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BRIEF REPORT

Developmental Change and Intraindividual Variability: Relating Cognitive Aging to Cognitive Plasticity, Cardiovascular Lability, and Emotional Diversity

Nilam Ram and Denis Gerstorf
The Pennsylvania State University and Max Planck Institute for Human Development

Ulman Lindenberger
Max Planck Institute for Human Development

Jacqui Smith
University of Michigan

Repeated assessments obtained over years can be used to measure individuals' developmental change, whereas repeated assessments obtained over a few weeks can be used to measure individuals' dynamic characteristics. Using data from a burst of measurement embedded in the Berlin Aging Study (BASE; Baltes & Mayer, 1999), we illustrate and examine how long-term changes in cognitive ability are related to short-term changes in cognitive performance, cardiovascular function, and emotional experience. Our findings suggest that "better" cognitive aging over approximately13 years was associated with greater cognitive plasticity, less cardiovascular lability, and less emotional diversity over approximately 2 weeks at age 90 years. The study highlights the potential benefits of multi-time scale longitudinal designs for the study of individual function and development.

Keywords: intraindividual variability, intraindividual change, lifespan development, multiple time scales, process, longitudinal analysis

Changes in behavior that manifest on different timescales are indicative of and can be used to measure different constructs. Nesselroade (1991, p. 215) defined *intraindividual change* as "more or less enduring change that is construed as developmental," whereas *intraindividual variability* is "relatively short-term change that is construed as more or less reversible and that occur more rapidly than the former." For example, long-term changes in cognitive performance over the course of a decade or more can be tethered to developmental phenomena—*cognitive aging*. In contrast, short-term changes in cognitive performance over closely spaced intervals such as the course of a few weeks can be tethered to a different set of phenomena—constructs such as practice, learning, or *cognitive plasticity*.

Longitudinal studies of aging have typically concentrated efforts on measuring individuals at (multi-)yearly intervals and describing interindividual differences in intraindividual change that accrue over relatively macro-time scales (e.g., rate of aging-related cognitive decline; Hertzog & Nesselroade, 2003; Hofer & Sliwinski, 2006). In contrast, *measurement bursts* (Nesselroade, 1991) are a central feature of diary, ecological momentary assessment (EMA), ambulatory, and other intensive longitudinal study designs wherein multiple reports or assessments are obtained over a relatively short time span (Bolger et al., 2003; Csikszentmihalyi & Larson, 1987; Shiffman et al., 2008; Hoppman & Riedeger, 2008; Walls & Schaffer, 2006). Such data can be used to describe interindividual differences in dynamic characteristics (Ram & Gerstorf, 2009). When integrated, longitudinal studies and measurement bursts provide a framework for examining relationships between developmental phenomena that manifest as long-term change and dynamic characteristics that manifest as short-term variability (Lindenberger, Li, & Bäckman, 2006; Nesselroade, 1991; Ram

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Nilam Ram and Denis Gerstorf, Department of Human Development and Family Studies, Pennsylvania State University, and Center for Lifespan Psychology at the Max Planck Institute for Human Development, Berlin, Germany; Ulman Lindenberger, Max Planck Institute for Human Development, Berlin, Germany; Jacqui Smith, Department of Psychology and Institute for Social Research, University of Michigan.

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Correspondence concerning this article should be addressed to Nilam Ram, Department of Human Development and Family Studies, 110 South Henderson Building, Pennsylvania State University, University Park, PA 16802-6505. E-mail: nilam.ram@psu.edu

& Gerstorf, 2009; Singer, Lindenberger, & Baltes, 2003; Sliwinski, 2008). Here, we used such a framework to investigate links between long-term developmental change (exemplified as cognitive aging) and short-term variability in cognition (cognitive plasticity), health (cardiovascular lability), and well-being (emotional diversity).

Cognitive Aging

Developmental changes in many cognitive abilities during adulthood and old age are often characterized by decline, especially when measured using indicators of processing speed (Salthouse, 1996; Schaie, 2005). Quantifications of interindividual differences in long-term change in individuals' performances on cognitive tasks (e.g., growth curve models) provide person-level indicators of the developmental phenomena—how much cognitive aging a person has experienced or accumulated. Much is known about how interindividual differences in cognitive aging relate to and are embedded in other systems of functioning (e.g., Finkel et al., 2003; Gerstorf et al., 2007; Ghisletta & Lindenberger, 2003; Hultsch, Hertzog, Dixon, & Small, 1998; Lindenberger & Ghisletta, 2009; McArdle et al., 2007). However, beyond a few studies examining trial-to-trial variability (e.g., Lövdén et al., 2007; MacDonald, Hultsch, & Dixon, 2003, 2008; Ram et al., 2005; Sliwinski et al., 2006), little is known about whether and how differences in long-term cognitive aging are related to short-term variability, especially in the very old. Our study adds another time scale to the emerging picture through examination of day-to-day variability.

Cognitive Plasticity

The capability to be changed is a key characteristic of humans and other adaptive organisms (Baltes, 1987; Ford, 1987; Gottlieb, 1998; Lerner, 1984). For instance, when given the opportunity (and with the motivation) to practice a task, individuals have the potential to assimilate and accommodate task-related information and to improve their performance (e.g., Kliegl et al., 1990; Lövdén et al., 2010). Interindividual differences in cognitive plasticity can be measured as differences in the efficiency of learning across multiple, relatively closely spaced assessments. Generally, these differences are related to a wide variety of other interindividual differences. For example, older and/or less healthy individuals do not have the same capability to improve performance as their younger or more healthy peers (e.g., Brehmer et al., 2007; Hertzog et al., 2008; Kliegl et al., 1990; Shing et al., 2008). Furthermore, a number of longitudinal studies have also found evidence of links between long-term developmental changes and the short-term changes that indicate cognitive plasticity (e.g., Brehmer et al., 2008; Schaie & Willis, 1986; Singer et al., 2003; Willis & Nesselroade, 1990; Zimprich et al., 2004). Based on these findings, we expected that greater cognitive plasticity would be associated with higher (i.e., more successful) cognitive aging.

Cardiovascular Lability

Resting heart rate (HR) is often considered as one of several indicators of autonomic function. Normally, the activity of sympathetic and parasympathetic branches of the autonomic nervous system stays in a dynamic balance and keeps resting HR relatively stable (Thayer & Lane, 2007). Autonomic imbalance in either the sympathetic (lower HR) or parasympathetic (higher HR) direction is associated with a wide range of dysfunction, disease, and mortality (Brook & Julius, 2000; for review, see Habib, 1999). Day-to-day changes in resting HR might be thought of as an indicator of the general state of the dynamic balance of the autonomic system. Fluctuations would be indicative of the fragility of the mechanisms that usually maintain autonomic balance and organization of energy resources. Presumably, such impairments in resources and/or resource allocation would also manifest in other areas, including cognition. Our expectation is that day-to-day fluctuations in resting HR would be associated with lower (i.e., worse) cognitive aging.

We note that this is a different prediction than would be derived from evidence on how the more common "micro-time" measure of heart rate variability (HRV; the variability in inter-beat-intervals over a few minutes) is related to systemic dysfunction. Generally, low levels of HRV are associated with aging, disease, and death (Cooper et al., 2007; De Meersman & Stein, 2007). Variability in HR at the beat-to-beat time scale indexes the dynamic flexibility needed for rapid modulation of sympathetic and parasympathetic balance. It is likely that variability in HR at the day-to-day time scale indexes something different—perhaps the ability of the modulatory system as a whole to settle into a dynamic equilibrium at rest.

Emotional Diversity

We define *emotional diversity* as the tendency of an individual to experience a variety of emotions during a given period of time. Following the biological literature (i.e., biodiversity: Morin, 1999), diversity is indicated by the total variation in emotional experiences in space (e.g., around the circumplex) and/or over time. For example, "moody" individuals would be characterized as high in emotional diversity because their emotions fluctuate widely and often (Eysenck & Eysenck, 1985; Larsen & Diener, 1987). Greater day-to-day fluctuations in emotional states are typically associated with indicators of compromised psychological adjustment and health, including neuroticism (i.e., the opposite pole of emotional stability), depressive symptoms, and pessimism (Carstensen et al., 2000; Eid & Diener, 1999; Gross & Thompson, 2007; Kuppens et al., 2007; Ong & Allaire, 2005). In general, theories of emotion regulation and self-development (for overview, see Röcke et al., 2009), as well as empirical evidence suggest that people with "better" psychological adjustment are characterized by less variability (i.e., stability and consistency) of reported emotional experience over time. We expected that individuals with "better" cognitive aging (i.e., less decline) would report experiencing relatively similar emotions across multiple, similarly structured, testing sessions. That is, given consistency in the assessment situation, cognitive aging will be negatively associated with emotional diversity.

Developmental Change and Intraindividual Variability

In sum, the objective of our study is to illustrate that a burst of closely spaced measurements embedded within an ongoing longitudinal study can be used to study how interindividual differences in development are associated with a variety of the dynamic characteristics that can be extracted from observations of short-term variability. We hypothesized that cognitive aging, observed over 13 years, would be predictive of and positively associated with subsequent differences in cognitive plasticity, and negatively associated with differences in cardiovascular lability and emotional diversity.

Method

Participants and Procedure

The Berlin Aging Study (BASE; Baltes & Mayer, 1999; Smith & Delius, 2010) is an on-going interdisciplinary, gerontological study in its third decade. At study inception in 1990, trained research assistants and medical personnel interviewed and assessed $N = 516$ individuals (stratified by age and gender) in face-to-face sessions at the participant's place of residence (i.e., private household or institution). Approximately every 2 years since, participants who were still alive, could be located, and agreed to further participation were assessed in the same manner. In conjunction with the seventh wave of data collection, 36 individuals (86% of those still alive and enrolled) agreed to participate in an additional "measurement burst" module that consisted of a series of six visits over two-plus weeks ($M = 17$ days, $SD = 5.6$). At each home visit, individuals completed, during the course of about one hour, a battery of cognitive, physical, well-being, and other measures.

These 36 burst participants (61% women) were a relatively homogenous sample of high-functioning elderly West Berliners. They were between 83 and 100 years of age ($M = 90.0$; $SD = 4.3$) and had all been providing data to the BASE research team for ~13 years. On average, they had obtained 10.46 ($SD = 2.03$) years of education and had an average income of 1,903 Deutsche-marks per month (i.e., relatively high socioeconomic status [SES]). Four were still married (11%), and seven were living in institutions (19%). This is a small and select sample that is not representative of the general population of old or even very old adults. They are, by many metrics, the "high performers" and "survivors" (see Lindenberger et al., unpublished manuscript). As such, the results should not be viewed as indicating the general state of affairs. Rather, the significant relationships reported here, obtained with such a small, homogenous sample should be viewed as illustrating the potential that measurement burst modules might hold for ongoing, long-term studies of development and aging where further heterogeneity and relationships can be uncovered even more easily.

Intraindividual Change (Development)

The six biyearly assessments of the BASE were used to obtain a measure of cognitive aging—a developmental phenomenon that manifests as long-term change.

Cognitive aging. We selected perceptual speed as our index of cognitive functioning. Perceptual speed is conceptually closer to a resource than many other abilities (Anstey et al., 2003; Salthouse, 1996) and can serve as a robust and parsimonious proxy for multivariate assessments of cognitive ability (Lindenberger & Ghisletta, 2009). At each wave, participants completed a Digit Letter substitution task, a highly reliable measure of perceptual speed that closely resembled the Digit Symbol Substitution subtest of the WAIS (Wechsler, 1982; see Lindenberger et al., 1993). Individuals' cognitive aging was indexed as the rate of linear change exhibited over ~13 years of old age. Individual trajectories are shown in the left panel of Figure 1. These long-term data were modeled at the individual level as

$$y_{wi} = \beta_{0i} + \beta_{1i}Year_{wi} + e_{wi}$$

where y_{wi} is individual i's Digit Letter score at wave w, β_{0i} represents the individual's estimated initial level of cognitive ability, β_{1i}, the parameter of greatest interest, represents the individual's rate of developmental change in cognitive ability per year, and e_{wi} are residual errors. Note that this regression (growth) model provided a simple framework for "calculating" scores, β_{1i}s, that represented the construct of interest. Measured in this way, *cognitive aging* scores for the 36 participants ranged from –2.94 to 0.54 BASE *T*-score units per year ($M = -0.49$, $SD = 0.74$). As expected, interindividual differences in cognitive aging were somewhat negatively related to age ($r = -.27$). The time variable, year, was coded such that the β_{0i}s, were indicative of and used as a measure of individuals' current *cognitive ability*, as measured at the start of the burst sessions.

Intraindividual Variability (Dynamic Characteristics)

Changes in behavior observed across the six closely spaced "burst" assessments were used to measure three dynamic constructs in the cognitive, health, and emotion domains.

Cognitive plasticity. Individuals' cognitive plasticity was measured from the burst data as the rate of change (i.e., improvement) across the six performances on parallel versions of the same Digit Letter substitution task described above. Individual trajectories are shown in the top-right panel of Figure 1. Linear growth curve models were fit at the individual level to obtain a measure of individuals' capability for improvement (e.g., learning) from repeated exposure to the cognitive task,

$$y_{ti} = \beta_{0i} + \beta_{1i}Session_{ti} + e_{ti}$$

where y_{ti} is individual i's Digit Letter score at visit t. The linear rate parameter β_{1i}, served as a model-derived quantification of an individual's short-term change or *cognitive plasticity*. Note that the mechanics of our calculations for obtaining the measure of cognitive aging and the measure of cognitive plasticity are identical. The distinction is a substantive one based on the time scale on which the changes occur, long-term change versus short-term change, and the processes thought to drive changes at those different time scales. Scores for the 30 persons who completed the repeated Digit-Letter tasks ranged from –0.74 to 2.38 BASE *T*-units per session ($M = 0.76$, $SD = 0.76$). Six participants were unable to perform the Digit Letter portion of the battery because of visual impairments (further homogenizing the sample).

Cardiovascular lability. About 10 min into each visit, after participants settled into the situation and answered a few questions, the interviewer recorded the individual's resting heart rate (beats per minute). Individual trajectories are shown in the right-middle panel of Figure 1. Individuals' cardiovascular lability was measured as the variability in their resting heart rate across the six visits. Specifically, we calculated intraindividual *SD*s (*iSD*) for each person as

$$iSD_i = \sqrt{\sigma_i^2} = \sqrt{\frac{1}{T-1}\sum_{t=1}^{T}(y_{ti} - \bar{y}_i)^2}$$

where the *iSD* for person i is the square root of the intraindividual variance, calculated as the sum of the daily $t = 1$ to T squared deviations in heart rate (intraindividual mean heart rate, $\bar{y}$, *subtracted from heart rate on occasion* t, y_{ti}) divided by 1 minus the total number of occasions, $T - 1$. *Cardiovasular lability* scores (*Mean* = 4.74, $SD = 2.63$) ranged from a "stable" 0.00 (this person's resting heart rate was 70 beats/min at each occasion) to a "labile" 13.93 beats/min.

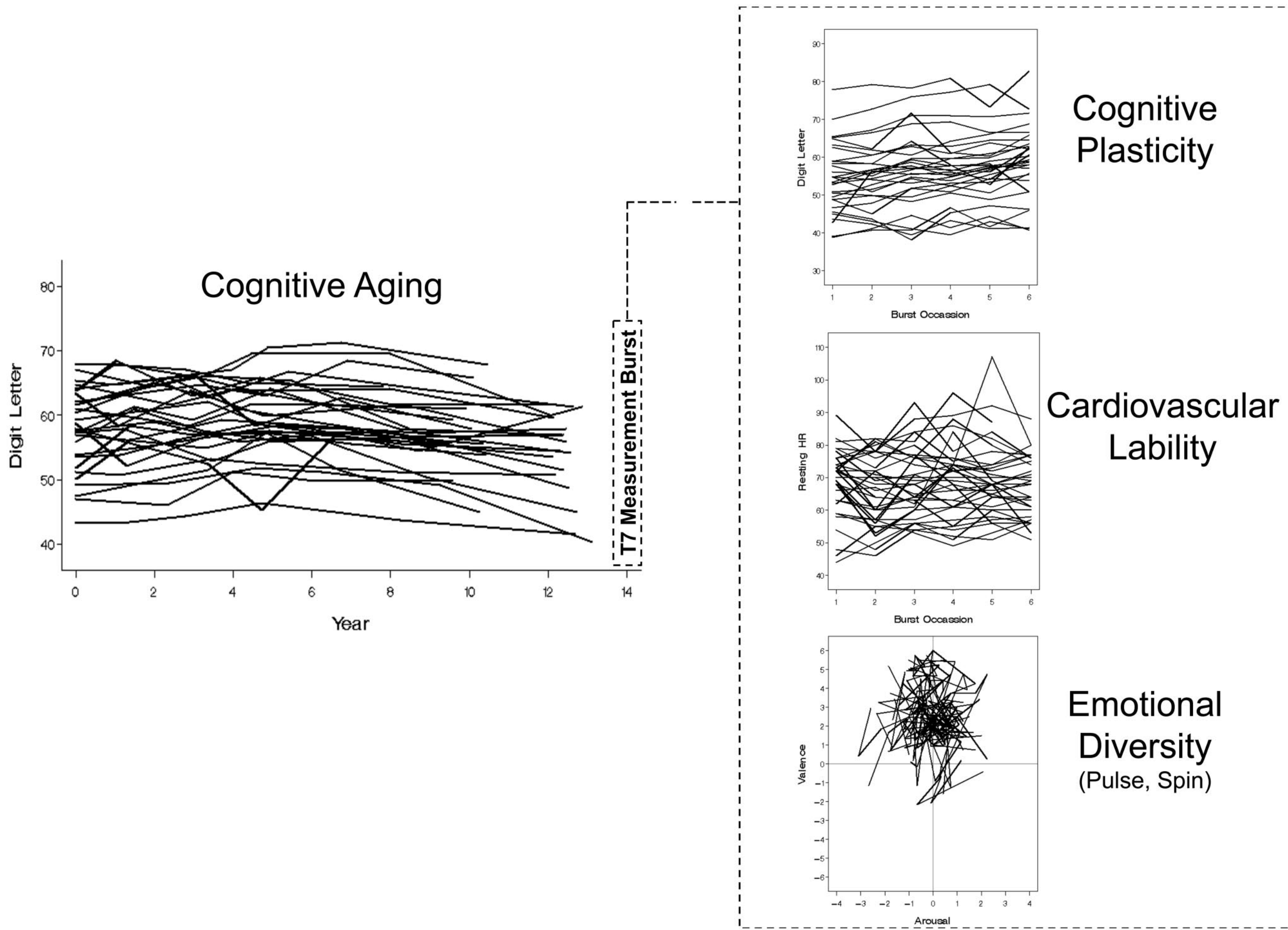

Figure 1. Linking long-term change and short-term variability. The left-hand panel illustrates interindividual differences in long-term development—cognitive aging—derived from measurements of cognitive performance obtained over ~13 years from the surviving subsample of the Berlin Aging Study (BASE). The right-hand panel shows short-term variability across a measurement burst (six repeated measures during 2+ weeks of intensive study during the fourteenth year) from which interindividual differences in three dynamic characteristics are derived: cognitive plasticity (upper panel), cardiovascular lability (middle panel), and emotional diversity (lower panel).

Emotional diversity. At each wave, individuals indicated the extent to which they "at this moment" felt each of 14 emotions (among a larger list of adjectives) on a 1 = "*not at all*" to 5 = "*very strong*" scale. Rather than calculating variability of *core affect* in a unidimensional way, we used a series of steps to calculate two bivariate measures from the responses individuals provided on the six occasions. Following procedures given in Kuppens et al. (2007), responses to individual items were converted into four subscales mapping onto quadrants of the core affect space (*positive active* = enthusiastic, excited, attentive; *positive deactive* = calm, at ease, relaxed, content; *negative active* = nervous, upset, stressed, jittery; and *negative deactive* = sluggish, sad, depressed). These composites were then summarized as scores in the two-dimensional space defined by *valence* and *activation*. Plots of the resulting bivariate time-series for each individual are seen in the right-lower panel of Figure 1. Finally, two measures of emotional diversity, pulse and spin, were used to summarize the individual-level fluctuations within the circumplex space defined by valence and activation (definitions and rationale of measures given in Moskowitz & Zuroff, 2004, 2005; specifics of the calculations we used follow Mardia, 1972). Individuals' pulse scores, the *iSD* of vector lengths (distance from origin), ranged from 0.23 to 1.89 units corresponding to those on a 0-to-6 response scale ($M = 0.87$, $SD = 0.40$). Spin scores, the circular-*iSD* of vector angles, ranged from 0.04 to 1.44 on a scale that goes from 0 to $+\infty$ ($M = 0.37$, $SD = .29$).

Results

Intraindividual Change and Intraindividual Variability

Our substantive interest was in determining whether and how interindividual differences in developmental change were related to interindividual differences in intraindividual variability. Specifically, we were interested in the relations among cognitive aging, cognitive plasticity, cardiovascular lability, and emotional diver-

Table 1
Correlations Among Constructs of Intraindividual Change (Developmental Change) and Intraindividual Variability (Dynamic Characteristics)

Construct	Age	1	2	3	4	5	6
Developmental change							
1. Cognitive ability	−.33	—					
2. Cognitive aging	−.42	.74	—				
Dynamic characteristics							
3. Cognitive plasticity	−.09	−.13	.39	—			
4. Cardiovascular lability	.18	−.23	−.43	−.30	—		
5. Emotional diversity: Pulse	.11	.06	−.19	.26	.03	—	
6. Emotional diversity: Spin	−.06	−.08	−.30	−.23	.08	.13	—

Note. $N = 36$. Cognitive ability (current level) and cognitive aging (change per year) indicated by parameters from individual linear growth models fit to digit letter performance over 13 years. Cognitive plasticity indicated by linear slope of Digit Letter performance over 6 occasions ($n = 30$). Cardiovascular lability indicated by intraindividual *SD* (iSD) of resting heart rate over 6 occasions. Emotional lability indicated by pulse (vector length variability) and spin (angular variability) in the valence/activation emotion space. Note that with the small *n*, none of the correlations reached conventional levels of statistical significance.

sity. Correlations among the model-derived measures of the intraindividual change and variability constructs are given in Table 1. Of particular note is the relative strength of relations between cognitive aging (Variable 2) with the various dynamic characteristics (Variables 3 to 6).

Intraindividual Change Predicting Intraindividual Variability

Our main research question was whether interindividual differences in cognitive aging were predictive of the later measured differences in cognitive plasticity, cardiovascular lability, and emotional diversity. To do so, we ran a series of regression analyses that regressed each dynamic characteristic onto (prior) cognitive aging, controlling for differences in age, gender, and current cognitive ability.

Plots of the zero-order relationships are shown in Figure 2. Results from the regressions, with covariates, are shown in Table 2, with the main parameters of interest indicated in bold. Given the small sample size, statistical inferences were based on bootstrapped confidence intervals for parameter estimates obtained using 5,000 resamples ($N = 36$) of the observed data, each obtained by random sampling with replacement (Yung & Chan, 1999).

Higher levels of *cognitive plasticity* were significantly associated with more positive long-term cognitive aging, B of interest = 0.88, (95% confidence interval [CI] = 0.38 to 1.25), standardized $\beta = .63$, *p*(one-tailed[1]) = .002. Lower levels of *cardiovascular lability* were significantly associated with more positive cognitive aging, $B = -2.20$ (-3.75, -0.69), $\beta = -.62$, $p = .008$. Similarly, lower levels of *emotional diversity* tended towards association with more positive cognitive aging, for pulse, $B = -0.26$ (-0.52, 0.00), $\beta = -.48$, $p = .034$, and for spin $B = -0.20$ (-0.44, 0.05), $\beta = -.49$, $p = .028$. In sum, the evidence suggests that interindividual differences in long-term development are related to short-term dynamic characteristics in very old individuals.

Discussion

Humans are dynamic beings. They can be shaped, they are labile, and they express a diversity of behavior. Our interest in this study was to describe and illustrate the potential value of supplementing longitudinal studies of development with additional modules wherein individual behavior is also measured across a series of more closely spaced occasions. We made use of data from a burst of daily measurements obtained from a very small, select, and relatively homogenous sub-sample of participants ($N = 36$) who had lived into very old age (mean age = 90 years). Substantively, we examined if differences in *developmental change* are related to individuals' *dynamic characteristics* (Ram & Gerstorf, 2009). Methodologically, the former was indicated by differential changes in cognitive performance that manifested across six measurements obtained over 13 + years, and the latter by patterns in the variability of cognitive performance, resting heart rate, and emotional experience that manifested across six measurements obtained within 2+ weeks.

Making use of the longitudinal depth of the study, we found evidence that long-term change was related to multiple aspects of short-term change—in expected and theoretically meaningful ways. Specifically, interindividual differences in cognitive aging were positively related to cognitive plasticity, and negatively related to cardiovascular lability and emotional diversity. Interpreted at a general level, these findings suggest that interindividual differences in (late-life) functioning manifest across domains and time scales. It was indeed surprising that we were able to obtain substantively meaningful relationships, even though the deck was, in many senses, stacked against finding anything statistically significant. With only 36 persons, statistical power to uncover significant effects was very low. The robustness of the findings across domains in such a small sample suggests that the associations among constructs are not simply because of chance. However, we still take great caution not to interpret the results as representative of the state of affairs among the very old or as indicative of causal relationships. Instead, we view the fact that the theoretical associations appeared in a severely restricted (small *N*, small *T*) analytic environment as a strong indicator of the promise that burst studies hold for further inquiry. Many new findings will emerge

[1] As a supplement to the bootstrap confidence intervals appropriate for the small sample, we also evaluated the directional nature of our hypothesized associations using traditional one-tailed tests with $\alpha = .05$.

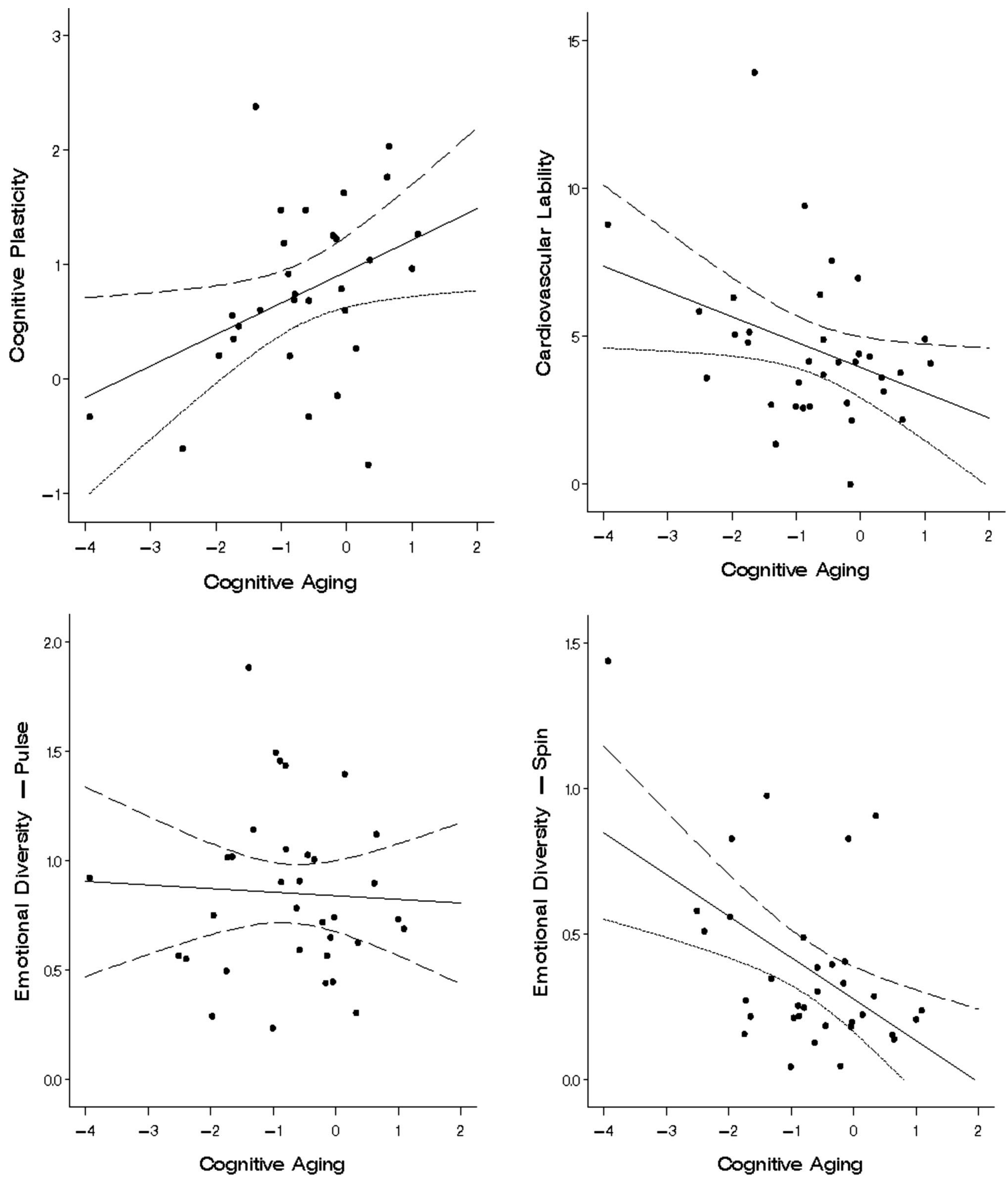

Figure 2. Plots of associations between long-term longitudinal changes in cognitive ability over approximately 13 years (*x*-axes) and short-term variability in cognitive performance, cardiovascular function, and emotional experience over approximately 2 weeks (*y*-axes). More positive cognitive aging on the Digit Letter test (i.e., less decline or increase in perceptual speed) was associated with greater cognitive plasticity (upper left-hand panel), lesser cardiovascular lability (upper right-hand panel), as well as lesser emotional diversity (pulse: lower left-hand panel; spin: lower right-hand panel). Dashed lines indicate 95% confidence intervals.

Table 2
Long-Term Longitudinal Change in the Digit Letter as Predictor of Short-Term Variability Across Multiple Domains of Functioning

	Dependent variable											
							Emotional diversity					
	Cognitive plasticity			Cardiovascular lability			Pulse (vector length)			Spin (angle)		
	β	*B*	95% CI of *B*	β	*B*	95% CI of *B*	β	*B*	95% CI of *B*	β	*B*	95% CI of *B*
Intercept		7.83	1.71, 14.85		−6.40	−31.98, 23.92		−1.46	−4.63, 2.54		0.93	−1.34, 2.72
Age	−0.19	−0.04	−0.11, 0.02	0.10	0.06	−0.20, 0.28	0.14	0.01	−0.03, 0.04	−0.16	−0.01	−0.03, 0.01
Gender	0.09	0.14	−0.37, 0.79	−0.15	−0.77	−2.64, 0.67	0.09	0.07	−0.22, 0.37	0.21	0.13	−0.08, 0.32
Cognitive ability	−0.51*	−0.06*	−0.11, −0.03	0.33	0.09	−0.09, 0.25	0.45	0.02	−0.01, 0.04	0.14	0.00	−0.01, 0.02
Cognitive aging	**0.63***	**0.88***	**0.38, 0.79**	**−0.62***	**−2.20***	**−3.75, −0.69**	**−0.49***	**−0.26***	**−0.52, 0.00**	**−0.49***	**−0.20***	**−0.44, 0.05**
Total R^2	.32	.23	.15	.18								

Note. $N = 36$. 95% confidence interval [CI] = 2.5%, 97.5% confidence bounds obtained using 5,000 bootstrap resamples. Cognitive plasticity indicated by linear slope of digit letter performance over 6 occasions. Cardiovascular Lability indicated by intraindividual *SD* (iSD) of resting heart rate over 6 occasions. Emotional diversity indicated by pulse (vector length variability) and spin (angular variability) in the valence/activation emotion space over 6 occasions. Cognitive ability (current level) and Cognitive Aging (change per year) indicated by parameters from individual linear growth models fit assessments of digit letter performance to digit letter performance over ~13 years.
* $p < .05$ using traditional one-tailed tests.

from similar studies that can make use of larger samples and more occasions.

Substantive Implications

Cautiously, we highlight how the results may inform several aspects of late-life development and indicate the viability of dynamic systems theory as a framework for studying life-span development. We used cognitive aging as a proxy developmental phenomenon. The utility of the construct is derived from the relative precision with which the underlying measure (Digit Letter substitution) can track subtle changes within individuals. Although homogenous, highly select, and still performing at relatively high levels (still above the average of the original sample), our measurement burst participants were not immune to the effects of aging. To separate the effects of aging from ability level, we controlled for "static" interindividual differences in current levels of performance. That differences in cognitive aging were still predictive of differences in dynamic characteristics suggests that unique information is held in our quantifications of developmental processes. It was not just the person's state that mattered, but also the specific pattern of changes he or she experienced in getting there. Although, as a field, we are still searching for what the *processes* underlying "cognitive aging" are, such results highlight the importance of considering developmental change as a separate and important predictor variable (or outcome variable; Wohlwill, 1973).

On average, these older participants' cognitive performance declined about 6.4 T-score units over 13+ years. These same individuals' performance increased, on average, about 4.6 T-score units across the six sessions during the 2+ weeks of the measurement burst. Taken literally, this suggests that some very old individuals are able to regain much of what was lost in previous years, and that cognitive plasticity can be preserved into advanced old age (see also Singer et al., 2003; Yang et al, 2006). However, care should be taken that while derived from the same test, the long-term and short-term changes in cognitive performance are indicative of different phenomena. Cardiovascular lability was relatively low in this sample, with the prototypical individual's resting HR not so likely to deviate beyond the ±5 beat/min range for normative day-to-day fluctuations among healthy adults. In addition, as might be noted in Figure 1 (right-lower panel), the vast majority of emotional fluctuations occurred within the positive-activated and positive-deactivated quadrants of the valence-arousal emotion space, perhaps indicating the general positivity of these older adults' well-being.

Considering interindividual differences, we found a consistent set of predictions for how differences in prior cognitive aging were related to subsequent differences in dynamic constructs in the cognitive, health, and emotion domains. Although the mechanisms that connect these phenomena are not yet well understood, our results could be interpreted as being indicative of common coordinative and emergent processes of the central nervous system that maintain homeostasis (see Ford & Lerner, 1992; Thelen & Smith, 1994).

Synopsis: Integrate Measurement Bursts Into Longitudinal Studies

Across ages and domains, studies of intraindividual variability are expanding our understanding of individual functioning. Coupled with data from on-going large-scale longitudinal studies, burst modules, wherein a small battery of measurements are obtained on many closely spaced occasions, can also expand our understanding of development and aging, how it proceeds, how it manifests, and how it can be optimized (Nesselroade, 1991). Using data from a small burst study module included as an "addendum" to the BASE, we found significant associations between the previously studied long-term cognitive aging and the newly available measurements of cognitive plasticity, cardiovascular robustness, and emotional diversity. We hope that our findings and experiences encourage other longitudinal studies of development and aging to augment their on-going data collections with "bursts" of measurement that can provide a rich and dynamic picture of how individuals change and develop over time – day-to-day, minute-to-minute, and year-to-year.

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