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Trait Stress Resistance and Dynamic Stress Dissipation on Health and Well-Being: The Reservoir Model

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Abstract

Daily data from the NDHWP (n = 783; age range 37–90) were analyzed to produce ‘dynamic characteristic’ estimates of stress input and dissipation. These were used in multi-level modeling (with age and trait stress resistance) to predict depression and health trajectories. Main effects suggest that dissipation and stress resistance predict lower depression and better health, but lower stress input was only related to lower depression. Interactions revealed that subjects with above average stress resistance had lower depression irrespective of their ability to dissipate stress, but for individuals low in trait resistance those with better stress dissipation show lower depression and better health.

Perceptions of stress are fundamentally about the organism’s ability to identify and adapt to challenging circumstances, and the psychobiological benefits, costs, and consequences of the subsequent regulatory processes (Monroe, 2008). When stress is measured comprehensively, that is, major life events, chronic strains, and challenges/hassles, the effects on health and well-being are considerable (Thoits, 2010). To better understand the stress–health link, researchers have articulated the pathways through which environmental demands, stress appraisal processes, and resistance resources result in stress physiology that can lead to adverse mental and physical health outcomes (Lupien et al., 2006; McEwen, 1998). Physiological stress responses are essential for mobilizing the resources needed to deal with a current threat. When the stressor is dealt with or passes, the body’s systems return to baseline levels. Unfortunately, many individuals suffer from chronic/repeated stressors that can be particularly pernicious and result in disability and disease. In understanding the stress–health link, it is important to examine individual differences associated with stress resistance and the capacity for stress dissipation.

Trait Stress Resistance: Dispositional Resilience

One of the most reliable findings in the stress literature is the remarkable degree of heterogeneity in the stress response (McEwen & Stellar, 1993). This result is found in within

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(Zautra, Berkhof, & Nicolson, 2002) and between-person analyses (van Eck, Nicolson, & Berkhof, 1998). Thus, not all individuals with high exposure to stress and adversity develop psychological disorders or medical diseases. The causal linkages in the stress process that ultimately confer susceptibility to, and eventuate in, disorder and disease are influenced by the individual's adaptive assets (Ong & Bergeman, 2007). Many resistance resources have been identified, including those from internal (e.g., dispositional resilience) and external (e.g., social support) sources (Bergeman & Wallace, 1999; Garmezy, 1985). When the influences of resilience resources, such as mastery, self-esteem, and social support, are considered, the deleterious effects of stress on health and well-being are reduced (Thoits, 2010).

One widely used personality characteristic is dispositional resilience, which measures the way a person encounters and interprets stressful experiences (Bartone, Ursano, Wright, & Ingraham, 1989). For example, individuals higher in dispositional resilience are less affected by increases in stress (Orr & Westman, 1990) and experience less distress in situations of sustained challenge, such as care giving (Clark & Hartman, 1996). They also show lower levels of depression and better physical health (Wallace, Bisconti, & Bergeman, 2001), healthy immune and neuroendocrine response to stress (Sandvika et al., 2013), and higher life satisfaction following the loss of a spouse (Rossi, Bisconti, & Bergeman, 2007). Thus, individuals high in dispositional resilience are more stress resistant and have better health and well-being outcomes across a variety of potentially stressful situations.

Dynamic Characteristics: Stress Input and Stress Disposition

Another important mechanism in protecting against the negative consequences of stress may be the ability to dissipate the stress that is experienced on a day-to-day basis. Although research focusing on various coping strategies infers that the benefit is due to decreasing the effects of stress on outcomes (i.e., as a mediator or moderator of the stress–health relationship), the ability to dissipate stress is not tested directly. As is described in more detail below, the reservoir model is applied to a single time series consisting of daily estimates of perceived stress. The model can be used to decompose an individual's perceptions of their stress into *stress input*—an average of the perceived daily increases in stress—and *stress dissipation*—the rate at which perceived stress decreases. These indicators represent what Ram and Gerstorf (2009) call “dynamic characteristics,” which are “trait”-like descriptions of individual's inherent capacity for change. This study examines the correlates of stress input and dissipation, how they differ with age, and how they may change over time. Finally, we predict health and well-being outcomes using a trait measure of dispositional resilience (stress resistance) and the input and dissipation parameters captured through our analysis of daily data.

Multiple Time-Scale Designs

At any given moment, individuals are complex configurations of characteristics, some of which change quickly whereas others are much more stable (Nesselroade & Ram, 2004). Nesselroade (1991) introduced measurement bursts as a useful tool to depict the “warp and the woof” of developmental dynamics. This analogy suggests that the structure that underlies

development consists of interwoven threads that denote longer term trends of continuity or change (warp) and the shorter term variability (woof) around which those trends are built. Here we have adopted a daily process approach to examine stress input and dissipation. This approach involves intensive, day-to-day assessments that allow us to view changes in the fluctuations of perceived stress, closer to their real-time moments of change. As has been suggested, the primary advantage of this methodology is its ability to reveal dynamic processes (e.g., Almeida, 2005) that are of particular interest to resilience researchers (e.g., capture perturbations to the system and to determine their influence on the organism; Nesselroade, 2001).

One approach to capturing changes to the system, is the use of dynamical systems analyses (DSA), which are methods that allow researchers to capture the process of development over time by explicitly mapping parameters of change onto the aspects of functioning to which they correspond. Because DSA incorporate time directly into the models, they allow for the discovery of processes by which one variable consistently affects another, independent of the specific time of measurement (Nesselroade & Schmidt McCollam, 2000). One example is the damped linear oscillator (DLO), which consists of modeling both the individual's general proclivity toward some stable state, referred to as equilibrium, and the short-term fluctuations around this mean trend or the intraindividual variability (Boker, 2002). An analogy for this model is the trajectory that a pendulum with friction would make as it swings back and forth—perturbed by force and returning to equilibrium over time. It is typically used as a model of self-regulation. Relations between the level and rates of change in the attribute(s) of interest are the focus of investigation, rather than solely the level of one or more variables at discrete time intervals. Parameters emerging from these analyses represent dynamic characteristics of individuals that can be used in subsequent analyses to predict individual differences (between subjects) and intraindividual trajectories of change (within subjects).

Although the DLO model is very useful, it may do a poor job of describing constructs that show floor effects, which occur when a measure possesses a distinct lower limit for potential responses and a large concentration of participants at or near this limit. The reservoir model is a related way to model a time series that uses derivatives to express the level of an attribute and how the attribute is changing with respect to time (Deboeck & Bergeman, 2013). Like the DLO, this model allows for constructs to fluctuate around a nonzero equilibrium with symmetrical deviations but also permits constructs that demonstrate deviations from some floor, which may result in a skewed distribution; both types of behavior have been observed in our ratings of perceived stress.

Stress Inputs and Dissipation: The Reservoir Model

Rather than conceptualize change over time as self-regulation around some nonzero equilibrium, the reservoir model treats the level of a construct at any given time as similar to the input and output of liquid in a reservoir (Deboeck & Bergeman, 2013). In this analogy, the height of the liquid corresponds to the self-reports that participants make about their levels of perceived stress. As depicted in Figures 1A and C, liquid enters the reservoir from a pipe suspended over the reservoir. There is an open drain at the bottom of the reservoir,

which reduces the height of the liquid. The height of the liquid varies over time depending on the volume of the inputs and the rate of output or dissipation, as in Figures 1B and D. Across days, one's stress can vary in magnitude, which is depicted as the height of the liquid in the reservoir. As one's perceptions of his or her stressful experiences accumulate, the height of the liquid in the reservoir rises, or colloquially, the stresses "add up." Rather than allowing stresses to increase unabated, people dissipate stress through passive (e.g., not working on weekends) and active means (e.g., exercising to "blow off steam"). Thus, one's level of perceived stress depends on how many stressors are experienced and the ability of the individual to dissipate the emotional and physiological arousal associated with them. This model allows for the possibility that the average output could be larger than the average input (Figure 1C). In such a case the reservoir will tend to be empty, although perceptions of stress (inputs) may still perturb the height of the liquid for a short time (Figure 1D).

The reservoir model does not assume that multiple time series have been collected to represent the level, inputs and outputs of a construct. Rather, the fluctuations in the level of a variable can be used to represent the inputs and output. The reservoir model consists of the differential equation model:

$$dx/dt = \beta x + \varepsilon \quad (1)$$

which states that the change in perceived stress with respect to time (dx/dt), which can be thought of as the rate at which a construct such as perceived stress is changing, is equal to the level of perceived stress (x) times β (the dissipation parameter described below), plus some distribution of random inputs ε . Unlike many models which would treat ε as innovations with a mean of zero, the reservoir model assumes the distribution of random inputs consists of only positive values, so that ε corresponds to the inputs depicted in Figures 1A and C. As a reservoir cannot contain "negative liquid," the construct of interest can only have positive values.

Fitting this model to a time series of perceptions of daily stress provides two useful estimates. The first is the distribution of inputs; the average of ε is calculated, which corresponds to the average perceived stress input reported by participants per unit time. Because the input distribution is constrained to consist only of positive values, that is, stressors can only increase one's reported stress, the average perceived input would necessarily be greater than zero. In the current analyses, the average perceived input corresponds to the change in the perceived stress scale scores per day.

The second parameter estimated by this modeling procedure is the parameter β , which we call the "dissipation parameter." As described in the differential equation model, the distribution of ε consists of only positive values; thus, the dissipation parameter will be less than zero and will represent the rate at which the reservoir is emptying, or the extent to which perceptions of stress are dissipating. The reservoir model is similar to models of exponential decay, and the dissipation parameter can be understood in these terms. For example, if one is interest in the time required to reduce one's perceived stress by half, this would be equal to $t = \ln(2)/-\beta$, where $\ln(2)$ indicates the natural log of 2. A person with a

dissipation parameter estimate of -1 is projected to require $\ln(2)/1 = 0.69$ days to reduce his or her stress by half; a person with a dissipation parameter estimate of -0.5 would require 1.38 days to reduce his or her stress by half—twice as long as the first example. Estimates of the dissipation parameter, as they related to perceived stress reduction, will necessarily be negative. Values close to zero (e.g., -0.1) indicate that an individual may take many days (over a week) to show a large reduction in the perceived effects of a stressor, whereas large negative values (e.g., -1.0) indicate an individual dissipates much of the effects of a stressor within a day or two. Estimates of stress dissipation much below -2 are not expected in these data, as larger dissipation parameters require intraday observations and/or a method of model estimation that differs from that presented by Deboeck and Bergeman (2013).

In sum, research suggests that the linkages between stress and health/well-being are strong (Thoits, 2010), but this relationship differs across individuals. This suggests that some people are more negatively affected by stress than others. Research focusing on possible resilience mechanism has identified protective factors that influence how one thinks about stressors (e.g., perceptions of control, openness to new experiences) or that can help one to reduce stress through social exchanges (e.g., receiving empathy or assistance). Many of these resources infer the ability to dissipate the detrimental effects of stress on outcomes of interest but do not directly incorporate an indicator of stress dissipation.

This study uses the modeling techniques described in the reservoir model to estimate parameters of stress input and dissipation from data collected at the daily level. To better understand continuity and change in these parameters over time, correlations from daily data assessed 3 times across a 5-year period were evaluated. Construct validity was tested by correlating stress input and dissipation with resilience measures available in the Notre Dame Study of Health & Well-Being (NDHWB). The indicators of stress input and dissipation were then used, in conjunction with a trait measure of stress resistance, to predict trajectories of health and depression over a 5-year period. The confluence of these analyses helps to better understand what the dynamic characteristics of stress input and dissipation reflect, how they change over time, how they relate to trait stress resistance, and how they predict health and well-being outcomes.

METHOD

Participants

The Notre Dame Study of Health & Well-Being (Whitehead & Bergeman, 2014) assesses midlife and older adults through survey data—five waves collected on a yearly basis, and “data bursts”—daily diary data collected 3 times for a 56-day period at Waves 1, 3, and 5. The sample at Wave 1 comprised 783 participants; average age of 59.3 ($SD = 10.0$, range 37–90). Fifty-nine percent of the sample is female, 83% is White, 10% African American, and the remainder are Asian, Hispanic, Native American, of mixed race, or did not report their race. One half of the sample is married (50.6%), 12.2% widowed, 23% divorced, 12.6% single, and 1.6% separated. Three percent has less than a highschool education, 31.1% completed high school, an additional 33.8% have vocational training/some college classes, 18% have a college degree, and 14% have postcollege training. Income includes 4.3% reporting less than \$7,500/year, 11.3% between \$7,500 and \$14,999, 15.5% between

\$15,000 and \$24,999, 23.6% between \$25,000 and \$39,999, 29% between \$40,000 and \$74,999, 8% between \$75,000 and \$99,999, and 8.3% making more than \$100,000/year.

Procedures

Each year participants were mailed a packet of global measures followed by daily assessments in Waves 1, 3, and 5. The participants completed one set of questions each day for 56 consecutive days. All packets were mailed to participants and included a self-addressed, postage-paid envelope. The distributions of the packets were counterbalanced across and within participants based on a predetermined schedule. Participants were asked to complete the diaries in the evening and to reflect on their day “as a whole.” If a participant missed a day, they were instructed to leave that day’s diary page blank. Participants received \$20 for each wave of the questionnaire and \$10 per week of daily diaries. The sample was supplemented with additional participants at each Wave (approximately 30 per year to compensate for attrition in the sample) for a total of 925, 822 (89%) of which provided daily diary data for at least one of the three time points.

The reservoir model was fit to each participant’s diary data, within each wave of observation. With 822 participants, the maximum possible number of estimates is 2,466 if all participants completed three waves of intensive sampling. We produced 1,557 estimates (63% of the possible data). Estimates were only calculated for individuals who had at least 50% of the data (i.e., 28+ observations), and there was a lack of model convergence for 1.5% of the sample. Fifty-nine percent of the sample had sufficient data to produce three estimates, an additional 28% had two, and 13% had only one estimate. The number of estimates was 598, 528, and 431, at Waves 1, 3, and 5, respectively. Analyses were performed to test for differences between individuals who completed daily diaries at all waves and those who were no longer participating by Wave 5. Results showed no significant differences between the groups in age ($t = .76, p = .45$), race ($\chi^2 = 3.43, p = .64$), or marital status ($\chi^2 = 4.14, p = .39$). There was a marginally-significant difference between the groups on gender ($\chi^2 = 3.81, p = .05$) and income ($\chi^2 = 12.87, p = .05$), with the sample that remained at Wave 5 including more women, fewer individuals making between \$25,000 and \$39,000 per year, and more individuals making more than \$75,000 a year.

Measures

Global Measures

Depression: Depression was measured using the 20-item Center for Epidemiologic Studies Depression Scale (Devins & Orme, 1985). Participants respond to questions like “I felt that I could not shake off the blues even with help from my family and friends” on a 4-point scale: 1 (*rarely or none of the time [less than one day]*), to 4 (*most of the time [5–7 days]*) using the past week as a time frame. A higher score indicates greater depressive severity. Cronbach’s α was .86.

Health: The measure of self-reported health included six items that evaluated overall general health, exercise, health status relative to 5 years ago, health status relative to others in the age group, and health limitations (Belloc, Breslow, & Hochstim, 1971); a higher score

indicated worse health. Because of differences in the response scales, items were standardized. Cronbach's α was .84.

Stress resistance: Stress resistance was assessed with the Dispositional Resilience Scale (DRS; Bartone et al., 1989), because individuals higher in dispositional resilience are more resistant to increases in stress and prolonged challenge (Clark & Hartman, 1996; Orr & Westman, 1990). The DRS includes three protective factors: control (i.e., whether one perceives they have agency in life), commitment (i.e., conscientiousness with regard to engaging in and following through on meaningful activities), and challenge, (i.e., perceives challenges as opportunities for growth rather than as disruptions or threats) assessed on a four-point scale: 1 (*not at all true*) to 4 (*completely true*). Higher scores reflect more of the trait. Cronbach's α was .88.

Resilience resources: Five resilience resource measures were used to assess their relation with stress input and dissipation. Trait Ego Resilience (Block & Kremen, 1996) assesses the dynamic capacity to modify a characteristic level of ego control as a function of demand characteristics to preserve the equilibrium of the system. The Social Scale from the COPE measures the extent to which individuals seek advice or information or get moral support, sympathy, or understanding from others to cope with difficult life circumstances (Carver, Scheier, & Weintraub, 1988). Scores on the Perceived Support from Family and Friends reflect the extent to which an individual perceives that his or her need for support, information, or feedback is fulfilled by family and friends (Procidano & Heller, 1983). Environmental Mastery is designed to measure the level at which individuals feel that they can shape their environment to meet personal needs and desires (Ryff & Keyes, 1995). The Rosenberg Self-Esteem Scale (Rosenberg, 1965) assesses self-worth and attitudes toward the self.

Daily Diary Measures

Daily stress: Perceived daily stress was measured using 10 items from the Perceived Stress Scale (Cohen & Williamson, 1988). Items include "Today I felt nervous and stressed" and "Today I felt that things were going my way." A 4-point scale (*strongly agree* to *strongly disagree*) was used; a higher score is more perceived stress. The reliability estimate α was .89 on Day 1.

Stress input and dissipation parameters: Perceived Stress scores from the daily burst data were analyzed using the reservoir model. Maximum likelihood estimates of average perceived input and dissipation of daily stress were calculated using code provided by the first author of Deboeck and Bergeman (2013); this code utilizes OpenMx (Boker et al. 2011, 2012) to fit a combination of a latent differential equation model (LDE) and a latent distribution model (LDM), as depicted in Figure 2. LDE is a method to estimate the derivatives of the time series and allows for estimation of relations between derivatives. LDM allows for the estimation of a non-normal distribution of inputs, which cannot have negative values and are likely to be positively skewed (i.e., small changes in perceptions of stress, rather than large changes). Combining these techniques, it is possible to fit a differential equation model using structural equation modeling (SEM) in which all of the

“errors” are positive, and two estimates related to input distribution (stress input) and the rate or reduction of stress (stress dissipation) result. Details of the distribution and interpretation of these parameters can be found in the introduction, and Deboeck and Bergeman (2013).

Analyses

Multilevel modeling was used to assess the extent to which stress dissipation and stress input predicted trajectories of health and depression across time. As can be seen in the equations below, trajectories of depression and health across a 5-year period are predicted by occasion of measurement (wave) at Level 1 and the intercepts are predicted at Level 2 by age, stress input, stress dissipation, stress resistance, and their interactions measured at Wave 1:

$$\text{Depression or Self- Reported Health}_{ij} = \beta_{0j} + \beta_{1j}(\text{Wave}) + e_{ij} \quad (2)$$

$$\begin{aligned} \beta_{0j} = & \gamma_{00} + \gamma_{01}(\text{age}) + \gamma_{02}(\text{input}) \\ & + \gamma_{03}(\text{dissipation}) \\ & + \gamma_{04}(\text{resistance}) \\ & + \gamma_{05}(\text{input} * \text{resistance}) \\ & + \gamma_{06}(\text{dissipation} * \text{resistance}) \\ & + \gamma_{07}(\text{dissipation} * \text{resistance} * \text{input}) + u_{0j} \quad (3) \end{aligned}$$

$$\beta_{1j} = \gamma_{10} + u_{0j} \quad (4)$$

The models are designed to assess whether stress input and dissipation predicted outcomes beyond a more traditional trait indicator of stress resistance. Age is included as a covariate due to the wide range and the possible influence on outcome trajectories. It should be noted that we did consider using the stress resistance, input, and dissipation measures as time-varying covariates (because they are available), but with only three occasions of measurement at which the daily data bursts occur and random effects for intercept and wave, it was not possible for the model to converge. Allowing all of the parameters to be random also resulted in poor model convergence. Thus, intercepts and slopes were specified as random, whereas the effects of age, resistance, dissipation, input, and the interactions were fixed.

RESULTS

Descriptive Statistics

Means and standard deviations and correlations with age are presented in Table 1. There were no significant relationship with age for the dissipation parameter, but there were significant correlations with age for input at Wave 1 and Wave 5, with older adults showing

lower input. The only gender differences were for dissipation at Wave 3, $F(1, 526) = 6.28$, $p < 0.02$, with men ($M = 0.81$) showing greater dissipation than women ($M = 0.66$). Histograms of the distribution of input and dissipation estimates are provided in Figure 3. As can be observed in the figures, the estimates are positively skewed such that most individuals have low levels of mean input, and negatively skewed such that most individuals have low rates of dissipation.

Correlations Among Stress Input and Dissipation Across Waves

Table 2 contains the correlations among the dissipation and input parameters across the three waves of daily burst data. Results indicate that there are significant, but modest, longitudinal relationships between the dissipation parameters over time, suggesting that individuals who are better at dissipating stress at one point in time are also better at dissipating stress at the other waves of measurement. These correlations range from 0.26 to 0.34. Additionally, there are significant relationships between stress input at consecutive waves, $r_{\text{waves } 1-3} = .13$, $r_{\text{waves } 3-5} = .27$, but not from Wave 1 to Wave 5, $r = .07$. Finally, the ability to dissipate stress is correlated with stress input within time points (correlations are -0.64 , -0.64 and -0.55 at Waves 1, 3, and 5, respectively), but not across time points. These results suggest that individuals higher in stress input at any given wave show greater stress dissipation (higher negative values), depicting the importance of assessing stress dissipation in context. The effect of stress input is time specific and does not relate to estimates of dissipation at later waves.

Correlations With Other Resilience Measures

Table 3 provides correlations for stress input and dissipation with other measures typically associated with resilience to stress. Stress dissipation shows significant correlations with dispositional resilience (current measure of stress resistance), ego resilience, social coping, support from family and friends, environmental mastery, and self-esteem. Stress input, on the other hand, is only significantly related to environmental mastery. All correlations are modest, which indicates that these dynamic characteristics may represent “traits” that are different from more traditional protective factors.

Effects of Stress Resistance, Input, and Dissipation on Health and Well-Being

Depression: As shown in Table 4, the random effect of Wave was significant, $\beta = .54$, $p = .006$, but the fixed effect was not. Age at Wave 1 was significant, $\beta = -0.10$, $p = .000$, and suggests that depression across the 5-year period is lower with increased age. Stress dissipation, $\beta = 44.09$, $p = .000$, input, $\beta = 2.70$, $p = .003$, and stress resistance, $\beta = -0.47$, $p = .000$, all have effects on levels of depression over time, with stress dissipation and trait resistance decreasing, and stress input increasing, levels of depression. Of particular interest is that dissipation and input predict depression beyond trait resistance, and there were significant interactions between stress resistance and dissipation $\beta = -0.28$, $p = .000$, and input, $\beta = -0.02$, $p = .01$. The two-way interactions are plotted in Figure 4(A and B) using the unstandardized estimates. As indicated, individuals who are the least depressed have lower levels of stress input and are high in the ability to resist and dissipate stress. Individuals with above-average levels of stress resistance had lower levels of depression

irrespective of their levels of input and ability to dissipate stress. Individuals showing more stress dissipation (large negative values) had lower levels of depression than individuals showing less stress dissipation (values near zero). For individuals below average in stress resistance, there was a stronger dependence on the dissipation parameter such that greater ability to dissipate stress was related to lower levels of depression (Figure 4A); a similar result is seen for individuals lower in stress input (Figure 4B).

Self-reported health: Table 4 also presents analyses for self-reported health. There are significant effects of Wave, fixed, $\beta = .10$, $p = .009$, and random, $\beta = .38$, $p < 0.001$. The effect of age on health was only a trend, $\beta = 0.03$, $p = .05$, with older adults having poorer health across the 5-year period. Stress dissipation, $\beta = 8.44$, $p = .03$, and resistance, $\beta = -0.13$, $p = .000$, significantly influence health, with higher dissipation and resistance related to better health. In contrast to the analyses with depression, there is no significant effect of stress input. There was a significant interaction effect of stress resistance and dissipation, $\beta = -0.05$, $p = .04$, on health, but no interaction between stress resistance and input. Again results were plotted, using the unstandardized estimates, to better understand the complex relationships among these variables (see Figure 4C). As was evident in the analyses of depression, individuals higher in stress resistance have better health regardless of dissipation, and those low in stress resistance are healthier if their ability to dissipate stress is greater.

DISCUSSION

Stress shows consistent effects on mental and physical health, and previous research indicates that it appears to be most pronounced during the period surrounding mid- and later life, when health changes and disease states, many of which are associated with stress, begin to emerge (Kiecolt-Glaser, McGuire, Robles, & Glaser, 2002). Of primary importance is the finding that not all people are affected in the same way, and there are large individual differences in the precursors and sequelae of stress. This study used a trait measure of stress resistance based on questionnaire data and supplemented it with dynamic characteristics of stress input and dissipation to better understand the complex relationship between stress and physical and mental health.

One benefit of a multiwave intensive measurement designs is the ability to understand continuity and change and to conduct empirical tests of hypotheses about intraindividual variability. These process-based constructs can then be used to predict outcomes of interest. The reservoir model was used to decompose an individual's perceptions of his or her stress into stress input and stress dissipation, and correlational analyses were conducted to look at the stability of these attributes. Results indicated that some individuals are generally better at dissipating stress than others, though the longitudinal correlations depicted a moderate effect, implying substantial change in this attribute as well. Although, there are significant relationships between stress inputs from one measurement occasion to the next, longer term relationships were not found. This pattern suggests that in the ebb and flow of life, stress experiences can vary in number and intensity. Finally, the ability to dissipate stress is correlated with stress input within time points, but not across time points. This makes sense, given that one's ability to demonstrate stress dissipation will be affected by the amount of

stress one experiences. The direction of the results support this, individuals with greater average stress increases (inputs) had greater average stress dissipation. At this point it is not clear whether the dynamic characteristics captured by the reservoir model are rigid or malleable. These attributes may be more trait like, as there was at least a moderate correlation with later waves. Monte Carlo analyses used in model testing and development, suggest that the correlation between the true values is likely higher, as the reservoir model estimates may have large errors of estimation given the relatively short time series used in this study (see Bergeman & Deboeck, 2013, Figures 7 and 9, which show relatively large empirical confidence intervals with 25–50 observations, even when fitting the correct model to the data). Additional research is needed to better understand the properties of dynamic characteristics such as those used here.

A second set of correlational analyses were used to assess the extent to which the reservoir model estimates of input and dissipation related to other measures of resilience. Stress dissipation is significantly related to dispositional resilience, ego resilience, social coping, support from family and friends, environmental mastery and self-esteem. Stress input, on the other hand, is only significantly related to environmental mastery. This pattern indicates that the ability to dissipate stress is related to other measures that are often considered protective factors in the stress-health/well-being relationship. Stress input is related to feelings of control over one's environment, but not to other measures of support, coping, or resilience. These correlations were used to provide some initial impressions as to what the dissipation/input parameters measure, but more extensive study is needed to understand convergent and discriminant aspects of their validity.

In the results of the multilevel modeling it was not surprising to see that individuals who are above average in stress resistance show lower levels of depression and better self-reported health over the period of study. Most studies have reported similar results (see Ong, Bergeman, & Boker, 2009); some of this relationship with depression may be due to content overlap in the types of questions used in each of these measures, especially given that characteristics of stress resistant people are often opposite of individuals who report symptoms of depression. Greater levels of stress input were associated with increased levels of depression, especially for individuals who were below average on stress resistance.

The most interesting finding is the effect of stress dissipation, which is related to lower levels of depression, beyond that predicted by the trait measure of resistance. When the interaction between stress dissipation and stress resistance is plotted, the findings indicate that if one is high in stress resistance, levels of depression are low, and self-reported health is good, irrespective of the ability to dissipate stress. For individuals who are below average in stress resistance, however, the results indicate that greater ability to dissipate is associated with better mental and physical health outcomes. These results underscore the importance of using multiple time-scale designs to understand the impact of stress. That is, although the extant evidence has provided a basis for understanding the relationship between stress and health/well-being, other basic information is necessary to understand the nature of this link. Although nomothetic (between-person) analyses have yielded converging evidence for complex relationships among measures of stress, resilience, and health, much less attention has been given to investigating dynamic characteristics, which necessitate idiographic, or

within person, perspectives. In this case, results indicate that the ability to dissipate stress provides essential information regarding who gets sick and who stays well.

Differential equation models are a promising way to describe the relationships between a person's current state and how that person is changing across different time-scales (Deboeck, Nicholson, Bergeman, & Preacher, 2013). The parameters of these models can quantify specific aspects of intraindividual variability that reflect dynamic characteristics of individuals. The reservoir model, rather than considering change over time as self-regulation around some nonzero equilibrium, treats behaviors of interest as if current levels of an attribute are the sum of inputs and outputs. Here the model quantified changes in perceptions of stress as a distribution of instantaneous inputs plus reductions due to the dissipation. Rather than treat the estimates from one time to the next as merely correlated, as is done with autoregressive models, the reservoir model specifically differentiates the processes that results in increasing stress from those that result in decreasing stress. The reservoir model represents one option for modeling intraindividual variability, to assess dynamic characteristics, but many variations of this model are possible, and the choice of models is a function of relevant theory and the process of interest.

As in all research there are limitations to the study presented here. The sample is from the northern Indiana area, and although it is representative of the socioeconomic and racial/ethnic distributions in the region, the results may not be generalizable to other groups and additional application of these techniques with other samples is needed. To help to facilitate this, the OpenMx program is available in Deboeck and Bergeman (2013). In addition, although every means possible is used to maintain our longitudinal, multiburst sample over time, some skewing of the data associated with attrition in the sample is likely. A third limitation was the inability to utilize all of the waves of input and dissipation data in the multilevel models. It is likely that the ability to dissipate stress on levels of depression and health would be more appropriately modeled in "real time," assessing the extent to which depression scores are lower and health better at waves in which individuals had higher dissipation scores. Because there was only three waves of data, models did not consistently converge, and it was not possible to focus on these questions. Further research with the NDHWB as more occasions of daily burst data are available will provide a better milieu for addressing analyses of this type. In addition, developing a second-order reservoir model would allow the rate of dissipation to change as a function of the input, which would be an interesting extension of the model presented here.

Currently, our capacity to develop age-appropriate interventions is limited by our lack of knowledge of the long-term developmental trajectories that extend from adulthood into old age. The use of longitudinal studies will not only shed light on when interventions would be most effective, but also allow for modeling complex interactive pathways across multiple domains of development. In all, research of this type provides an unprecedented opportunity to study the stressors to which adults are exposed, the personal resources upon which they are able to draw in response to stressors, and the emotional and physiological outcomes through which stress is manifested and may eventually contribute to disability and disease. Researchers differ in their conceptualization of resilience to stress, with some suggesting that it is a personality trait and others portraying it as a dynamic developmental process

(Luther, Cicchetti, & Becker, 2000). Few studies, however, have explicitly incorporated methods and/or analytic techniques that differentiate these alternate definitions. The modeling of dynamic characteristics, and the use of the reservoir model in particular, is in its infancy, and as such these results are only a first step in understanding these complex relationships. This applies to the stability of stress input and dissipation across time and type of stressor, the reliability and validity properties of measures estimated from a time series, and the ways in which trait and dynamic attributes of individuals complement one another. This is an exciting new field of inquiry, which is expected to flourish in the coming years.

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FIGURE 1.

Sample time series from the reservoir model. Panel A shows a reservoir with liquid (e.g., a stressor) being added, and a hole in the base that leaks water (left). Panel B (right) shows a plot of the height of the liquid as it changes over time; in this example the inputs and outputs are nearly balanced, so the person's time series appears to vary around a nonzero equilibrium. Panel C is similar to Panel A, but the hole in the bottom of the reservoir is larger. Consequently, the level of liquid the reservoir can dissipate quickly, resulting in floor effect in this person's time series (Panel D, right).

FIGURE 2.

Structural equation model of the reservoir model. The 0th and first derivatives, x and dx/dt , respectively, are estimated by fixing the paths to pairs of subsequent observations on the construct $\mathbf{X}$, that is $\mathbf{X}(t)$ and $\mathbf{X}(t+1)$. The inputs, ϵ_{input} , consist of a range of discrete values constituting a separate class c ; the probability of each class, and consequently each input value, is estimated. By multiplying the input values by the probability of each value and summing, one can calculate the average of ϵ_{input} . The parameter β , the relationship between the derivatives, is a negative value related to the rate of change. The negative β , when multiplied by the positive values of x , will result in a negative value for dx/dt (velocity, i.e., linear change) thus dissipating the construct of interest. From Deboeck and Bergeman, 2013.

FIGURE 3.

Histograms representing the distribution of stress dissipation and input scores at Wave 1.

The black line represents the mean of the distribution (-0.65 for dissipation and 4.54 for input). The gray lines signify 1st quartile, median, and 3rd quartile. This figure collapse the estimates of input and dissipation made across all three waves, for all participants.

FIGURE 4.

Plots of the effects of stress resistance (dispositional resilience), stress dissipation, and average perceived input on depression (A and B) and Health (C) using unstandardized parameter estimates. Dissipation values near zero represent a low rate of dissipation, whereas large negative values represent higher rates of stress dissipation.

TABLE 1

Means and Standard Deviations for Stress Input and Stress Dissipation Across Waves 1, 3, and 5 and Correlations of These Parameters With Age

Variable	Sample Size	Mean	Standard Deviation	Correlation With Age
Stress dissipation Wave 1	598	−0.655	0.627	−0.05
Stress input Wave 1	598	4.541	4.148	−0.13 **
Stress dissipation Wave 3	528	−0.719	0.686	−0.08
Stress input Wave 3	528	4.557	4.449	−0.06
Stress dissipation Wave 5	431	−0.776	0.720	−0.07
Stress input Wave 5	431	4.614	4.618	−0.10 *

Note.

*
 $p < .05$

**
 $p < .01$.

TABLE 2
Correlations Among the Stress Input and Stress Dissipation Variables Across Waves 1, 3, and 5

	Strdlss1	Input1	Strdlss3	Input3	Strdlss5
Input1	−0.64***				
Strdlss3	0.26***	0.03			
Input3	0.02	0.13**	−0.64***		
Strdlss5	0.33***	0.06	0.34***	−0.06	
Input5	0.05	0.07	−0.03	0.27***	−0.55***

Note. Strdlss1 = stress dissipation Wave 1; Strdlss3 = stress dissipation Wave 3; Strdlss5 = stress dissipation Wave 5; Input1 = average stress input at Wave 1; Input3 = average stress input at Wave 3 and Input5 = average stress input at Wave 5.

**

 $p < 0.01$.
 $p < 0.001$.

TABLE 3
Correlations (at Wave 1) of Stress Input and Dissipation With Other Measures Associated With Resilience to Stress

	Stress Resistance	Ego Resilience	Social Coping	Friend Support	Family Support	Environmental Mastery	Self-Esteem
Stress input Wave 1	−0.04	−0.06	0.04	−0.05	−0.06	−0.10*	−0.07
Stress dissipation Wave 1	−0.20***	−0.15**	−0.14**	−0.17***	−0.14**	−0.25***	−0.23***

NS range from 553–598.

**
 $p < 0.01$.

 $p < 0.001$.

TABLE 4
Results of Multilevel Modeling Predicting Trajectories of Depression (Top) and Self-Reported Health (Bottom) Over a Five-Year Period

Effect	df	Unstandardized Parameter Estimate	Standard Error	p value	Standardized Parameter Estimate	Standard Error	p Value
Depression							
Random Intercept	599	32.93	3.70	<.0001	32.18	3.66	<.0001
Wave	464	0.54	0.22	.006	0.54	0.22	.006
Fixed Intercept	599	100.93	4.77	<.0001	29.71	0.33	<.0001
Wave	464	0.11	0.08	0.16	0.11	0.08	.16
Age	581	-0.10	0.03	<.001	-0.11	0.03	<.001
Stress Dissipation	590	44.09	6.77	<.0001	5.61	0.65	<.0001
Stress Input	581	2.70	0.91	<.01	0.52	0.09	<.0001
Stress Resistance	599	-0.47	0.03	<.0001	-0.36	0.02	<.0001
Dissip*Resist	591	-0.28	0.05	<.0001	-0.28	0.05	.015
Input*Resist	580	-0.02	0.01	<.02	-0.02	0.01	<.0001
Self-Reported Health							
Random Intercept	599	19.33	1.43	<.0001	19.45	1.43	<.0001
Wave	464	0.38	0.05	<.0001	0.39	.05	<.0001
Fixed Intercept	599	16.76	2.76	<.0001	-0.26	0.21	.210
Wave	517	0.10	0.04	<.01	0.10	0.04	.009
Age	580	0.03	0.02	<.06	0.03	0.02	.053
Stress Dissipation	572	8.44	3.89	<.03	0.97	0.38	<.001
Stress Input	566	0.21	0.52	.69	0.05	0.05	.314
Stress Resistance	600	-0.13	0.02	<.0001	-0.10	0.01	<.0001
Dissip*Resist	573	-0.05	0.03	<.05	-0.05	0.02	.04
Input*Resist	565	-0.00	0.00	.76	-0.00	0.00	.76

Note. Age, stress dissipation, stress input and stress resistance are all measured at Wave 1. Unstandardized parameter estimates are preferred, because unlike many psychological scales for which the placement of a score of zero is arbitrary, zero is a meaningful value for both of the reservoir model estimates. To aid in evaluation standardized parameter estimates are also listed, with the variables at Level 2 centered on group means.