, NA and SBP were positively and significantly related at lower levels of PA ($b = -.36$, $SE = .07$, $p < .01$). Figure 1 displays how the relative absence of daily PA interacts with NA to increase daily levels of SBP.

We also examined whether the individual slopes relating PA and NA to BP were predictable from individual differences in social connectedness. The findings indicate that for individuals high in social connectedness (1 *SD* above the mean in social connectedness), there was a significant reduction in the magnitude of the NA–SBP association on days in which greater PA was also present ($b = -.22$, $SE = .04$, $p < .03$). Finally, higher levels of social connectedness interacted with NA to attenuate its effect on both SBP ($b = -.18$, $SE = .02$, $p < .01$) and DBP ($b = -.13$, $SE = .03$, $p < .02$), respectively. As shown in Figures 2 and 3, the slope of the line defining the NA and BP association was steeper among persons low in social connectedness than those high on the trait.

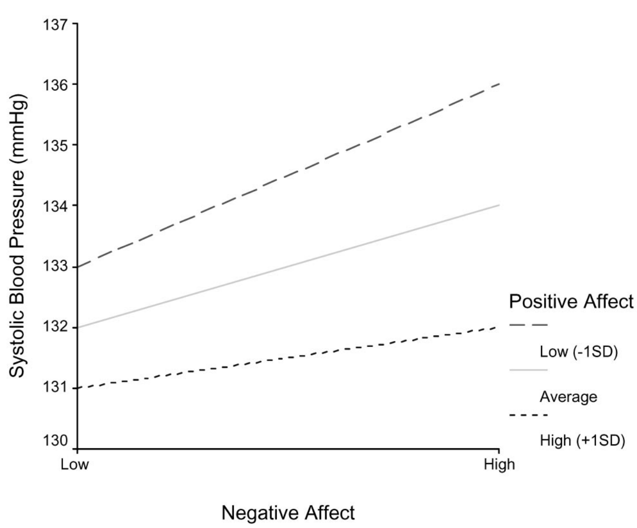

Figure 1. Concurrent relationship between negative affect and systolic blood pressure as a function of positive affect. High and low positive affect were defined as one standard deviation from the mean.

Lagged effects. Because concurrent associations between affect and BP may in part reflect the effects of BP on affect (Kamarck et al., 1998), we also focused on lagged associations. Lagging predictor variables permits the investigation of whether, for example, affect measured at time $t - 1$ exerts a valence-specific or crossover effect on affect measured at time t. Using lagged predictors also allows us to make stronger claims about the directionality of effects (e.g., whether the daily fluctuations between affect and BP are unidirectional or bidirectional in nature). In addition, multilevel modeling makes it possible to study inter-individual differences in the lagged relationships between lower level variables. Thus, for example, we can examine the extent to which individual differences in social connectedness reduce the impact of prior-day NA on next-day BP. To rule out the possibility that any lagged effect of affect on BP might be an artifact of initial BP level, baseline levels of SBP and DBP were included in the model as control variables. In such a model, the dependent variable can be interpreted as the residual change in BP from day t to day $t + 1$ (Kessler & Greenberg, 1981).

The analysis model for changes in BP for each individual can be written as follows:

$$\Delta D_{t+1} = \beta_{0j} + \beta_{1j}D_t + \beta_{2j}NA_t \pm \beta_{3j}PA_t + e_{t+1}, \qquad (6)$$

where ΔD_{t+1} is the change in BP between day t and day $t + 1$; β_{0j} is a regression intercept for person j. β_{1j} represents an individual's level of BP on day t (with the grand mean across all person-days subtracted)[2]; $\beta_{2j} - \beta_{3j}$ are the within-person slopes of the NA–BP and PA–BP relationships on day t for person j, respectively; and e_{t+1} is a residual component of change in BP. A similar model can be expressed for PA and NA.

Table 2 shows that both NA and PA at time $t - 1$ predicted next-day NA and PA. In addition, NA at $t - 1$ had a valence-specific effect on both next-day PA ($b = -.21$, $SE = .10$, $p < .05$) and SBP ($b = .33$, $SE = .15$, $p < .05$), indicating that elevations in NA were associated with lower PA and higher SBP the following day. The results also indicate that some effects are still in evidence several days later. Additional analyses revealed that PA continued to precipitate subsequent PA even after two lags ($b = .31$, $SE = .05$, $p < .01$).

We also investigated the extent to which interindividual differences in the slopes relating lagged predictors to outcome variables could be explained by social connectedness. That is, the Level 1 (within-person) slopes, $\beta_{2j} - \beta_{3j}$, represent dependent variables in the Level 2 (between-person) equations. The Level 2 equations express each randomly varying effect as a function of a mean value (the effect for the average person) plus a deviation (the extent to which each individual's effect is higher or lower than the effect for the average person). The equations are as follows:

[2] Because the associations between variables of interest may reflect the influence of linear trends, we included day of study as a control variable in all analyses.

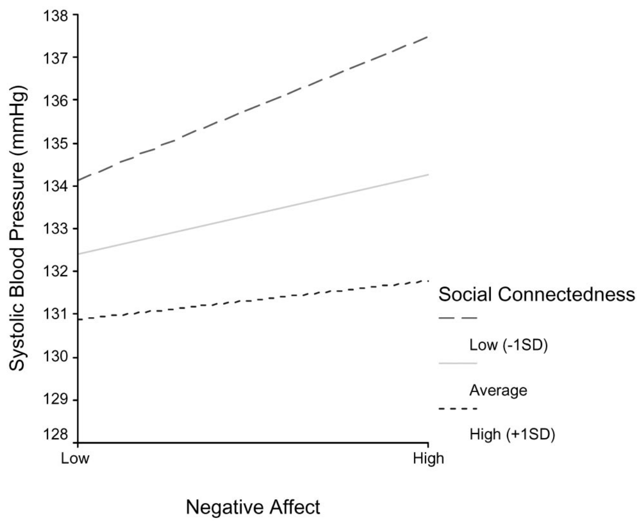

Figure 2. Concurrent relationship between negative affect and systolic blood pressure as a function of social connectedness. High and low social connectedness were defined as one standard deviation from the mean.

$$\beta_{2j} = \gamma_{20} + \gamma_{21}\text{SBP}' + \gamma_{22}\text{DBP}' + \gamma_{23}\,\text{social connectedness} + s_i.$$

$$\beta_{3j} = \gamma_{30} + \gamma_{31}\text{SBP}' + \gamma_{32}\text{DBP}' + \gamma_{33}\text{socialconnectedness} + s_i. \quad (7)$$

Thus, Equation 7 indicates that each participant's daily coefficient for NA and PA is a function of an intercept, baseline levels of SBP′ and DBP′, a social connectedness component, and a random component (the random component, s_i, is assumed to be drawn from a normal distribution with mean 0 and variance σ^2_s).

We hypothesized that the coefficient for the Social Connectedness × NA interaction would be negative, reflecting that social connectedness reduces the effect of NA on next-day BP. The results point to two valence-specific cross-level interactions. As predicted, social connectedness negatively predicted person–level slopes such that the effect of NA on SBP (assessed two lags later) was more pronounced in individuals low in social connectedness ($b = -.24$, $SE = .06$, $p < .05$). The reverse lead–lag relationship connecting social connectedness and SBP to NA did not garner statistical support, however.[3] Finally, the mood-boosting effects of daily PA were particularly durable (i.e., an effect spanning 3 days) among persons high in social connectedness ($b = .23$, $SE = .01$, $p < .05$) relative to those low on the trait ($b = -.06$, $SE = .17$, $p > .10$). Taken together, the findings suggest that socially connected individuals are more likely to strategically mobilize positive emotions not only to shore up resistance to ongoing negative emotions but also to generate upward spirals of prolonged positive emotionality.

Table 2
Lagged Relationships Between Affect and Blood Pressure

Today	Next day	*b*	*SE*	*p*
NA	NA	0.059	0.027	0.04*
PA	PA	0.402	0.043	0.001**
SBP	SBP	0.153	0.029	0.001**
DPB	DPB	0.108	0.027	0.001**
NA	SBP	0.331	0.152	0.04*
SBP	NA	0.005	0.004	0.25
PA	SBP	−0.067	0.081	0.42
SBP	PA	−0.020	0.015	0.19
NA	DBP	0.099	0.083	0.24
DPB	NA	0.005	0.006	0.39
PA	DBP	−0.030	0.037	0.41
DPB	PA	−0.004	0.024	0.86
NA	PA	−0.204	0.097	0.04*
PA	NA	0.004	0.009	0.70

Note. NA = negative affect; PA = positive affect; SBP = systolic blood pressure; DBP = diastolic blood pressure.
* $p < .05$. ** $p < .01$.

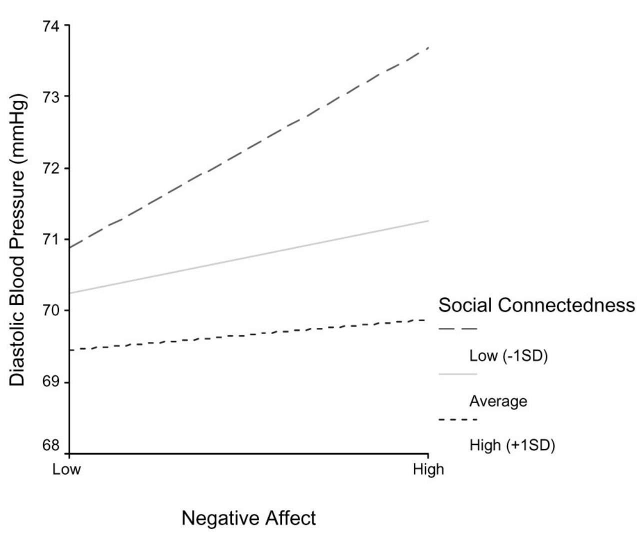

Figure 3. Concurrent relationship between negative affect and diastolic blood pressure as a function of social connectedness. High and low social connectedness were defined as one standard deviation from the mean.

Discussion

The socioemotional contexts in which individuals develop exert strong influences on health and well-being, such that those who develop in environments that provide supportive social relations and positive emotional experiences do better than those who develop in environments bereft of the same resources (cf. Fredrickson, 1998; Uchino et al., 1996). The results of the current study suggest that several of the predicted relationships among social connectedness, affect, and cardiovascular outcomes previously observed at the group level with younger adults (e.g., Fredrickson et al., 2000; Hawkley et al., 2003) also can be observed at the individual or within-person level in older adults.

To restate our central findings, both positive emotions and social connectedness moderated the relationship between daily negative emotions and BP. At the within-person level, daily positive emo-

[3] We note that, although lagged and cross-lagged correlations provide some indication of the lead–lag relationship between two constructs, they are by no means a tool for making causal inferences (Rogosa, 1979).

tions were shown to reduce or undo cardiovascular activation following negative emotions (Fredrickson & Levenson, 1998; Fredrickson et al., 2000). At the between-person level, persons high in social connectedness displayed diminished BP reactivity and more rapid BP recovery following negative emotional arousal (Hawkley et al., 2003; Uchino & Garvey, 1997). Additionally, chronically low levels of social connectedness appear to contribute to delayed recovery from negative emotions (Cohen et al., 1994). A greater level of social connectedness, in contrast, appears to confer benefits through its impact on subsequent positive emotion. That is, compared with less connected individuals, socially connected individuals showed extended positive emotion. Taken as a whole, these findings suggest that persistently low levels of social connectedness may potentiate the relation between daily negative emotions and cardiovascular functioning and leave individuals more vulnerable to the ongoing strains of daily life (Hawkley et al., 2003; Hawkley, Preacher, & Cacioppo, in press). In contrast, the findings are also consistent with the interpretation that high social connectedness and positive emotion characterize those who are resilient in the face of major life stressors and mounting daily NA (cf. Bolger, Foster, Vinokur, & Ng, 1996; Ong, Bergeman, & Bisconti, 2004).

The Undoing Benefits of Daily Positive Emotions

The first objective of this study was to investigate the extent to which positive emotions counteract the cardiovascular activation engendered by negative emotions. In support of the undoing hypothesis (Fredrickson & Levenson, 1998; Fredrickson et al., 2000), positive emotions were observed to dampen the cardiovascular impact of daily negative emotions. That these relationships hold, even after controlling for variables thought to influence these daily processes (i.e., trait PA and NA), is noteworthy. The results thus provide additional empirical footing for the broaden-and-build model of positive emotions (Fredrickson, 1998, 2001, 2003) by providing an important conceptual link to previous laboratory studies with younger adults. Specifically, the current work provides a model of how positive emotions serve to buffer the effects of daily negative emotions on the day-to-day cardiovascular functioning of older adults.

It is possible that a more differentiated assessment of emotions (positive, negative, and their blends) may have resulted in different patterns of cardiovascular activation. Several laboratory studies, however, have shown that various discrete positive emotions that differ in phenomenology and activation level (i.e., contentment, amusement) share the same operative underlying mechanism of undoing lingering negative emotional arousal (Fredrickson, B. L., & Levenson, R. W., 1998; Fredrickson et al., 2000). Nevertheless, additional studies will be needed to assess whether the undoing effect generalizes to other discrete positive emotions, such as love, pride, and interest. Similarly, there is a need for richer empirical formulation of the emotional routes through which these effects occur vis-à-vis discrete negative emotions (e.g., anger, sadness, shame).

The Emotional Consequences of Social Connectedness

The second objective of this study was to examine the extent to which the cardiovascular effect of daily positive emotions would vary systematically as a function of individual differences in social connectedness. At the between-person level, individuals lower in social connectedness reported greater NA and BP. Noteworthy was the interaction between social connectedness and daily NA, which revealed that higher daily NA was associated with higher daily BP, particularly among individuals low in social connectedness. These findings are consistent with prior studies that suggest that, compared with socially isolated individuals, socially connected individuals show less cardiovascular reactivity following negative emotional arousal (Hawkley et al., 2003; Uchino et al., 1996; Uchino & Garvey, 1997). Of particular importance was the presence of cross-level interactions between within- and between-person variables, such that the cardiovascular impact of daily positive emotions on negative emotions was most clearly evident among those high in social connectedness. These results thus provide further support for the broaden-and-build model (Fredrickson, 1998, 2001) by identifying an individual difference variable (i.e., social connectedness) thought to influence the underlying undoing benefits occasioned by positive emotions.

It may be that socially connected individuals have higher average levels of PA (cf. Fredrickson et al., 2000; Hobfoll, 1989) and, therefore, are more adept at mobilizing appropriate levels of positive emotion to regulate daily negative emotional experiences. Alternatively, socially connected individuals may have developed a way of life that provides for relatively few negative emotional experiences and, therefore, are better protected against the harmful effects of daily negative mood states (Bolger & Eckenrode, 1991; Hawkley et al., in press). However, trait assessments of PA and NA did not predict lower BP responses, suggesting that only elevations in PA on days in which NA was also high appear to reduce the NA–BP relationship.

The Influence of Social Connectedness on Cardiovascular Recovery

Finally, we sought to examine the lagged effects of daily emotions on cardiovascular activation and the extent to which these within-person relationships varied as a function of between-person differences in social connectedness. Growing evidence suggests that the rate of recovery of cardiovascular responses following negative emotional arousal is as important as the magnitude of responses in signaling vulnerability to cardiovascular disease (Borghi et al., 1986; Gerin & Pickering, 1995; Haynes et al., 1991). Additionally, several authors have alluded to the possible relation between interpersonal connection and biological resilience (Ryff & Singer, 2000; Ryff et al., 2001), suggesting that socially connected individuals may recover from negative emotions more quickly. The current study directly tested this hypothesis by examining lagged relationships between daily emotion and BP responses to determine the direction and duration of effects and whether social connectedness moderated these effects. The results of these analyses revealed a cascade of valence-specific relationships between daily NA and SBP responses. These relations were not limited to concurrent effects but extended to influence each other as much as 2 days later. These findings lend support to the hypothesis that the subjective experience of daily negative emotions exerts continual influence on health and well-being over time (DeLongis, Folkman, & Lazarus, 1988; Stone, Neale, & Shiffman, 1993).

The results of our analyses also indicated the presence of significant cross-level interactions between traits and lagged daily variables. Specifically, individuals who reported lower levels of social connectedness were more likely to have difficulty modulating the intensity of negative emotion once it had been triggered. Conversely, those high in social connectedness showed greater ability to inhibit the detrimental impact of negative emotion on subsequent BP responses. Social connectedness also interacted with lagged positive emotion to predict next-day positive emotion. These results imply that social connectedness enhances the mood-boosting effects of positive emotion, fueling a snowball effect of consecutive positive outcomes (Fredrickson & Joiner, 2002).

Although greater cardiovascular reactivity is generally interpreted as a marker for risk (Blascovich & Katkin, 1993; Krantz & Manuck, 1984), increases in BP are not inherently pathogenic (Gerin & Pickering, 1995; Julius, Li, Brant, Krause, & Buda, 1989). It may be slow or prolonged recovery from stress responses that portends risk to older adults (McEwen, 1998; McEwen & Stellar, 1993). By accelerating cardiovascular recovery from daily negative emotions, social connectedness may function in the service of health by averting delays in adaptation to subsequent stressors. These effects, moreover, may be more evident in older adults because of the centrality of quality social ties in late life (Lang, 2001; Lang & Carstensen, 1994). Taken together, the results of the current study highlight the importance of integrative multilevel approaches to the study of social processes and health outcomes in later adulthood (Cacioppo & Berntson, 1992; House et al., 1988).

Limitations and Future Directions

Several limitations should be noted in evaluating the results of this study. First, the study made use of a unidimensional measure of social connectedness. Multidimensional assessments of interpersonal functioning may allow for an examination of more specific associations of interpersonal functioning (Uchino, Cacioppo, Malarkey, Glaser, & Kiecolt-Glaser, 1995). In a related vein, multidimensional conceptualizations of physiological processes may allow for greater specificity in the potential mechanisms underlying the health benefits of social connectedness (Uchino et al., 1996). Future studies should, therefore, use more detailed and dynamic measures of cardiovascular function (i.e., total peripheral resistance, sympathetic and parasympathetic control of the heart, ambulatory BP) along with multivariate techniques (e.g., dynamic factor analysis) to map the daily emotional correlates of relational flourishing and elaborate their physiological substrates in later life (Ryff & Singer, 2000; Ryff, Singer, Love, & Essex, 1998).

Second, a number of variables known to have an impact on cardiovascular functioning were not examined. In particular, we did not attempt to measure variation in coping (Smith, Ruiz, & Uchino, 2000), life events (Uchino, Kietcolt-Glaser, & Cacioppo, 1992), or social networks (Uchino, Holt-Lunstad, Uno, & Flinders, 2001) as possible predictors of either cardiovascular reactivity or recovery. The influence of daily NA may also depend on how closely it is linked to various life tasks (Cantor et al., 1991) and chronic difficulties (Ormel & Wohlfarth, 1991). Additionally, the personality dimension of trait hostility has been shown to be an important psychosocial risk factor for cardiovascular disease (Houston, 1994; Suls & Wan, 1993). Thus, it will be important for future studies to determine the unique ways in which interpersonal variables interact with situational and personality factors to influence health and well-being.

Third, we limited the current investigation to a normotensive and homogeneous sample of older adults. As such, the mechanisms responsible for these effects may be distinct from those operating in hypertensive populations (Manuck, 1994). In addition, we focused on cardiovascular functioning as a lens through which to examine the daily health consequences of social connectedness and positive and negative emotional states. However, alterations in the endocrine and immune systems also have important health consequences. Studies of at-risk populations that incorporate assessments of cardiovascular, endocrine, and immune functioning may, therefore, help to illuminate the multiple physiologically specific consequences of social connectedness (Uchino et al., 1996).

Finally, the current study focused on the moderating effects of social connectedness and positive emotions on cardiovascular health. The findings clearly indicate that the influence of daily negative emotions is not uniform across individuals. Nevertheless, we emphasize that identifying statistical interaction effects should be viewed as the starting point for future studies designed to test hypotheses regarding process (cf. Rutter, 1983, 1990). That is, in addition to identifying protective factors, future studies should strive to elucidate underlying protective mechanisms. Such attention to underlying processes is essential for designing appropriate prevention and intervention strategies for older adults (cf. Ong & Bergeman, 2004b; Uchino et al., 1996).

Conclusion

The results of the present investigation support the view that PA is a dynamic process that ebbs and flows well into the later years of adult development (Ong & Bergeman, 2004a). It may be in the context of negative emotions, however, that the benefits of positive emotions are most dramatically manifest (Fredrickson, 2003; Ong et al., 2004). Rather than being free-floating or objectless, positive emotions represent an important pathway through which social connectedness influences daily adaptation to negative emotional experiences. Collectively, the results suggest that it is the dynamic interplay between trait and state variables that provides substantive insight into the importance of social connectedness and positive emotions in later life.

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Received December 21, 2004
Revision received May 2, 2005
Accepted May 24, 2005 ■