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A framework for studying mechanisms underlying terminal decline in well-being

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Abstract

Multiple facets of well-being are known to show steep end-of-life deteriorations. However, the underlying mechanisms and pathways are vague. Capitalizing on an earlier review of the existing empirical literature on terminal decline, we present a conceptual/methodological framework that can be used as a tool to structure future inquiry aimed at refining the precision and specificity of the terminal decline concept. Specifically, we propose a model of terminal decline in well-being in which within-person mean levels of, inconsistencies in, or couplings among multiple domains of functioning serve as indicators or sources of well-being. The model, based on time-varying dynamic factor analysis of intensive longitudinal data, provides for concise articulation and testing of central tenets of theories of successful aging, including hypotheses regarding shifts in goals away from some domains and towards others (e.g. secondary control). We conclude by suggesting routes for empirical research.

Keywords

end-of-life, developmental methods, longitudinal change, self-regulation, well-being

Well-being is considered a central indicator of quality of life (Diener, Suh, Lucas, & Smith, 1999). Age-related inquiries into well-being have often been heralded as evidence for successful aging. The phrase 'well-being paradox of old age' describes the observation that during old age, average well-being remains relatively stable despite severe losses in physical health, cognitive abilities, and social structures (e.g. loss of spouse; M. M. Baltes & Carstensen, 1996). However, over the past decade, studies have documented that this positive picture of aging does not prevail into the last years of life (Berg, Hassing, Thorvadsson, & Johansson, 2011; Gerstorf et al., 2014; Mroczek & Spiro, 2005). Rather, in the years before death, the typical person's well-being declines at an alarmingly rapid pace (Burns, Byles, Magliano, Mitchell, & Anstey, 2014; Palgi, 2010; for a review, see Gerstorf & Ram, 2013). *Terminal decline* typically begins between 3 and 5 years before death, with average well-being falling a full *SD* during this period. The average is, of course, complemented by a full range of individual differences in both onset times and extent of decline. Our interest is to understand why: Why are some persons able to maintain well-being in the face of physical health, cognitive, and social difficulty, while others' well-being exhibits terminal decline?

As we have argued elsewhere, the extent of change and the extent of between-person differences in extent of terminal decline provide a unique opportunity to identify and understand the mechanisms and factors that contribute to changes (or stability) in well-being more generally (Gerstorf & Ram, 2012). Recently, we have reviewed the existing empirical literature on terminal decline, using the lens provided by Baltes and Nesselroade's (1979) five objectives of longitudinal research to identify several aspects of terminal decline that needed further consideration (Gerstorf & Ram, 2013). Specifically, we noted the gaps in knowledge about the interrelations among late-life change in different domains of function, the underlying mechanisms of change, and the factors that contribute to individual differences in change. We speculated that these gaps might be filled through collection and analysis of intensive longitudinal data, but did not yet grasp how such data could actually be mapped to developmental theory.

Thus, our objective here is to outline a conceptual/methodological framework that can be used to study the specifics of terminal decline and, more generally, life-span development. Simultaneously engaging the central tenets of theories of successful aging and the analytical tools used for longitudinal research, we seek to identify a more precise set of hypotheses about terminal decline in well-being that can be operationally defined, written out in mathematical form, and tested empirically with longitudinal data. In doing so, we expand current notions of terminal decline, typically considered as changes in level of function that occur in the last years of life, in several ways. In particular, as will be outlined below, we suggest that terminal declines in well-being may be driven by (a) differential weighting of level of function across domains and across time and (b) evaluation of within-person fluctuations (i.e., across-occasion variability) and within-person coupling (i.e., across-occasion covariation among multiple domains of functioning). We then speculate, using mathematical models and simulation, how the expanded theory can be articulated and tested empirically.

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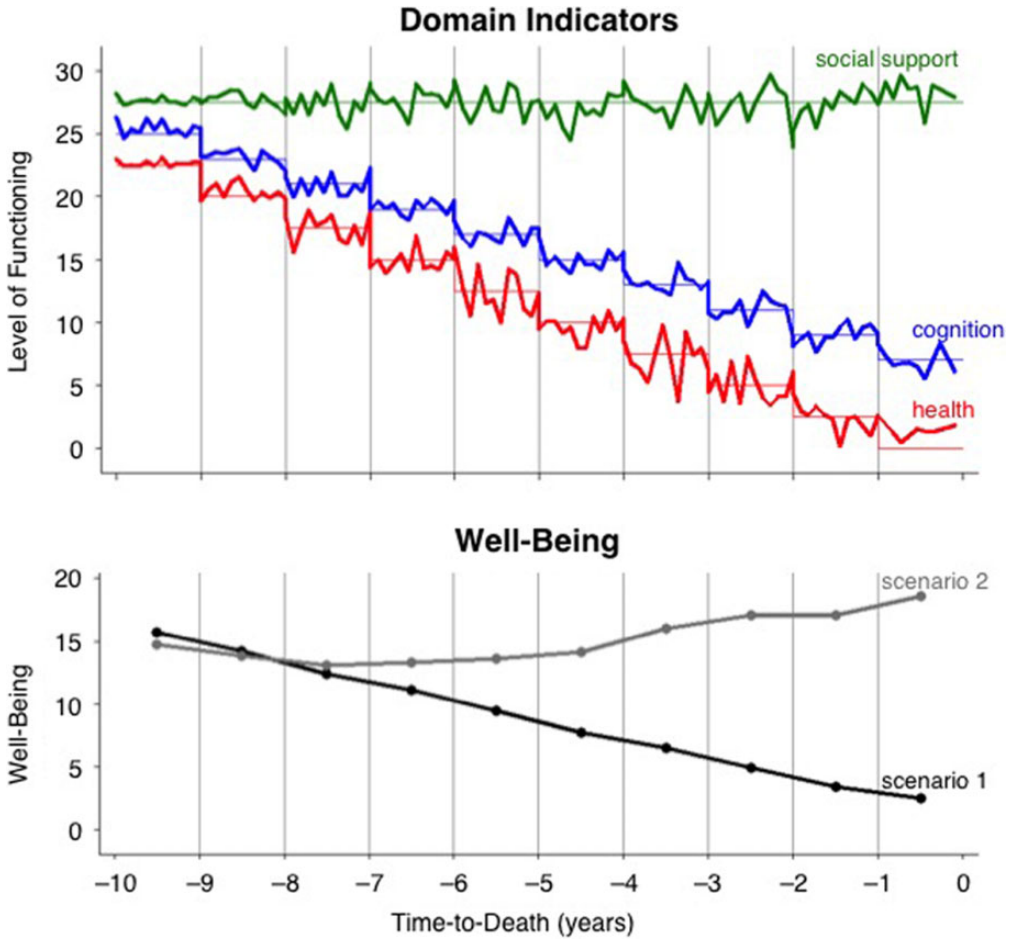

Figure 1. Hypothetical data obtained monthly from an individual over his or her last 10 years of life. Upper panel: Within-year mean levels of physical health (red) and cognition (blue) decline at slightly different rates, whereas social support (green) remains stable. Within-year inconsistency (variance) of physical health (red) and social support (green) increase as the individual approaches death, whereas the inconsistency of cognition (blue) remains stable. Within-year couplings (covariance) of cognition with social support (green) remain high and positive throughout, whereas coupling of physical health (red) and the other domains begins high and positive, goes through zero and becomes negative. Lower panel: Illustration of well-being trajectories if the person does or does not re-weight the domain in evaluating well-being. In Scenario 1 (solid black line), the individual maintains the same equal weights for each domain through to the end of life. As a consequence, well-being evaluations follow the trajectories of the domains and also exhibit terminal decline. In Scenario 2 (solid gray line), the individual reweights the domains such that later in the series, well-being is indicated primarily by the relatively intact domain (or couplings) and less so by the impaired domains (or couplings). As a consequence, the individual is able to maintain well-being in the face of declines in multiple domains (or linkages). (The colour version of this figure is available at jbd.sagepub.com.)

Terminal decline – the phenomenon and some hypothetical data

Notions of terminal decline aim at describing late-life developmental processes that end in death (Birren & Cunningham, 1985; Kleemeier, 1962; Riegel & Riegel, 1972). Typically, developmental processes are examined in relation to birth, with time-since-birth (chronological age) serving as a proxy measure for age-related processes. Inverting the life span, terminal decline processes are examined, by definition, in relation to death, with time-to-death (calculated post-hoc) serving as a proxy measure of mortality-related processes (see Ram, Gerstorf, Fauth, Zarit, & Malmberg, 2010). That is, terminal decline is the change that accrues as time runs out. The existing literature suggests that the end of life is, like other stages of the life span, characterized by *differential development*. There is evidence of (a) within-person change in multiple domains of function (e.g. physical health, cognitive, social) in the years before death; (b) between-domain differences in the extent of typical decline; and (c) between-person differences in timing of onset and rates of terminal decline (Gerstorf & Ram, 2013).

Terminal decline is a within-person (developmental) process that manifests in and can be observed through collection of repeated measures data. A simulation of this process is shown in the upper portion of Figure 1. Here, repeated monthly assessments of an individual's function in three domains (physical health, cognition, and social support) were obtained (i.e., generated via one of our simulation engines, see Ram, Gatze-Kopp, et al., in press) for the last 10 years of life ($T_{occasions} = 120$). Following the empirical literature, the example data were generated so that the individual's levels of physical health (red) and cognition (blue) decline at slightly different rates. While these are hypothetical trends, precipitous proximate-to-death declines have long been documented in the physical health and cognitive domains (Bäckman & MacDonald, 2006; Wilson et al., 2012). In contrast, social support (green)

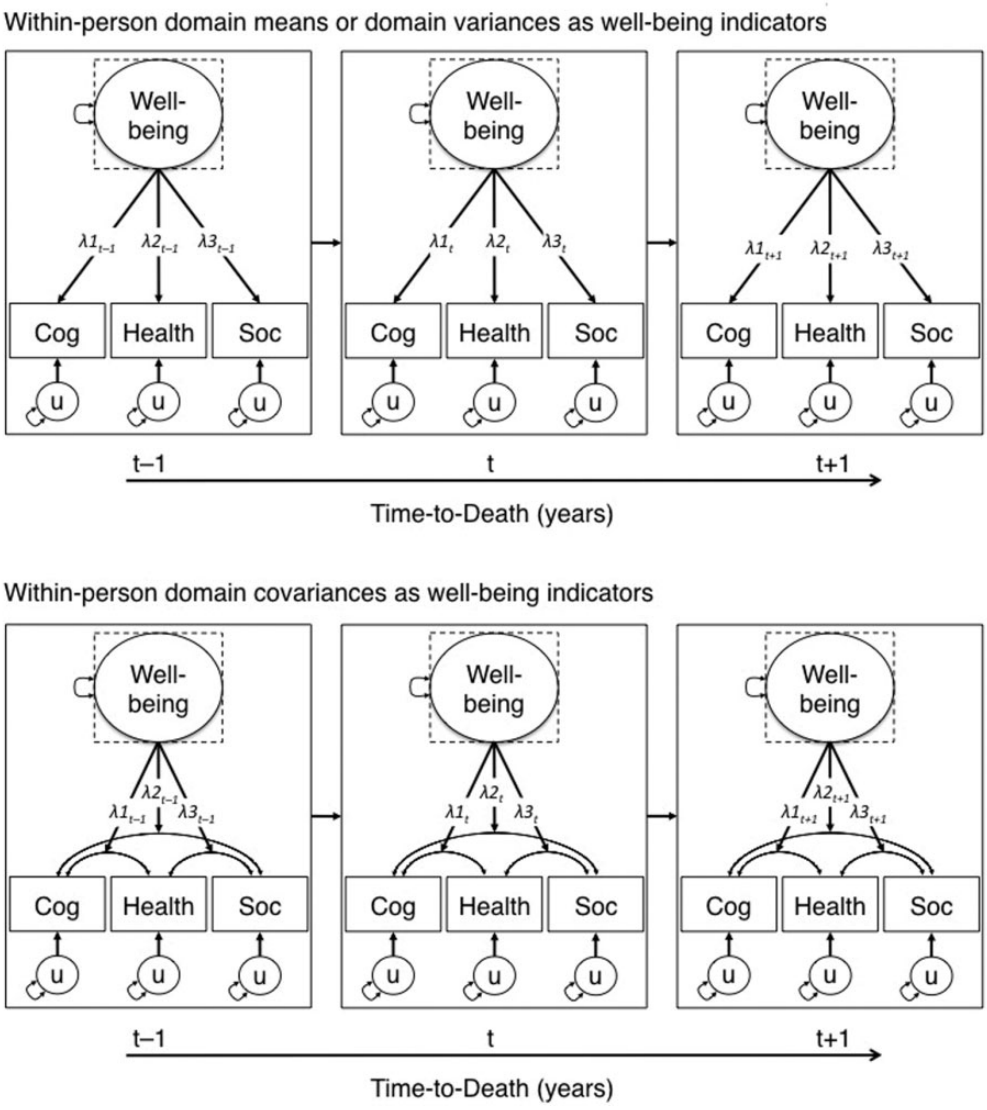

Figure 2. A "measurement model" of well-being in which within-person mean levels of and fluctuations in physical health, cognitive functioning, and social support (upper panel) or couplings between these key domains of functioning (lower panel) serve as indicators or sources of well-being. The factor loadings change over time, thereby articulating hypotheses about the operation of secondary control strategies (e.g. changes in the weight certain domains have in shaping well-being). For parsimony, factor means are not displayed in the figure, but are modeled.

remains relatively stable over the long term. Again, a hypothetical trend, but one that is consistent with reports suggesting that social support, when operationally defined using qualitative indicators of support from and feeling close to one's confidants, remains relatively stable through very old age (Antonucci, Fiori, Birditt, & Jackey, 2010; Pruchno & Rosenbaum, 2003).

In sum, following the basic tenets of life-span development and the empirical literature on terminal decline, simulated data in the upper panel of Figure 1 exhibit both (a) within-person change in multiple domains of function and (b) between-domain differences in rates of decline. For conceptual clarity, we have, for the moment, set aside (c) between-person differences. Concentrating on the data from a single individual purposively prioritizes consideration of how terminal decline plays out as a within-person phenomenon. However, through the remainder of our presentation, between-person differences in how this within-person phenomenon proceeds are used to both expand conceptual notions of terminal decline in well-being and illustrate how various hypotheses about successful aging might be articulated mathematically (the lingua franca of science) and empirically.

A theoretico-mathematical framework

To bring the notion of terminal decline to life (apologies for the awkward pun), we introduce "Jack" and "Diane," two American elders doing the best that they can. Paralleling what we see in our empirical studies, we consider scenarios where Jack and Diane both exhibit the typically noted trajectories of physical health, cognition, and social support, but exhibit very different well-being trajectories. That is, both Jack and Diane follow the domain-specific trajectories shown in the upper panel of Figure 1, but Jack's well-being declines with the approach to death (Scenario 1 in the bottom panel of Figure 1) and Diane's well-being remains relatively stable (Scenario 2 in the bottom panel of Figure 1). Jack exhibits terminal

decline in well-being, while Diane does not (she ages successfully, so to speak; see P. B. Baltes & Baltes, 1990). In the sections that follow, we develop a framework for articulating both how these differences emerge and how they can be studied.

Well-being

First, we articulate the relation between well-being and function in the three illustration domains (physical health, cognition, social support). In doing so, we adopt one of the many definitions of well-being (acknowledging that other perspectives are also viable; Ryff, 1989). In the well-being literature, researchers have forwarded a "bottom-up" perspective, wherein individuals' well-being ratings are considered as a self-evaluation of function in multiple domains (for overview, see Diener, 1984). Conceptually, when asked to provide a well-being rating, individuals evaluate and summarize the integrity of and function in multiple domains (e.g. physical health, cognition, social support; Maier & Smith, 1999). In other words, individuals use a "measurement model" to compile their evaluations into a single well-being rating – a "factor score." Considering the hypothetical data outlined above: Each year, Jack/Diane evaluates his/her physical health, cognition, and social support, and combines them into an overall well-being evaluation.

Methodologically, these yearly evaluations of well-being might be articulated using the common factor model (see center portion in the upper Panel of Figure 2) – one of the main models used to describe how "latent" factor scores are indicated by a multivariate vector of scores (see e.g. Brose & Ram, 2012, for discussion of within-person application). Formally, the "bottom-up" perspective can be written as

$$\begin{bmatrix} Domain1_t \\ Domain2_t \\ Domain3_t \end{bmatrix} = \begin{bmatrix} \lambda_1 \\ \lambda_2 \\ \lambda_3 \end{bmatrix}_t Wellbeing_t + \begin{bmatrix} u_{1t} \\ u_{2t} \\ u_{3t} \end{bmatrix} \quad (1)$$

where $Domain\#_t$ are the yearly evaluations of each domain (physical health, cognition, social support), λ_1, λ_2, and λ_3 are the domain-specific weights, and u_1, u_2 and u_3 are the residual portions of each domain score that were not used in the well-being evaluation. Conceptually, a portion of the available domain-specific information is deemed relevant to the evaluation of well-being and another portion (the *u*s) is deemed irrelevant. For example, in the physical health domain, Jack may consider the experience of severe side effects caused by antihypertensive medication (e.g. gastrointestinal disturbance, lethargy, drowsiness) when calculating his well-being evaluation, but not consider the absence of dizziness, which was also affected by the medication. In contrast, Diane may consider that her physical health is relatively well preserved as compared with her same-aged friends, but not consider her inability to go on her previously beloved after lunch walks.

Developmental change

As noted earlier, the data in Figure 1 were simulated to depict the developmental (i.e., year-to-year) trajectories of Jack and Diane's level of function in multiple domains (upper panel: physical health = $Domain1_t$, cognition = $Domain2_t$, social support = $Domain3_t$) and in well-being (lower panel: $Well\text{-}being_t$). Bringing together conceptual and mathematical representations of development (i.e., in this context, representations of terminal decline), the observed changes are generated through two "common pathways:" (i) within-person changes in domain levels and (ii) within-person changes in weights for well-being evaluation, where the former follow traditional notions of development as an incremental change in ability and the latter follow traditional notions of development as discrete changes in structure of thought and/or behaviour (for discussion, see Ford & Lerner, 1992).

Model formulation. Looking at the entirety of the upper Panel of Figure 2, changes between $t-1$, t, and $t+1$ manifest in the content of the squares and circles (changes in level) and/or the content of the arrows (changes in structure). The time-specific factor models and the time-specific subscripts are organized to indicate that, in addition to the observed and latent scores, the factor loadings can differ at each occasion. Formally written out in a more compact vector/matrix notation,

$$Domains_t = \Lambda_t Wellbeing_t + U_t, \quad (2)$$

where each element in the equation are the vectors given above (Equation 1), and the t subscripts indicate that all of those vectors may vary over *time*. That is,

$$Domains_t = f(t, X), \text{ and} \quad (3)$$

$$\Lambda_t = g(t, X), \quad (4)$$

where the domain scores *and* the weights change as a function of time, t, (e.g. time-to-death) and/or other variables, X (e.g. between-person differences in perceived control, within-person changes in context). In essence, this formulation uses separate "growth models" to describe (i) within-person changes in each domain and (ii) within-person changes in the weighting scheme.

Within-person changes in domain levels. Corroborating notions of terminal decline, evidence is accumulating that numerous measures of physical health and cognition show precipitous declines late in life (for overview, see Gerstorf & Ram, 2013). For example, motor ability was found to decline an average of 1.4 *SD* in the last 2.5 years (Wilson et al., 2012; see also Rabbitt, Lunn, Pendleton, & Yardefagar, 2011). Similarly, Wilson, Beckett, Bienias, Evans, and Bennett (2003) reported that decline in cognition amounted to an average loss of more than a full *SD* in the 3.5 years before death (see also Muniz-Terrera, van den Hout, Piccinin, Matthews, & Hofer, 2013; Sliwinski, Hofer, Hall, Buschke, & Lipton, 2003; Thorvaldsson, Hofer, & Johansson, 2006). Although late-life appears to be generally characterized by broad-based decrements, functioning in some domains is less prone to declines. In the social domain, for example, loneliness increased at a rate of less than 0.5 *SD* in the last 10 years of life (Gerstorf, Ram, Lindenberger, & Smith, 2013).

Generally, all these empirical reports describe terminal decline using a growth model wherein yearly (or longer interval) assessments of individuals' level of function are modeled as a function of time. Generalizing from these reports, we generated Jack and Diane's data (year-to-year progression of bold lines) shown in the upper panel of Figure 1 using a standard multivariate linear growth model version of Equation 3. Specifically,

$$\begin{bmatrix} Physical_t \\ Cognition_t \\ Social_t \end{bmatrix} = \begin{bmatrix} 22.5 \\ 25.0 \\ 27.5 \end{bmatrix} + \begin{bmatrix} -2.5 \\ -2.0 \\ 0 \end{bmatrix} year_t + \begin{bmatrix} e_{1t} \\ e_{2t} \\ e_{3t} \end{bmatrix}. \quad (5)$$

where $year_t$ is runs from 0 to 9, and the x-axis in Figure 1 is the inversion $time\text{-}to\text{-}death_t = year_t - 10$. As argued above, physical health and cognition were modelled so as to decline relatively rapidly ($\beta_{physicalhealth} = -2.5$, $\beta_{cognition} = -2.0$) and social support was

modelled to remain stable ($\beta_{socialsupport} = 0.0$). We note that although our example is framed with respect to terminal decline and change with respect to time-to-death, the model can straightforwardly be applied to many other 'slow-moving' time scales (e.g. years, decades), events (e.g. birth, menarche, marriage), or patterns of change (e.g. logistic, sigmoid, sinusoid; Ram & Grimm, in press).

Within-person changes in weights for well-being evaluation. Theories of life-span development suggest a variety of shifts in the structure of individuals' thoughts and behaviours with advancing age. For example, theories of cognitive development suggest differentiation of abilities from childhood through adolescence to adulthood and dedifferentiation through old age (see Hueluer, Ram, Willis, Schaie, & Gerstorf, 2014; Li et al., 2004). Similarly, theories of successful aging generally suggest selective shifts in which behaviours are selected for maintenance, optimized, and/or compensated for (P. B. Baltes & Baltes, 1990; Carstensen, 2006). For example, the Motivational Theory of Life-Span Development (Heckhausen, Wrosch, & Schulz, 2010) proposes that primary control striving (i.e., directed at bringing the environment in line with one's wishes) is the ultimate purpose of self-regulation. As a consequence, substantial and irreversible losses of primary control capacities (e.g. no longer being able to walk several blocks) severely impact well-being. Such a scenario could only be alleviated if people manage to disengage from some primary control pursuits and adjust their goals towards those pursuits that are still feasible (e.g. still being capable of moving in and around the house). Such strategies of secondary control strivings are directed at changing the self to bring one's goals in line with environmental constraints (see also P. B. Baltes & Baltes, 1990).

Tethering the theoretical propositions to the mathematical model, goal disengagement and goal reengagement are operationalized as within-person changes in the weights used in the well-being evaluation. When individuals hold primary control strivings (e.g. Jack strives to walk 5 miles a day), specific domains of function (e.g. physical health) are likely to be up-weighted when evaluating their well-being. In contrast, when individuals make use of secondary control strivings and disengage from particular goals and domains (e.g. Diane no longer enjoys walking), specific domains of function will be down-weighted when evaluating well-being.

Analytically, the task is to use the available information to determine what an individual's "measurement model" is—how are individuals weighting the various domains when evaluating their well-being and how those weights are changing as they engage and disengage with specific goals. That is, what are the factor loadings shown in Figure 2, and how are they changing across the panels? In essence, when individuals provide reports of well-being, they are providing estimates of the well-being factor scores. When both the well-being assessments (circle in a square) and the domain-specific assessments (e.g. cognitive ability, squares) are available, we can derive the parameters (factor loadings) that describe how an individual weights the domains and how those weights change or remain stable over time. Specific hypotheses can then be tested regarding within-person changes in the weights and between-person differences in those changes.

Using our hypothetical data to illustrate: Both Jack and Diane are faced with a situation where physical health and cognitive ability decline, while social support remains high. Let us assume that at the outset (10 years prior to death), both Jack and Diane have primary control pursuits in all three domains. All three domains are weighted equally in their internal "measurement model" for well-being (e.g. $\lambda_1 = \lambda_2 = \lambda_3 = 0.33$). As they approach death, though, Jack and Diane's primary and secondary control pursuits diverge. Jack maintains primary control pursuits in all three domains. Thus, as he gets closer to death, he continues to evaluate his well-being equally with respect to his physical health, cognitive ability, and social support. The weights in Jack's internal "measurement model" remain constant through to the end of life. That is,

$$\begin{bmatrix}\lambda_1\\ \lambda_2\\ \lambda_3\end{bmatrix}_t = \begin{bmatrix}0.33\\ 0.33\\ 0.33\end{bmatrix} + \begin{bmatrix}0\\ 0\\ 0\end{bmatrix} year_t. \quad (6a)$$

Combining the specifics of Equations 5 and 6 into Equation 2, we can see in the black line in the lower panel of Figure 1 (scenario 1), that when weighted in this way, Jack's well-being follows the domain trajectories. Like physical health, and cognition, his well-being manifests terminal decline. In contrast, as Diane gets closer to death, she employs secondary control strivings, disengaging from goals in specific domains and redirecting towards other domains. Her well-being is initially indicated by relatively equal weighting of all three domains (e.g. $\lambda_1 = \lambda_2 = \lambda_3 = 0.33$), but is reweighted over time so that later in the series, well-being is indicated primarily by the relatively intact social support domain (e.g. $\lambda_1 = 0.1$, $\lambda_2 = 0.1$, $\lambda_3 = 0.8$). That is,

$$\begin{bmatrix}\lambda_1\\ \lambda_2\\ \lambda_3\end{bmatrix}_t = \begin{bmatrix}0.33\\ 0.33\\ 0.33\end{bmatrix} + \begin{bmatrix}-0.05\\ -0.05\\ +0.10\end{bmatrix} year_t \quad (6b)$$

with the constraint that elements of $\lambda_t < 0$ or $\lambda_t > 1$ are fixed to $= 0$ or $= 1$, respectively, to maintain a floor to ceiling standardized scaling. The reweighting of the "measurement model" over time allows Diane to maintain well-being despite declines in multiple domains. The resulting stability of well-being is seen in the grey line in the lower panel of Figure 1 (scenario 2). The contrast between Jack's and Diane's well-being trajectories highlights how the pattern of within-person change in weights for the well-being evaluation might contribute to quality of life outcomes. Given the same physical health and cognitive decrements, one individual is able to maintain well-being and the other is not.

In our simple example, we have structured the within-person changes in weights for well-being evaluation as driven purely by time-to-death, a variable that serves as a proxy for all mortality-related processes. However, as noted above, theoretical propositions have in some cases implicated specific underlying processes (e.g. Heckhausen et al., 2010). For example, when individuals' engagement in secondary control has been measured repeatedly, these time-varying covariates can be explicitly included among the variables that influence the weighting scheme (as part of the X variables in Equation 4). Similarly, other theories of life-span development highlight how changes in motivation (Carstensen, 2006) and selective optimization and compensation (P. B. Baltes & Baltes, 1990) will influence individuals' weighting schemes. All such variables can be included in Equation 4. With the proper data, we can use this framework to test whether the hypothesized role these processes play in sustaining well-being do indeed provide a viable explanation of the data.

An expanded set of information

The sections above forward a general framework where "growth models" that describe (i) within-person changes in each domain

and (ii) within-person changes in the weighting scheme are combined together to model the relation between domain-specific function and well-being. However, we have been somewhat vague about how the *yearly evaluations of function in each domain* (i.e., the squares in Figure 2) are themselves derived. What aspects of domain-specific function are relevant in individuals' evaluations of their well-being?

Starting "bottom up" from the assumption that repeated measures of ability shown in the upper Panel of Figure 1 are available (whether through implicit self-monitoring or explicit researcher-monitoring), the 12 (monthly) repeated multivariate assessments from a given year can be summarized in three ways: (a) for each domain, we can calculate the within-person mean to index *level* of function; (b) for each domain, we can calculate the within-person variance to index *inconsistency* of function; and (c) for each pair of domains, we can calculate the within-person covariance to index *coupling* of function. For the full 10 years of assessments, we aggregate across months to obtain 10 yearly measures of level (means) and 10 yearly measures of inconsistency (variance) for each of the three variables, and 10 yearly measures of coupling (covariances) for each pairing of the variables (= 30 covariances). Note that all three types of person-specific measures are available in intensive repeated measures designs, whereas only single-assessment proxies for *level* would be available in standard longitudinal panel study designs.

Let us consider, narratively from Jack and Diane's perspective, whether and how these three types of *yearly evaluations of function in each domain* (level, inconsistency, and coupling) might be used when individuals are evaluating their well-being. As noted above, **Jack** has always considered good health and preserved physical functioning a key component of his life. Because he continues to do so late in life, well-being evaluations for him follow the same downward trends as does his physical health. Average declines in health, however, may not be the only reason for Jack's well-being declines. It is also possible that the primary source of Jack's well-being has for the past 20 years been the day-to-day stability (opposite of inconsistency) of his health, and by implication its predictability. Late in life, his well-being thus primarily suffers from the tremendous fluctuations his physical health shows from one day to the next (e.g. that he is able to leave the bed on one day, but not on the next). Alternatively (or in addition), Jack's well-being may have always resulted from evaluating and valuing the tight coupling between his functioning in both the physical health domain and the cognitive domain, with his beloved daily walks after lunch always being a good inspiration for solving the most difficult crossword puzzles he had read before lunch. Later in life, when Jack still considers the close coupling of the now impaired health domain with the cognitive domain to be a central source of his well-being, his well-being declines.

Diane is also confronted with severely debilitating physical health conditions late in life. In contrast to Jack, however, Diane manages to keep her well-being relatively stable across her last years. Diane is successful in doing so because she draws from a set of secondary control strategies (P. B. Baltes & Baltes, 1990; Heckhausen et al., 2010) that help her disengage from and thus lower the value she assigns to particular domains of functioning, while increasing the value she assigns to other domains (i.e., re-engagement). To illustrate, Diane has managed to let go of goals in the health domain that have become out of reach because of her mean-level declines in physical capabilities (e.g. her formerly beloved walk after lunch is not possible anymore). Instead, she now focuses on goals that are still feasible by, for example, keeping up her social network through frequent phone calls with long-term friends and close family members, which in turn helps maintain her well-being. The increasingly large health fluctuations from one day to the next that Diane is confronted with are also not a major source of discomfort for her because those health fluctuations (implicitly) receive lower and lower weight in shaping her well-being. Another source of Diane's well-being may be the coupling between domains of functioning. For example, Diane (implicitly) assigns more weight to the coupling of the intact social domain with the cognitive functioning domain and thereby values that her regular phone calls and involvement in the everyday lives of her acquaintances help her remain cognitively fit, which in turn contributes to her well-being.

Domain variances as well-being indicators. As illustrated in the example above, well-being ratings may not only result from evaluating levels of function (yearly intra-individual means), but people may use other information as well. For example, one alternative is that yearly evaluations of well-being are derived from assessments of *inconsistency* in function: How variable is my physical health, cognitive ability, and social support, as suggested in the Jack and Diane examples above? Looking again at the upper Panel of Figure 1, the variances (month-to-month inconsistency of scores within a year) are changing with time. Variances of both health (red) and social support (green) are increasing as the individual approaches death, whereas the variance of cognitive ability (blue) remains stable. Note that the year-to-year changes in the domain-specific variances seen in Figure 1 are meant to highlight that these variances do indeed change—and may move in different directions. The specific rates and directions of change are not exact representations of the changes reported in the literature thus far. However, a growing body of research has described age-related differences in variability (MacDonald, Li, & Bäckman, 2009) and how such variability is related to survival (Eizenman, Nesselroade, Featherman, & Rowe, 1997). In most domains, inconsistency of function is expected to increase as individuals approach death (Ram & Gerstorf, 2009). When inconsistency is the focus, well-being is indicated (inversely) by the extent of "turbulence" an individual experiences in his or her function in multiple domains. The graphical and mathematical depiction of the model are the same as in the upper panel of Figure 2, but the content of the squares (domain score vectors) are within-person variances rather than within-person means. Looking at the data in Figure 1, Jack and Diane's physical health fluctuates dramatically from occasion to occasion late in life. Physical health is inconsistent. Jack is able to get out of the bed easily on one day, but has extreme difficulty on another day. Jack's well-being may be lower if he considers the inconsistency in physical health as a major impediment to accomplishing personally meaningful tasks.

Hypotheses for how the changes in the domain-specific variances are related to well-being are derived as before. Domain inconsistency scores (computed after removing trends) and the factor loadings are modelled as a function of time and other variables (e.g. secondary control). Given equal weighting of domains (Scenario 1; Jack) within a "measurement model" for well-being based on evaluations of inconsistency, well-being would decline as inconsistency of function increases (see lower Panel of Figure 1: black line). In contrast, a person who changes his or her weighting scheme towards more stable domains (Scenario 2; Diane) would be able to maintain relatively stable well-being (see lower Panel of Figure 1: grey line).

Coupling among domains (covariances) as well-being indicators. Following from mean, to variance, to covariance, a third possibility

is that well-being is an evaluation of the coupling or coordination among multiple domains. Drawing from developmental systems theory (Ford & Lerner, 1992), the systems responsible for physical health, cognitive, social, and other functions are conceptualized as components of a larger whole involved in coordinated action. Here, well-being is indicated by the integrity of the links among sub-systems. This possibility is depicted graphically in the bottom panel of Figure 2. Yearly evaluations of well-being are derived from assessments of the extent of coordination (covariances depicted by double-headed arrows) among the functioning of multiple domains; How coupled vs. un-coupled are my physical health, cognition, and social support?

In this systems-oriented perspective, terminal well-being declines result from individuals' perceiving that dynamic coordination and coupling of the sub-components are breaking down. To illustrate, in Figure 1, the within-year fluctuations in each domain all follow the same pattern of month-to-month ups and downs during the first few years; coupling among all three domains is very high and positive. Proceeding towards death, cognition and social support remain highly coupled, whereas the coupling of health with the other two domains declines (proceeding through zero to become highly negative in the year before death). As before, the covariances and the factor loadings are a function of time and other variables (Equations 3 and 4). Given equal weighting among all pairs of domains (Scenario 1; Jack) within a "measurement model" for well-being based on evaluations of coupling, well-being may decline (see lower Panel of Figure 1: black line). Changing their weighting scheme towards the pairs that remain coupled (Scenario 2; Diane), an individual's well-being may remain relatively stable (see lower Panel of Figure 1: grey line).

In the hypothetical scenario for Diane, we have assumed that high positive coupling among domains would be evaluated as good, resulting in preserved well-being. This assumption is based on the notion that impairment of core mechanisms common to many domains (e.g. neuronal connectivity, sympathetic/parasympathetic, approach/avoidance, arousal) compromises the coordinative interplay among multiple systems (e.g. between physical health and cognition). The lack of coordination and integration among parts would be reflected in lowered well-being evaluations. However, there are also reasons why high positive coupling among domains may be evaluated as bad (consider Jack's scenario), resulting in lower well-being. When health is tightly coupled with other domains, health declines past a critical threshold place burdens on and drag down other areas of functioning—potentially setting off a terminal cascade (Birren, 1959). The highly coordinated changes would be reflected in well-being evaluations that highlight the "fragility" of the entire system. Empirically, well-being declines may then result from a lack of relative independence (e.g. in Jack's perspective, poor health precludes cognitively stimulating activity). If the domains were not coupled, critical changes in health may be isolated and not propagate through the rest of the system. In the end, it is an empirical question whether mortality-related processes operate as "chaotic" systemic dysregulation that contributes to the emergence and enhancement of associations among previously independent processes or the breakdown of associations among previously coupled processes. Data like those plotted in Figure 1 and the "measurement" model presented in Figure 2 (lower Panel) allow for articulating and testing both scenarios. We note that other scenarios are possible, too. For example, days with impaired health may be coupled with receiving more support than usual, which in turn may help maintain well-being. Of interest will also be whether breakdowns in across-domain coupling are triggered by or portend the steep mean-level declines that often foreshadow death. We have discussed the three sources of well-being separately, but note explicitly that multiple weightings are possible at the same time and one weighting scheme may interact with and/or override another.

If it is across-domain coupling rather than mean-levels or variability in a given domain that matters for well-being, one major question is under which conditions can well-being be maintained into late-life? Employing secondary control strategies could contribute to the maintenance of well-being by helping people to reweight toward domains whose coordination is still intact. For example, if physical health and cognition are both declining but are still in synchrony, then on days when health is reasonably good, cognition would also be in relatively good shape. It would probably be much more frustrating and detrimental to one's well-being if on the good health days, the mind would not work well. In this case, a negative covariance between health and cognitions would be interpreted as worse for well-being than a near-zero covariance. In a similar vein, if people are able to align the "good days" across domains (e.g. seeing the grand-children on a good health day), well-being could probably be maintained, even if people must "pay" for those good days with subsequent bad days (e.g. not seeing the grand-children on a poor health day). Given these two contrasting possibilities, it will be intriguing to explore whether people are including cross-domain couplings (whether real or perceived) in their evaluations of well-being, whether they are indeed employing secondary control strategies to reweight specific cross-domain couplings, and whether specific scenarios promote the reweighting process. One interesting scenario, for example, is the transition into disability. Treating time as an event-contingent indicator, the λs at $t-1$ in Figure 2 could indicate the weighting scheme in the period prior to an event (e.g. before disability), λs at t during the event period (e.g. at around disability onset), and λs at $t+1$ during the post-event period (e.g. after disability has set-in). Data spanning across all three periods might provide some evidence for how major life events promote engagement of secondary control strategies and reorganization of primary strivings (Heckhausen, Wrosch, & Schulz, 2013).

Summary and outlook

We have proposed a framework for articulating and examining changes in well-being that may accompany or, for some individuals, may not accompany terminal decline. A crucial step in our thinking is considering terminal decline as something more than just within-person changes in levels of function (e.g. presumed 'true-scores' available from yearly assessments). We now have a way to also include information about within-person variability (i.e., across-occasion fluctuations/inconsistency) and within-person covariances (i.e., across-occasion coupling among multiple domains). Further, the framework articulates, in a mathematical form that can be fit to empirical data, why some individuals are able to maintain well-being all the way until death despite severe losses in multiple domains of functioning. Changes in within-person factor loadings provide a clear, concise articulation of central tenets of theories of successful aging.

In exploring the possibilities, we have worked through a variety of scenarios where two hypothetical elders, Jack and Diane, have or have not engaged secondary control strategies to shift their goals

away from some domains (e.g. those that are no longer under their control) and towards others (Heckhausen et al., 2010). Our framework accommodates and provides for examination of how such secondary control processes may operate. One possibility is that people alter their evaluation of the integrity and function in different domains, here operationally defined as mean-level changes (e.g. year-to-year declines in physical health). Another possibility is that control processes operate to buffer the consequences of these evaluations on satisfaction or affective well-being, here operationally defined as low or declining factor loading of a given domain (e.g. physical health). Comparing the relative fit of various model variants, we can test which of these possibilities might provide the best representation of a given individual's data.

Alternative models of well-being

We have built our framework on a "bottom-up" model where well-being is considered as a self-evaluation of function in multiple domains (Diener, 1984). The model presented can also be expanded to include moderators such as personality factors that shape the weighting schemes people apply. For example, people who score high on neuroticism can be expected to assign more weight to (perceived) health declines (Eysenck, 1967), whereas the well-being of more extraverted people may be more strongly shaped by social contacts (DeNeve & Cooper, 1998).

Other definitions of well-being are also viable, but generally require some reworking of the model. For example, "top-down" conceptions of well-being assume that domain-specific satisfactions (e.g. with one's finances, health, or social life) are, in part, derived from one's overall satisfaction with life (see Diener, 1984). Liberally interpreting the "top-down" perspective, well-being is viewed as a root "cause" of domain-specific function. Operationalizing this perspective within the framework proposed above seems possible, but requires a change in the interpretation of the factor models shown in Figure 2. Rather than interpreting the factor model as a representation of the "measurement model" a person uses internally to calculate their well-being (latent well-being variable interpreted as "being indicated by" the domain variables), the factor model is interpreted as a representation of a causal model (latent well-being variable interpreted as a "cause" of the domain variables). This latter interpretation accommodates evidence that well-being influences function in other domains through a variety of physiological (Pressman & Cohen, 2005) and behavioural–motivational (Levy, 2003) mechanisms. For example, meta-analytic findings suggest that well-being protects against cardiovascular disease, independent of traditional risk factors in the demographic (e.g. age), biological (e.g. physical disease), and behavioural domains (e.g. Body Mass Index; Boehm & Kubzansky, 2012). As a consequence, low and declining well-being may (further) undermine efficient functioning in domains that are immediately relevant for survival, and so play a more causal role in the pervasive nature of terminal declines than assumed and implied by the "bottom-up" framework used above. Extending the framework to accommodate yet other well-being definitions is also possible and should be pursued. For example, it is also possible to interpret the "bottom-up" perspective from a causal perspective, where the domain variables are not "indicators of well-being" but "causes of well-being." This interpretation would require that the arrows in Figure 2 be reversed so that the framework would resemble a regression model with time-varying parameters rather than a latent variable model with time-varying factor loadings. The nuances of these conceptual and mathematical distinctions among these various definitions of well-being should be considered further because each conceptual-mathematical tethering has implications for how repeated measures of well-being can and should be obtained.

Intensive longitudinal data and analysis

The framework outlined here is grounded in thinking about the possibilities afforded by intensive longitudinal study designs, where a large number of repeated measures are obtained at relatively fast time scales (e.g. monthly). Our simulation demonstrates that such data allow tracking within-person changes in level, inconsistency, and couplings. At a practical level, however, obtaining monthly assessments for the last decade of individuals' lives is difficult. We nevertheless selected such an intensive design to illustrate—in contrast to designs currently available in the literature—affordances for modelling terminal decline (in well-being) as a within-person phenomenon inclusive of fluctuations in and couplings among multiple domains of functioning. Results obtained from our in-silica experiments suggest that researchers should indeed obtain these data. In our experience, collecting intensive within-person data from people who live under taxing life conditions represents a formidable challenge. However, the speed at which new sensor technologies are being deployed suggests that massive, relatively non-intrusive data collections will soon be possible (see Ram & Diehl, in press). High-density repeated assessments can be integrated into the daily work routines of staff in health-care settings (e.g. physicians, nurses, or professional caregivers) without excessive burden for either participants or practitioners (e.g. use of online and/or automated cognitive tests, ambulatory physiology monitors, questionnaires). From our perspective, collection of such data, while beyond current capabilities, is (based on technologists' predictions) less than a decade away, particularly when coupled with planned missingness designs (Little & Rhemtulla, 2013).

Generalizability and between-person differences

Data collections embedded directly into health care settings may also alleviate generalizability concerns that stem from studying single individuals (as presented above) or convenience samples. Health-care settings provide for selection of samples at risk for health losses, which could then be divided into groups with high and low secondary control capabilities. In this way, we can investigate how between-person differences in change (in levels, inconsistency, and coupling) across domains *and* between-person differences in "measurement model" weights are related to changes in well-being. Formally, we simply add *i* subscripts to Equations 2, 3, and 4. In brief, the models shown in Figure 2 are time-varying dynamic factor models (e.g. Molenaar, Sinclair, Rovine, Ram, Corneal, 2009). Between-person differences are accommodated by placing multiple models within a multilevel (or multigroup) framework (see Ram, Brose & Molenaar, 2013). Treating the data as repeated measures nested within years nested within persons maintains metric factorial invariance across "windows" of occasions (e.g. within-person, within-year; Level 1) and provides for differences in structure between-years and between-persons (modeled at Levels 2 and 3). As per the usual assumptions in multivariate multilevel models, scale invariance must be

maintained at the manifest variable level across all repeated measures (Bolger & Laurenceau, 2013). That is, the domain measures (e.g. of physical health, cognition, and social support) should be measured and scaled so that within-person and between-person differences are intact and reliable across all observations.

At the between-person level, many types of differences are possible. These include differences in how the weights for well-being evaluation change over time, and what specific aspects of function are even considered. For example, for one person, mean-level changes are the primary source of well-being, whereas for another person, fluctuations or within-person couplings are more important for his or her well-being. Our use of a "measurement model" that changes over time is derived from the theoretical propositions embedded in lifespan theories of change. However, this approach is notably at odds with the traditional application of longitudinal factor models. Typically, researchers seek to establish measurement invariance—so that the meaning of the latent well-being factors shown in Figure 2 are identical across individuals and situations (i.e., occasions). Typically, this is accomplished by keeping the factor loadings (measurement weights) fixed across persons and time (see Widaman, Ferrer, & Conger, 2010). However, we are working in a theoretical framework that explicitly hypothesizes that the weights will change over time. In fact, the theory suggests that the weights must change *in specific ways* if an individual is to maintain his or her well-being. Thus, the theoretical propositions of the developmental theory challenge the traditional notions of measurement invariance (invariant weights). Acknowledging the incongruence between theory and measurement practice, we alert readers (and ourselves) to the need for new definitions of measurement invariance in developmental settings (see Edwards & Wirth, 2009; Nesselroade, Gerstorf, Hardy, & Ram, 2007). In the framework described here, we stretch those definitions to include and accommodate the hypothesized changes in weighting that likely accompany terminal decline.

Our analytic framework accommodates the so-called "well-being paradox of old age" by allowing, for example, that people notice and perceive the losses that may occur in their lives (e.g. mean-level changes in the domain indicators), but the weighted contribution of these losses to well-being is (implicitly) modulated down (e.g. factor loadings are reduced). Our model also accommodates the precipitous late-life declines in well-being often observed. For example, given the substantial between-person differences in late-life living conditions, routines, and medications, we would expect that well-being declines are steeper among people dying from prolonged debilitating diseases than among those dying from acute vascular diseases such as stroke or heart attack. We could examine whether these differences result from decrements in levels of health, larger (day-to-day) fluctuations in health, or stronger couplings among health and other domains of functioning. We could also test whether the self-protective re-weighting of domains with approaching death is impaired among the chronically-ill group. Two different scenarios appear plausible. Assuming that well-being is a product of the integrity and functioning of an individual's regulatory capacity (operationally defined in our model as factor loadings), the question is whether terminal well-being decrements emerge because the sheer load of losses overwhelms our regulatory capacities or whether (in addition) poor health and impoverished cognitive abilities also undermine the efficiency and robustness of how self-regulation processes operate. In the first scenario, the mechanisms themselves still operate efficiently, but the burdens are simply too heavy to carry such that the above described self-protective re-weighting is approaching its limits. If true, the 'measurement model' would evince the proposed changes in the weighting scheme, yet well-being declines nevertheless as a result of the sheer magnitude and pervasiveness of losses of, fluctuations in, or couplings between key domains. In the alternative (and probably complementary) second scenario, lower-level physiological changes such as deteriorations in the integrity of neurocognitive control systems or late-life neuropathology (e.g. more plaques and tangles associated with Alzheimer's Disease, Lewy Bodies) impede efficient functioning of higher-level processes such as self-regulation. In other words, the "mechanics" of self-regulation itself become more and more compromised and people have more difficulty in employing efficient self-regulation strategies (see also Charles, 2010). Here, the severe well-being declines are driven by the increasing fragility and inefficiency of individuals' self-regulation capabilities and processes. If true, the "measurement model" would evince basically invariant factor loadings despite major health problems.

Evaluation of multiple domains

For parsimony in our presentation, we used hypothetical data from only three domains (physical health, cognition, and social support). There is no doubt that other domains play an important role in systemic function and are used in individuals' evaluations of well-being. To obtain comprehensive and robust descriptions of late-life change in all its forms, a wider set of relevant domains should be identified and included as part of the intensive repeated assessment (e.g. constraints in carrying out simple prohedonic positive activities; Lyubomirsky & Layous, 2013). An intriguing additional question would be whether it is possible to ask people directly what their weighting/evaluation schema is at each occasion, and to track how closely the "measurement model" derived from performance-based or observed domain indices (e.g. cognitive tests, number of medical diagnoses) matches their self-reported schema for summarizing level, inconsistency, and coupling information. Further open questions revolve around for whom such convergence indeed occurs, and which functional implications arise from non-convergence. Broadly speaking, we would expect that an awareness of the evaluation scheme (i.e., relative convergence) would be of tremendous help for people. This awareness would facilitate conscious selection of those domains people can still influence and turn away from those domains that cannot be influenced anymore. If empirical evidence would support this expectation, another pivotal question would be whether eventually targeted interventions can be developed that teach people how to converge. Related to this question is also whether the shifting of weights proceeds in an implicit or rather volitional manner.

Conclusion

In summary, the framework presented can be used as a tool to operationally define, empirically test, and refine the precision and specificity of developmental theories that make predictions about when, how, and why late-life decrements in well-being begin and proceed. More comprehensive descriptions will in turn inform the design and implementation of interventions and social policies focused on the particular processes most likely to alleviate the societal and personal costs of late-life decline and help people to live their last phase of life with a sense of dignity.

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