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## The Structure of Self-Regulation and Its Psychological and Physical Health Correlates in Older Adults

Rebecca G. Reed<sup>\*,†</sup>, Hannah L. Combs<sup>‡,†</sup>, Suzanne C. Segerstrom<sup>§</sup>

\* Department of Psychology, University of Pittsburgh, Pittsburgh, PA, US

† Formerly affiliated with the Department of Psychology, University of Kentucky, Lexington, KY, US

‡ Houston Methodist Sugar Land Neurology Associates, Sugar Land, TX, US

§ Department of Psychology, University of Kentucky, Lexington, KY, US

### Abstract

Self-regulation refers to effortful control over one's thoughts, emotions, choices, impulses, and behaviors, and has implications for older adults' health. Executive function, physiological, and subjective indices have all been proposed to reflect self-regulation. Pairwise associations among these indices have been previously examined; however, a self-regulation constellation encompassing all of these indices has never been tested in older adults. The present study described the relationships among indices of self-regulation and tested their between- and within-person associations with upstream personality factors (conscientiousness) and downstream psychological and physical health in 149 older adults aged 60–93 years, assessed semi-annually for five years (up to 10 waves). Indices of self-regulation were only modestly correlated with each other but were each associated with health. Better executive function was associated with better psychological and physical health between and within people, whereas higher heart rate variability was associated with psychological health within people. Better subjective self-regulation had the most between- and within-person associations with better psychological and physical health. Conscientiousness was associated with subjective self-regulation and better psychological and physical health. These findings support the non-unitary nature of self-regulation in older adults and the health relevance of each of its indices between and within older adults. The aging process may change how the indices relate to each other, and older adults may draw more on certain self-regulatory components over others, given limited resources. Subjective self-regulation may be an important final common pathway to psychological and physical health in older adults.

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Corresponding author: Rebecca G. Reed (rebecca.reed@pitt.edu).

#### Contributions

RGR, HLC, and SCS conceptualized, wrote, and edited this article. RGR and SCS performed the statistical analyses.

#### Competing Interests

The authors have no competing interests to declare.

#### Data Accessibility Statement

The script is available on the project's OSF page <https://osf.io/mbrz2/> and the data are available at [https://osf.io/cq9ns/?view\\_only=ce144614ba794ed78d1e05c576ed9094](https://osf.io/cq9ns/?view_only=ce144614ba794ed78d1e05c576ed9094). The data are made available for the purpose of reproducing the results or validating conclusions based on the results. If you want to perform analyses focused on questions not addressed in the manuscript, you must contact Dr. Reed or Dr. Segerstrom to discuss appropriate attribution.

## Keywords

self-regulation; executive functions; heart rate variability; health; aging

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Self-regulation - control over one's thoughts, emotions, behaviors, and impulses - has been associated with better life outcomes (Moffitt et al., 2011; Tangney, Baumeister, & Boone, 2004). Among younger adults, better self-regulatory ability and strength (i.e., the motivation and capacity to meet self-regulatory demands), might be indexed by two measures. First, executive function (EF) reflects the ability to perform set-shifting, inhibition, and updating and to utilize working memory effectively, typically acting on abstract content such as numbers, letters, and colors and measured using neuropsychological tests (Miyake, Friedman, Emerson, Witzki, & Howerter, 2000). When this ability is applied to everyday thoughts, emotions, behaviors, and impulses, self-regulation results. Among younger adults, better EF correlated with less propensity for mind-wandering, worry, and rumination (Crowe, Matthews, & Walkenhorst, 2007; Davis & Nolen-Hoeksema, 2000; Kane et al., 2007) and better emotion regulation and less experience of negative emotion (Compton et al., 2008; Robinson, Schmeichel, & Inzlicht, 2009).

Second, heart rate variability (HRV) has been proposed to reflect the activity of a central inhibitory network that implements both EF and self-regulatory functions (i.e., Neurovisceral Integration Theory, Thayer & Brosschot, 2005; Polyvagal Theory, Porges, 2001). Both theories draw on evidence that prefrontal cortical areas important for self-regulation, including the medial prefrontal cortex, affect the parasympathetic nervous system, which in turn influences cardiac activity and allows for high variability in heart rate (Thayer, Hansen, Saus-Rose, & Johnsen, 2009). Among younger adults, higher resting HRV correlated with better self-regulatory function during laboratory tasks (e.g., persistence, emotion regulation), and better scores on questionnaire measures of self-regulatory function such as emotional control, thought control, inhibition of impulses, active coping, and frustration tolerance (Allen, Matthews, & Kenyon, 2000; Demaree et al., 2004; Diamond & Hicks, 2005; Gyurak, & Ayduk, 2008; Hansen, Johnsen, & Thayer, 2003; Holzman & Bridgett, 2017; Mathewson et al., 2010; Segerstrom & Solberg Nes, 2007).

Assessment of self-regulation in younger adults typically draws on this constellation of three interrelated elements: behavior (self-regulation), cognition (EF), and physiology (HRV) (Hansen, Johnsen, & Thayer, 2003; Holzman & Bridgett, 2017; Thayer et al., 2009). This constellation is less well established among older adults. Compared with younger adults, older adults have different abilities, motivations, and physiology relevant to self-regulation. Nonetheless, some reports have linked executive function to self-regulation (e.g., Henry, von Hippel, & Baynes, 2009). Although specific relationships are of interest, they cannot establish the "big picture" of the shared variance among the domains of a self-regulation constellation. A latent self-regulation constellation could provide support for an integrated theoretical framework from which to interpret the diversity of observed data across EF, physiological, and subjective domains. Moreover, a latent composite could provide more robust descriptive power than single measures alone and show more reliable relationships with health outcomes of interest (c.f. Mather & Knight, 2005). The purpose of the present

investigation was threefold: first, to correlate elements of the self-regulation constellation over time in older adults; second, to correlate the constellation with personality and with intra- and inter-personal psychological outcomes, between and within older adults, that have been related to self-regulatory ability and strength; and third, to correlate the constellation between and within older adults with health behavior and health indices that could suggest its adaptiveness among older adults.

## Self-Regulation Over Time

Longitudinal data of self-regulation indices in older adults are scarce. Testing a latent self-regulatory constellation of EF, HRV, and subjective factors addresses several measurement and validity-related issues (e.g., are the constructs measured equivalently across time?); moreover, because the self-regulation indices are repeatedly assessed, these validity issues are more rigorously evaluated than would be the case with cross-sectional data (Little, Preacher, Selig, & Card, 2007). Related, static and laboratory analog designs provide limited evidence for the relevance, particularly the health relevance, of self-regulation. They are typically limited to testing between-person relationships. However, components of self-regulation can also be dynamic and change over time within people (Hofmann et al., 2012; Sliwinski et al., 2006; Stawski, Mogle, & Sliwinski, 2011). Therefore, we incorporated both a between-person “trait-like” and within-person “state-like” perspective (Enders & Tofighi, 2007) to assess how an index of self-regulation associates with psychological and physical health over time in older adults. Between-person associations that average data across all occasions per person to yield a person-level predictor represent stable individual differences. Within-person associations reflect an individual’s deviation from their mean at each time point and represent dynamic state-like fluctuations over time. Between-person associations have the benefit of averaging across several waves worth of data, thus increasing reliability and sensitivity to detect an effect; within-person associations have the benefit of treating each person as his or her own control for potential between-person confounders.

## Self-Regulation: Personality and Outcomes

Upstream from self-regulatory ability and strength are personality traits that reflect ability and motivation to self-regulate, such as the five-factor model dimension of conscientiousness, the social-cognitive trait of dispositional optimism, and trait self-control. Experimental evidence suggests that motivation and ability are distinct and important in self-regulatory success (Evans, Boggero, & Segerstrom, 2016; Vohs, Baumeister, & Schmeichel, 2012). Conscientiousness in particular may reflect motivation to self-regulate or the goal to self-regulate well (e.g., “I try to perform all the tasks assigned to me conscientiously”; Costa & McCrae, 1992). However, personality measures of self-regulation such as conscientiousness appear to be less highly correlated with indices such as EF and HRV than are frank measures of self-regulatory success or failure (Fleming, Heintzelman, & Bartholow, 2016; Holzman & Bridgett, 2017; Segerstrom & Solberg Nes, 2007; Shepherd, Mulgrew, & Hautus, 2015; Unsworth et al., 2009; Williams, Suchy, & Kraybill, 2010). Additionally, conscientiousness is considered one of the strongest personality correlates of physical health (Bogg & Roberts, 2004, 2013).

Downstream from self-regulatory ability and strength are intrapersonal outcomes such as cognition and emotion and interpersonal outcomes such as cooperation. These outcomes have typically been evaluated with regard to EF. Repetitive thought (thinking attentively, repetitively, or frequently about oneself and one's world) encompasses worry and rumination as well as reflection, processing, and planning (Segerstrom, Stanton, Alden, & Shortridge, 2003). Maladaptive forms of repetitive thought such as worry and rumination can increase negative mood states (e.g., anxiety, depression) and dysregulate physiology and health in older adults (Segerstrom et al., 2003; Watkins, 2008). The dimensional model of repetitive thought gives two qualitative descriptors: Valence (positive to negative content) and Purpose (searching to solving content). In addition, repetitive thought can be described quantitatively as a Total propensity. The Valence dimension is more highly correlated than other dimensions with self-rated control over thoughts among younger adults and with executive function (Trail Making Test) among older adults (Segerstrom et al., 2003; Segerstrom et al., 2010). Older adults with better cognitive control including selective attention and inhibition of goal-irrelevant information show more positively valenced attention and memory biases (Mather & Knight, 2005). Therefore, older adults with better self-regulation may have repetitive thought content that is more positively valenced. Related, emotion regulation has been proposed to rely on self-regulatory ability and strength and on EF (Urry & Gross, 2010). Reappraisal is particularly effective at increasing positive and decreasing negative emotions and is associated with neurophysiological substrates of self-regulation including more prefrontal cortical activation, increases in HRV, and better EF among younger adults (Butler, Wilhelm, & Gross, 2006; Kalisch, 2009; Opitz, Rauch, Terry, & Urry, 2012; Schmeichel, Volokhov, & Demaree, 2008). Age-related brain changes may cause some older adults to use reappraisal less often or less successfully (Opitz, Rauch, Terry, & Urry, 2012), however, on average, older adults report using this strategy more than younger adults (John & Gross, 2004). Therefore, generally healthy older adults with better self-regulation may also use reappraisal often.

In the interpersonal domain, warm, close interactions are promoted by social self-regulation. Social interactions often evoke strong emotions and behaviors such that individuals require self-regulatory strength to cooperate as well as to avoid hostile or inappropriate comments or the impulse to respond reciprocally to negativity (i.e., "biting one's tongue"; Finkel & Campbell, 2001; Finkel et al., 2006; Hagger, Wood, Stiff, & Chatzisarantis, 2010; Henry, von Hippel, & Baynes, 2009; Vohs, Baumeister, & Ciarocco, 2005). Higher resting HRV predicted more interpersonal warmth in young couples engaging in a dyadic discussion task (Smith et al., 2011). Therefore, an index of self-regulation should be associated with more interpersonal cohesion in close relationships.

## Self-Regulation and Physical Health

People with better self-regulatory ability and strength generally engage in healthier behaviors and enjoy better physical health (Buckley et al., 2014; Ginis & Bray, 2010). Health behaviors such as physical activity, diet, and smoking (and smoking cessation) are linked to self-regulation (e.g., Ginis & Bray, 2010; Junger & van Kampen, 2010; McAuley et al., 2011; Will Crescioni et al., 2011). Health behaviors also partially account for the robust relationship between conscientiousness and longevity (Friedman et al., 1995; Turiano

et al., 2012). Therefore, an index of self-regulation should be associated with healthier behavior and better health. Conditions associated with poor self-regulation, particularly the interrelated conditions of sedentariness, high body fat, and hypertension, become more prevalent with age (Burt et al., 1995; Caspersen & Merritt, 1995). (Note that because older adults lose muscle and bone mass, body mass index may be a poorer index of body composition for older than for younger adults; Davison, Ford, Cogswell, & Dietz, 2002.) Another important index of health is self-rated health. The sense of whether one's health is generally excellent, very good, good, fair, or poor predicts mortality risk above and beyond other factors such as comorbidities, depression, and physical function (DeSalvo, Bloser, Reynolds, He, & Muntner, 2006). Self-rated health therefore provides a complement to behavior such as physical activity and biomarkers such as blood pressure in assessing older adults' physical health and well-being.

## The Present Study

Three hypotheses were tested in a longitudinal study of healthy older adults followed over 5 years. Between-person differences and within-person changes over time in measures of self-regulation were tested as predictors of intrapersonal, interpersonal, and physical health outcomes. The study first examined whether the constellation of measures of self-regulatory ability and strength that has been identified in younger adults could also be identified in older adults:

Hypothesis 1. Executive functions, HRV, and self-reported self-regulation have substantial shared variance and form a reliable (latent) composite of self-regulation among older adults over time. Convergent validity of the composite is provided by a significant correlation with the personality trait of conscientiousness.

Second, it examined whether self-regulatory ability and strength correlated with intrapersonal and interpersonal outcomes of better self-regulation within and between older adults:

Hypothesis 2. Better self-regulation associates with more positive (vs. negative) repetitive thought, more adaptive emotion regulation (i.e., more reappraisal), and higher dyadic cohesion.

Third, it examined whether self-regulatory ability and strength correlated with physical health outcomes associated with better self-regulation within and between older adults:

Hypothesis 3. Better self-regulation associates with higher physical activity; lower BMI, waist circumference, and blood pressure; and better self-rated health.

## Method

### Participants

Participants were 149 community-dwelling older adults over the age of 60 ( $M_{\text{age}}=75$  years; range: 60–93 at study entry). The gender ratio (58% female) approximated the gender ratio of older adults in the general population. The majority of the sample was white (94%), and the remainder was African American (4%) and Asian American/Pacific Islander (2%).

Median household income was \$60,000 (range: \$9,000 – \$400,000), and median education was 16 years (range: 9–22). Spouses of enrolled participants were excluded to prevent interdependent data. The majority of participants (77%, n=114) were married at study entry and the remaining were widowed (n=21), divorced (n=7), single (n=6), or separated (n=1). Because the parent study also involved measurement of immune parameters, exclusion criteria at enrollment included diseases or disorders affecting the immune system, chemotherapy or radiation treatment within the past 5 years, unwillingness to undergo venipuncture, immunomodulatory medications including opiates and steroids, and more than two of the following classes of medications: psychotropics, antihypertensives, hormone replacement, or thyroid supplements. No participants were cognitively impaired at baseline testing.

## Procedures

Participants were recruited from a volunteer subject pool maintained by the Center on Aging at the University of Kentucky. All study materials and procedures were approved by this university's Institutional Review Board. Prospective participants were contacted and screened by telephone. Those who were interested and eligible gave informed consent, were enrolled, and completed questionnaire measures verbally with the assistance of a research assistant and response cards. Participants were interviewed in their homes at 6-month intervals for 5 years (up to 10 waves)<sup>1</sup> between the years 2011 and 2018. Participants were enrolled in the study on a rolling basis (70 participants were enrolled in 2011; 6 in 2012; 58 in 2013; and 15 in 2014) and data collection is ongoing. At each completed wave, participants received a US\$50 gift card. On average, participants completed 7.0 waves (SD=2.7, median = 7, range = 1–10). Of the 149 participants, 35 completed 10 waves, 23 completed 9 waves, 15 completed 8 waves, 19 completed 7 waves, 18 completed 6 waves, 13 completed 5 waves, 6 completed 4 waves, 8 completed 3 waves, 3 completed 2 waves, and 9 completed 1 wave (see Figure 1 for a visualization of waves completed per participant).

Of the 1490 possible observations, data were missing because 22 people dropped out due to no longer wanting to participate (112 person-waves missing); 18 people dropped out due to moving to a nursing home and losing contact (4 people) or due to an illness (of these, 9 people no longer wanted to participate because of a recent illness, and 5 people were judged to be unable to give informed consent due to significant cognitive declines and were excluded<sup>2</sup>) (89 person-waves missing); 13 people dropped out due to lost contact (71 person-waves missing); 5 people died (30 person-waves missing); 30 people skipped one or more waves (45 person-waves missing); 15 people had data that were lost in transit, prior to data entry, during the research process (16 person-waves); and 40 people have one or more interviews due in the future (81 person-waves missing). Overall, 1046 person-waves of data were available for analysis (see Table 1).

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<sup>1</sup>Most scales were administered at every wave. Thus, when appropriate, we present the reliability of the scale both between people across all waves and within people over time. PROC VARCOMP in SAS was used to estimate the variances associated with items, waves, people, and their interactions; the variance components were then used to estimate reliability (equations #4 and #5 from Cranford et al., 2006).

<sup>2</sup>Only the data preceding their cognitive status change were used in analyses.

## Measures

**Demographics and medications**—Demographic information was collected at the first wave. Date of birth and wave date were used to calculate exact chronological age at study entry. Gender and maximum achieved education level (years of schooling) were also assessed. Last, participants provided a list of current medications, including antihypertensive medications, at each wave.

**Executive function**—The Trail Making Test, Controlled Oral Word Association Test, Letter Number Sequencing, and Digit Span captured several domains of EF, including cognitive flexibility, verbal fluency, and working memory. Following testing recommendations regarding practice effects, the Trail Making Test and Controlled Oral Word Association Test (using alternating forms) were assessed at every wave, but the Letter Number Sequencing and Digit Span were assessed at every other (i.e., odd-numbered) waves beginning with the first wave. Two versions of executive function were used: separate test scores from the Trail Making Test, Controlled Oral Word Association Test, Letter Number Sequencing, and Digit Span; and a composite EF score (described below).

**Trail making test:** The Trail Making Test (Tombaugh, 2004) is a timed task administered in two parts: Parts A and B. In Part A, participants are asked to connect circles numbered from 1 to 25 with lines as quickly as possible. Part A captures motor speed and visual scanning and allows for measurement and control of these factors. In Part B, participants are asked to connect circles containing numbers (from 1 to 13) or letters (from A to L) in an alternating numeric/alphabetical order (i.e., 1-A-2-B-3-C, etc.). Part B additionally captures mental flexibility and set-shifting (i.e., shifting between numbers and letters). The Trail Making Test A-B score, calculated as the difference between time to complete Part A and Part B, is considered a measure of cognitive flexibility relatively independent of manual dexterity, with higher scores indicating faster times and thus better executive function (Crowe, 1998; Sánchez-Cubillo et al., 2009).

**Controlled oral word association:** The Controlled Oral Word Association Test (Reitan & Wolfson, 1985) is part of the Halstead-Reitan Neuropsychological Battery as a test of phonemic verbal fluency. It measures spontaneous retrieval and production of words beginning with a designated letter. Participants are asked to name words beginning with either letters “C”, “F”, and “L” or “P”, “R”, and “W” (at alternating waves). Higher total scores (sum of the number of unique words produced) indicate better verbal fluency.

**Letter-number sequencing:** The Letter-Number Sequencing subtest from the Wechsler Adult Intelligence Scale-IV (WAIS-IV; Wechsler, 2008) captures working memory. Participants are read a sequence of numbers and letters and recall the numbers in increasing order and the letters in alphabetical order. Higher total scores indicate better working memory.

**Digit span:** The Digit Span subset from the WAIS-IV (Wechsler, 2008) measures auditory attention, working memory, and mental manipulation. The participant is read sequences of numbers and is asked to recall the numbers in the same order (forward), in reverse order

(backward), and in ascending order (sequencing). A priori, we decided not to include Digit Span *forward* in the investigation because theoretically, it measures immediate attention capacity and does not require the same mental manipulation as backward and sequencing. Higher scores indicate better working memory and mental manipulation.

**Executive function composite:** An EF composite was calculated using all available data (i.e., both odd- and even-numbered waves) and applying the proportion of maximum scaling method (Little, 2013) to the Trail Making Test A-B score, Controlled Oral Word Association Test, Letter Number Sequencing total, Digit Span backward and sequencing scores. This approach transforms each score to a metric from 0 (minimum possible) to 1 (maximum possible) by first making the score range from 0 to the highest value and then dividing the scores by the highest value. This approach, unlike standardization, does not change the multivariate distribution and covariance matrix of the transformed variables and is the recommended approach for longitudinal data (Moeller, 2015). The scaled EF tests were then averaged together to create an EF composite. Alpha across all time points of the EF composite was adequate at .73. Higher composite scores indicate better EF.

**Heart rate variability—**Heart rate variability (HRV) reflects control of the heart by the efferent vagus, with higher vagal control resulting in higher HRV. HRV was calculated from a 10 minute resting EKG collected using a MindWare MW5000A ambulatory unit. Abnormal interbeat intervals were edited using MindWare HRV software (version 3.1; MindWare, Gahanna, OH), and HRV was operationalized as high-frequency power in the .12-.40 Hz band. Two versions of resting HRV were used: averages from three segments of equal duration and the average over the total 10-minute resting period.

**Subjective self-regulation—**The Behavior Rating Inventory of Executive Functioning-Adult (BRIEF; Roth, Isquith, & Gioia, 2005) assessed participants' perceived self-regulation abilities at each wave. The BRIEF includes 75 items capturing self-regulatory difficulties in four domains of Behavioral Regulation (i.e., Inhibition: "I am impulsive"; Behavioral Shifting: "I have trouble changing from one activity or task to another"; Emotional Control: "I overreact to small problems"; and Self-Monitoring: "I say things without thinking") and five domains of Metacognition (i.e., Initiation: "I have trouble getting started on tasks"; Working Memory: "I forget instructions easily"; Planning/Organization: "I have trouble organizing work"; Task Monitoring: "I make careless mistakes"; and Organization of Materials: "I leave my room or home a mess"). The nine domain scores (subscales) were coded such that higher scores represent better subjective self-regulation. Overall, the scale was reliable between people across all waves ( $\alpha = .99$ ) and within people over time ( $\alpha = .83$ ). To provide an additional validity index, raw scores were calculated for the Inconsistency Scale, which indicate the extent to which respondents answered BRIEF items in an inconsistent manner relative to the clinical samples. There were eight observations in which respondents were inconsistent.

**Conscientiousness—**Conscientiousness was measured once at baseline using the 12-item NEO Five Factor Inventory (Costa & McCrae, 1992). The scale was reliable between people ( $\alpha = .78$ ).



**Repetitive thought**—An established 8-item method was used to assess three dimensions of repetitive thought: valence (positive to negative content), purpose (solving to searching), and total (low or high in the tendency to engage in all kinds of repetitive thought) (Segerstrom, Hardy, Evans, Boggero, Alden, & Stanton, 2016). Dimension scores were calculated by standardizing the items and using suggested item weights for valence, purpose, and total. Higher scores on valence represent more negative content; higher scores on purpose represent more searching. Calculation of circumplex reliability requires more observations than were available in the present study, but the valence and purpose dimensions had adequate reliability in the validation samples (Segerstrom et al., 2015). The total dimension was reliable between people across all waves ( $\alpha = .98$ ), but had low reliability within people over time ( $\alpha = .28$ ). Within-person reliabilities are typically lower than between-person reliabilities (e.g., Cranford et al., 2006), and low within-person reliabilities will follow from high intraclass correlations (Repetitive Thought Total ICC = .69; Table 2).

**Emotion regulation**—The Emotion Regulation Questionnaire was used to assess use of emotion regulation strategies, namely reappraisal and suppression (Gross & John, 2003). An example of a reappraisal item is, “When I want to feel less *negative* emotion (such as sadness or anger), I *change what I’m thinking about*”. An example of a suppression item is, “I control my emotions by not expressing them”. Items were rated on a 7-point Likert-type scale from 1 (strongly disagree) to 7 (strongly agree). The total scale was reliable between people across all waves ( $\alpha = .97$ ) and had moderate reliability within people over time ( $\alpha = .62$ ).

**Dyadic cohesion**—Married participants completed the cohesion subscale from the Revised Dyadic Adjustment Scale (Busby, Crane, Larson, & Christensen, 1995), which assesses the degree of closeness and shared activities experienced by a couple. (Participants whose spouse died during the study period [ $n=12$ ] contributed dyadic cohesion data for only the waves at which they reported being married.) Participants were asked to answer how often events (have a stimulating exchange of ideas, work together on a project, and calmly discuss something) occurred between them and their mate (0 = never, 5 = more often [than once a day]), as well as “Do you and your mate engage in outside interests together?” (0 = never, 4 = all the time). Cohesion was assessed beginning in wave 2. The measure was reliable both between people across all waves ( $\alpha = .94$ ) and within people over time ( $\alpha = .69$ ).

**Physical activity**—The Physical Activity Scale for the Elderly (Washburn, Smith, Jette, & Jannery, 1993) was administered at each wave to assess a range of activities from low-expenditure to strenuous as well as time spent in those activities (e.g., “Over the past 7 days, how often did you engage in *moderate* sport or recreational activities such as doubles tennis, ballroom dancing, golf without a cart, softball, or other similar activities?”). Activity time is multiplied by an empirically derived weight to derive the total activity score. The total score has been validated against biometric measures of fitness (peak O<sub>2</sub> uptake, blood pressure, heart rate, strength, balance). Validity is particularly good for adults over age 65 (Washburn et al., 1999). The measure was reliable both between people across all waves ( $\alpha = .92$ ) and

within people over time ( $\alpha = .84$ ). Physical activity was moderately positively skewed, so values were square root transformed prior to analyses.

**Body mass index**—Height and weight were self-reported at each wave and used to calculate body mass index (BMI). The standard CDC equation was used:  $\text{weight} / (\text{height}^2) * 703$ . BMI was positively skewed, so values were log transformed prior to analyses.

**Waist circumference**—Waist circumference was measured in centimeters at each wave using a tape measure, taken three times at the level of the natural waist. The average of the three measurements was used. Waist circumference adds informational value to BMI in the assessment of abdominal adiposity (Clasey et al., 1999), particularly among older adults for whom loss of muscle mass can contribute to lower BMI.

**Blood pressure**—Blood pressure was measured at each wave using the Omron Automatic Blood Pressure Monitor (Model HEM-773AC; Bannockburn, IL). Two measurements taken approximately three minutes apart were averaged for the measures of resting systolic and diastolic blood pressure. Systolic blood pressure and diastolic blood pressure were correlated ( $r = .62$ ) and so were combined into mean arterial blood pressure, calculated using the standard formula:  $(1/3) * (\text{Systolic Blood Pressure} + (2 * \text{Diastolic Blood Pressure}))$ .

**Self-rated health**—Self-rated health at each wave was measured using a single item from the Medical Outcomes Study Health-Related Quality of Life scale (Stewart & Ware, 1992). The item reads, “In general, would you say your health is...” with possible responses *excellent, very good, good, fair, and poor*. Higher values represent better self-rated health.

## Data Analysis

**Hypothesis 1: Structure of self-regulation**—Confirmatory factor analysis (CFA) was used to evaluate the structure and inter-relatedness between the three factors (EF, HRV, and subjective self-regulation) at each time point. CFAs were performed on data from waves 1, 3, and 5 because some EF measures were administered only at alternate waves due to testing recommendations (see Measures). Five indicators of EF were included: Trail Making Test A-B score, Controlled Oral Word Association Test total score, Letter Number Sequencing total score, and Digit Span backward and Digit Span sequencing scores. Three indicators of HRV were included, each of which corresponded to one-third of the 10-minute EKG. Last, the nine domain subscale scores were used rather than the 75 items for subjective self-regulation. This parceling technique has the advantages of providing more reliable indicators than individual items and requiring the estimation of fewer parameters (Little, Cunningham, Shahar, & Widaman, 2002). Next, longitudinal CFA evaluated measurement invariance over time in the three factors. Testing and establishing longitudinal measurement invariance provides empirical evidence that the fundamental meaning of the construct has not changed across time (Little, Preacher, Selig, & Card, 2007). The models allowed for correlated residuals over time.

All models were implemented with the `cfa` function from the `lavaan` package (version 0.5.17) in R (version 3.0.3). In addition to the overall  $\chi^2$  statistic, several overall goodness-

of-fit indices were employed to examine the fit of the factor models, including the root mean square error of approximation (RMSEA), Comparative Fit index (CFI), Tucker-Lewis Index (TLI), and standardized root mean squared residual (SRMSR). Although in several instances, the  $\chi^2$  values were significant, indicating some level of misspecification, we examined model fit according to CFI and RMSEA reasonableness tests (Cheung & Rensvold, 2002), and used recommendations from Little (2013) on acceptable CFI and TLI fit ranges.

Ultimately, given the low inter-relatedness between the EF, HRV, and subjective factors at each time point, we did not pursue a second-order CFA (i.e., testing “self-regulation” as a second-order factor, with EF, HRV, and subjective components as first-order factors). Therefore, we also did not output self-regulation factor scores to be used in subsequent analyses; instead we examined EF, HRV, and subjective self-regulation individually and their associations with upstream conscientiousness and downstream psychological and physical health.

### **Hypotheses 2 and 3: Self-regulation and health within- and between-persons**

—We used multilevel models with waves at Level 1 and people at Level 2 using the lme function from the nlme package (version 3.1–118) in R (version 3.0.3) to test our two remaining longitudinal hypotheses. Specifically, we examined how the three indices of self-regulation (i.e., EF composite; HRV averaged across the 10 min sampling period; and subjective self-regulation total score) individually (Models 1–3) and when included together in the same model (Model 4) associated within- and between-persons with intra- and interpersonal psychological health (Hypothesis 2) and physical health (Hypothesis 3).

In a multilevel framework, each psychological or physical health outcome (e.g., reappraisal or BMI) for person  $j$  at wave  $i$  can be partitioned into a stable part associated with between-person variance ( $\beta_{0j}$ ), representing person  $j$ 's average across waves, and a dynamic part associated with within-person variance ( $R_{ij}$ ), representing person  $j$ 's deviation from their average associated with wave  $i$ :

$$\text{Health}_{ij} = \beta_{0j} + R_{ij}.$$

Between-person variance can be predicted by between-person (Level 2) predictors. Within-person variance can be predicted by within-person (Level 1) predictors. At Level 1, deviations in self-regulation indices (EF, HRV, and subjective) at wave  $i$  predict deviations in health outcomes at the corresponding wave. This part of the model estimates the covariance between fluctuations in self-regulation indices and fluctuations in health within people (subscript  $wi$ ):

$$\text{Health}_{ij} = \beta_{0j} + \beta_{1j}(\text{Self-Regulation}_{wi}) + R_{ij}$$

At Level 2, average levels of self-regulation indices (EF, HRV, and subjective) across waves predict average health outcomes between people (subscript  $bw$ ), across the 10 waves:

$$\beta_{0j} = \gamma_{00} + \gamma_{01}(\text{Self-Regulation}_{bw}) + U_{0j}.$$

Additionally, the Level 2 component of the model allows within-person effects of self-regulation indices to vary across people (i.e., to be treated as a random effect):

$$\beta_{1j} = \gamma_{10} + U_{1j}$$

Following testing recommendations for multilevel models by Singer and Willett (2003), random effects of within-person self-regulation predictors were included in the model when they improved model fit as indicated by likelihood ratio tests of nested models. Finally, across all waves, and substitution for  $\beta_{0j}$  and  $\beta_{1j}$  yields the final model:

$\text{Health}_{ij} = \gamma_{00} + \gamma_{01}(\text{Self-Regulation}_{bw}) + \gamma_{10}(\text{Self-Regulation}_{wi}) + U_{0j} + U_{1j} + R_{ij}$ . Fixed effects were estimated using maximum likelihood and are reported as  $\gamma$  weights, which are analogous to unstandardized  $\beta$  weights in regression models. Level 2 self-regulation indices (EF, HRV, and subjective) were centered around their respective grand means. All models controlled for age at study entry (centered around the grand mean of 75 years) and years of education (centered around the grand mean of 16 years). Models predicting physical health outcomes also controlled for gender. Last, models predicting blood pressure included whether or not participants were taking antihypertensive medication (1=yes, 0=no). Additionally, because some participants (N=76) were administered the Trail Making Test in an earlier study phase, a dummy variable was included in models with the EF composite to account for practice effects (1=previously tested; 0=not previously tested). Last, we ran sensitivity analyses excluding the 8 person-wave observations that had inconsistent subjective self-regulation scores; results remain unchanged.

### Validation Models: Conscientiousness, Self-Regulation, and Health

We used multilevel models to examine conscientiousness as an upstream determinant of self-regulation indices (EF, HRV, and subjective) and of intra- and interpersonal psychological health and physical health. In addition, given the implied associations in line with our theoretical framework, we decided post-hoc to examine mediation models of conscientiousness  $\rightarrow$  self-regulation  $\rightarrow$  psychological and physical health. Multilevel mediation was tested using the RMediation program (<https://amplab.shinyapps.io/MEDCI/>) (Tofiqhi & MacKinnon, 2011; Tofiqhi & Thoemmes, 2014), which provided an estimate of the indirect effect along with its 95% confidence interval (CI).

### Exploratory Models: Components of Executive Function and Subjective Self-Regulation

Finally, we ran exploratory multilevel analyses to determine how conscientiousness correlated with components of EF (i.e., Trail Making Test A-B score, Controlled Oral Word Association Test, Letter Number Sequencing, Digit Span backward and sequencing) and of subjective self-regulation (i.e., the nine domain scores of the BRIEF: Inhibit, Shift, Emotional Control, Self-Monitor, Initiate, Working Memory, Plan, Task Monitor, and Organization of Materials). Additionally, we examined which components of EF and of subjective self-regulation correlated with psychological and physical health between and

within people. Due to the exploratory nature of these analyses, Bonferroni corrections were applied, so alpha was set at .01 (.05/5 predictors) for the EF exploratory analyses and at .006 (.05/9 predictors) for the subjective self-regulation exploratory analyses.

## Results

Table 2 shows descriptive statistics for all study variables.

### Missing Data

To investigate the impact of incomplete data (i.e., missing at random), we performed a series of multilevel logistic regressions testing if missingness at any time point (i.e., waves 1–10) was related to any of the study variables. Missingness was predicted by older age at study entry (i.e., one-year older age at study entry increased the odds of being missing by 5%), higher levels of composite EF (i.e., being one unit higher in mean composite EF, re-scaled from 0–1 to range from 0–10, decreased the odds of being missing by 24%), and higher mean BMI and waist circumference (i.e., being one BMI unit higher and one inch larger in waist circumference decreased the odds of being missing by factors of 6% and 2%, respectively). Missingness was not predicted by education, gender, other self-regulation indices (HRV or subjective self-regulation), conscientiousness, or other psychological or physical health variables.

Zero-inflated Poisson regression models predicted the number of missing waves (mean = 2.98, SD=2.69, median =3, range 0–9) and the odds of not missing any waves (i.e., complete data) from relevant study variables. For each year older at study entry, the expected number of missing waves increased by 0.0001% and the odds of complete data decreased by 11%. Additionally, for each additional year of education, the expected number of missing waves decreased by 4% and the odds of complete data decreased by 3%. Last, being one unit higher in mean composite EF (rescaled to range from 0–10) decreased the expected number of missing waves by 13% and increased the odds of complete data by 8%.

Last, dropout analyses determined whether there were any statistically significant differences on relevant study variables between those who dropped out of the study (n=58, of which 22 no longer wanted to participate, 18 became ill or moved away to a nursing home, 13 dropped out due to lost contact, and 5 died) versus those who did not drop out (n=91). Those who did not drop out had significantly higher mean EF composite scores (5.62 vs. 5.07;  $t=3.17$ ,  $p=.002$ ) and significantly higher mean BMI (27.48 vs. 25.71;  $t=2.11$ ,  $p=.036$ ) than those who did drop out. No significant mean level differences were found for other indices of self-regulation (HRV, subjective self-regulation), conscientiousness, psychological and physical health variables, or covariates. Overall, the pattern of missingness suggests data were missing at random. Furthermore, including age in the statistical models reduces bias and accounts for the higher likelihood of missingness among older people.

### Hypothesis 1: Latent Structure of Self-Regulation

The CFA at waves 1, 3, and 5 resulted in satisfactory model fits (Supplemental Table S1). Modification indices suggested the specification of theoretically plausible correlated errors

for one pair of BRIEF indicators (the Inhibit and Self-Monitor sub-scales). All indicators significantly loaded onto each factor with  $p < .001$ . Specifically, the five indicators loaded onto the *executive function* latent factor at  $r_s = .45-.78$  at wave 1,  $r_s = .40-.77$  at wave 3, and  $r_s = .47-.72$  at wave 5. The three HRV indicators loaded onto the *physiology* latent factor at  $r_s = .84-.99$  at wave 1,  $r_s = .84-.98$  at wave 3, and  $r_s = .74-.99$  at wave 5. The nine subjective self-regulation (BRIEF) indicators loaded onto the *subjective* latent factor at  $r_s = .66-.89$  at wave 1,  $r_s = .65-.88$  at wave 3, and  $r_s = .60-.87$  at wave 5. Contrary to the first hypothesis, however, these self-regulation indicators were not highly or consistently correlated with each other within each time point (see Table 3). EF had small to medium correlations with subjective self-regulation ( $r_s = .21-.30$ ), but subjective self-regulation and HRV were not substantially correlated, nor were HRV and EF.

Next, longitudinal CFA was fit to evaluate measurement invariance in the three factors across waves 1, 3, and 5. The metric of the latent variable was determined by fixing the factor loading of the first indicator to 1.0. For all factors (subjective self-regulation, EF, and HRV), the constraint of weak invariance held according to the  $\chi^2$  difference test and resulted in satisfactory model fits (Supplemental Table S2; Cheung & Rensvold, 2002; Little, 2013). The constraint of strong invariance also held for the HRV factor according to the  $\chi^2$  difference test and resulted in acceptable, but not ideal, model fit (e.g., RMSEA was  $>.60$ , Supplemental Table S2). These models also indicated that subjective self-regulation ratings were highly stable over 6-month intervals ( $r_s = .85-.95$ ), as was executive function ( $r_s = .91-.95$ ). HRV was less stable ( $r_s = -.005-.29$ ). Given the low inter-relatedness between the factors at each time point, we did not pursue a second-order CFA (i.e., testing self-regulation as a second-order factor) and instead used the individual indices of self-regulation (EF, HRV, and subjective) in subsequent analyses.

### Longitudinal Aspects of Self-Regulation Components and Health Outcomes

Prior to discussing the results for Hypotheses 2 and 3 (below), we present intraclass correlations (ICCs) with waves at Level 1 and people at Level 2 of key study variables to provide estimates of the amount of variance due to stable between-person differences versus dynamic within-person changes over time (see Table 2). Regarding the self-regulation indices, the majority of variance in the EF composite and subjective self-regulation was due to stable between-person differences, whereas the majority of variance in HRV was due to within-person fluctuations over time. Among the psychological outcomes, between-person differences accounted for the majority of the variance in total repetitive thought and suppression, whereas the variance in repetitive thought valence and purpose, reappraisal, and dyadic cohesion was more evenly divided between stable between-person differences and dynamic within-person changes. Among the physical outcomes, the majority of variance in BMI, waist circumference, and self-rated health was due to between-person differences, variance in physical activity was more evenly divided between stable between-person differences and dynamic within-person changes, and the majority of variance in blood pressure was due to within-person changes.

## Hypothesis 2: Self-Regulation and Psychological Health Within- and Between-Persons

Tables 4–7 report significant results from multilevel models that tested self-regulation indices (EF, HRV, and subjective) individually (Models 1–3) and when included together in the same model (Model 4) as between- and within- person predictors of intrapersonal (repetitive thought, emotion regulation) and interpersonal (dyadic cohesion) psychological health.

**Repetitive thought**—Between people, better subjective self-regulation was associated with more positively valenced repetitive thought ( $\gamma = -.044$ ,  $SE = .007$ ,  $t(144) = -6.46$ ,  $p < .001$ ; Table 4). Within people, waves at which subjective self-regulation was better were also characterized by more positively valenced repetitive thought ( $\gamma = -.034$ ,  $SE = .006$ ,  $t(836) = -5.30$ ,  $p < .001$ ); however, this effect was not statistically significant when all indices were included in the model ( $\gamma = -.004$ ,  $SE = .015$ ,  $t(157) = -.277$ ,  $p = .78$ ). Between people, better subjective self-regulation ( $\gamma = -.086$ ,  $SE = .017$ ,  $t(144) = -5.17$ ,  $p < .001$ ) and better EF ( $\gamma = -9.58$ ,  $SE = 3.19$ ,  $t(139) = -3.00$ ,  $p = .003$ ) were each associated with less total repetitive thought (Table 5). The EF effect diminished and was no longer significant when including all predictors in the same model ( $\gamma = -6.12$ ,  $SE = 3.45$ ,  $t(123) = -1.78$ ,  $p = .078$ ). There were no significant associations between any of the self-regulation indices and repetitive thought purpose between or within people (Supplemental Table S3).

**Emotion regulation**—Within people, waves at which subjective self-regulation was better were also characterized by more reappraisal ( $\gamma = .006$ ,  $SE = .003$ ,  $t(841) = 2.40$ ,  $p = .017$ ; Table 6); this effect was unchanged but the standard error increased, resulting in non-significance, when all indices were included in the same model ( $\gamma = .006$ ,  $SE = .006$ ,  $t(159) = .975$ ,  $p = .33$ ). Within people, waves at which HRV was higher were also characterized by more use of reappraisal when all indices were included in the same model ( $\gamma = .059$ ,  $SE = .029$ ,  $t(159) = 2.02$ ,  $p = .045$ ). Between people, better EF was associated with less use of suppression ( $\gamma = -2.46$ ,  $SE = 0.81$ ,  $t(140) = -3.04$ ,  $p = .003$ ; Table 7). With all of the indices in the same model, waves at which EF was higher were also characterized by more suppression within people ( $\gamma = 3.23$ ,  $SE = 1.10$ ,  $t(159) = 2.93$ ,  $p = .004$ ).

**Dyadic cohesion**—There were no significant associations between any of the self-regulation indices and dyadic cohesion between or within people (Supplemental Table S4).

## Hypothesis 3: Self-Regulation and Physical Health Within- and Between-Persons

Tables 8–10 report significant results from multilevel models that tested self-regulation indices (EF, HRV, and subjective) individually (Models 1–3) and when included together in the same model (Model 4) as between- and within- person predictors of health behaviors (physical activity) and physical health (BMI, waist circumference, blood pressure, and self-rated health).

**Physical activity**—Between people, better subjective self-regulation was associated with more physical activity ( $\gamma = .022$ ,  $SE = .009$ ,  $t(144) = 2.41$ ,  $p = .017$ ; Table 8). Within people, waves at which EF was higher were also characterized by more physical activity ( $\gamma = 4.94$ ,  $SE = 2.22$ ,  $t(296) = 2.22$ ,  $p = .027$ ).

**BMI**—When including all predictors in the same model, better subjective self-regulation was associated with lower BMI between people ( $\gamma = -.002$ ,  $SE = .001$ ,  $t(123) = -2.30$ ,  $p = .023$ ; Table 9). Within people, waves at which subjective self-regulation was higher were also characterized by higher BMI ( $\gamma = .0005$ ,  $SE = .0002$ ,  $t(848) = 2.53$ ,  $p = .012$ ), however, this effect was no longer significant when all indices were included in the model ( $\gamma = .0002$ ,  $SE = .0006$ ,  $t(160) = .303$ ,  $p = .76$ ).

**Waist circumference**—There were no significant associations between any of the self-regulation indices and waist circumference between or within people (Supplemental Table S5).

**Blood pressure**—There were no significant associations between any of the self-regulation indices and blood pressure between or within people (Supplemental Table S6).

**Self-rated health**—Between people, better subjective self-regulation was associated with better self-rated health ( $\gamma = .016$ ,  $SE = .003$ ,  $t(144) = 5.20$ ,  $p < .001$ ; Table 10). There were no significant associations between any other self-regulation indices and self-rated health within people.

### Validation Models: Conscientiousness, Self-Regulation, and Health

Conscientiousness was tested as a predictor of self-regulation indices (EF, HRV, and subjective) and of psychological and physical health. Conscientiousness was positively associated with subjective self-regulation ( $\gamma = 20.99$ ,  $SE = 2.59$ ,  $t(145) = 8.11$ ,  $p < .001$ ), HRV ( $\gamma = .394$ ,  $SE = .203$ ,  $t(135) = 1.95$ ,  $p = .054$ ), and EF ( $\gamma = .015$ ,  $SE = .018$ ,  $t(142) = .829$ ,  $p = .41$ ), although the HRV and EF associations were not statistically significant. Regarding psychological and physical health outcomes, higher conscientiousness was associated with more positively valenced repetitive thought ( $\gamma = -1.11$ ,  $SE = .274$ ,  $t(144) = -4.04$ ,  $p < .001$ ); more use of reappraisal ( $\gamma = 0.332$ ,  $SE = .126$ ,  $t(145) = 2.63$ ,  $p = .010$ ); higher physical activity ( $\gamma = 1.14$ ,  $SE = .331$ ,  $t(145) = 3.44$ ,  $p = .001$ ); lower BMI ( $\gamma = -.071$ ,  $SE = .032$ ,  $t(144) = -2.20$ ,  $p = .030$ ); and better self-rated health ( $\gamma = .580$ ,  $SE = .118$ ,  $t(145) = 4.91$ ,  $p < .001$ ). Associations between conscientiousness and repetitive thought purpose, repetitive thought total, suppression, dyadic cohesion, mean arterial pressure, and waist circumference were not statistically significant.

Given that conscientiousness was associated with subjective self-regulation and similar psychological and physical health outcomes (repetitive thought valence, physical activity, and self-rated health), we also tested, post-hoc, theoretically plausible mediation models of conscientiousness predicting psychological and physical health via between-person subjective self-regulation. The indirect path from conscientiousness  $\rightarrow$  self-regulation  $\rightarrow$  repetitive thought valence was statistically significant (estimate =  $-.84$ ,  $SE = .20$ , 95% CI =  $-1.261$  to  $-.47$ ). Sensitivity analyses that varied the value of rho from  $-0.9$  to  $0.9$  by  $0.1$  increments revealed the 95% CI did not include zero at any rho estimate. When conscientiousness and subjective self-regulation were entered into the model together, the effect of conscientiousness decreased from  $-1.11$  to  $-.25$  and was no longer statistically significant ( $\gamma = -.253$ ,  $SE = .305$ ,  $t(143) = -.83$ ,  $p = .41$ ). The indirect path from



conscientiousness → self-regulation → physical activity was not statistically significant (estimate = .14, SE = .23, 95% CI = -.30 to .60); additionally, when conscientiousness and subjective self-regulation were entered into the model together, the effect of conscientiousness decreased from 1.14 to 1.01 but remained statistically significant ( $\gamma = 1.01$ , SE = .403,  $t(143) = 2.51$ ,  $p = .013$ ). Last, the indirect path from conscientiousness → self-regulation → self-rated health was statistically significant (estimate = .24, SE = .084, 95% CI = .082 to .413). Sensitivity analyses that varied the value of rho from -0.9 to 0.9 by 0.1 increments revealed the 95% CI did not include zero at any rho estimate. However, when conscientiousness and subjective self-regulation were entered into the model together, the effect of conscientiousness decreased from .58 to .33, but was still statistically significant ( $\gamma = .333$ , SE = .140,  $t(143) = 2.39$ ,  $p = .018$ ).

### Exploratory Models Testing Individual EF and Subjective Self-Regulation Components

Exploratory models evaluated associations between conscientiousness and the five components of the EF composite and the nine subscales of subjective self-regulation (Supplemental Table S7). Conscientiousness was not significantly associated with any of the neurocognitive test scores. However, higher conscientiousness was associated with better subjective self-regulation in all nine BRIEF subscales (all  $ps < .001$ ).

Additional exploratory models evaluated associations between components of the EF composite (Supplemental Table S8) and the nine subscales of subjective self-regulation (Supplemental Tables S9 and S10) with psychological and physical health. These exploratory models allow evaluation of two possible relationships with the composite. First, one component might drive the relationship between the composite and the outcome: Stronger inhibition, but not better working memory, might allow people to disengage from repetitive thought. In this case, one or two components should have relationships with the outcome. Second, a combination of the components might be necessary to achieve the outcome: Ability to shift, initiate, and organize might all be needed to engage in more physical activity; one component alone might not be adequate. In this case, although the combination might be associated with the outcome, it is possible that none of the components alone would be.

In the domain of executive function, higher composite EF was associated with more positive repetitive thought valence, although this relationship was not statistically significant (see Table 4). However, of the EF components, stronger verbal fluency was significantly associated with more positive repetitive thought valence (Supplemental Table S8). Higher composite EF was associated with less total repetitive thought (see Table 5). Stronger working memory was significantly associated with less total repetitive thought, and may be the component driving this effect (Table S8). Higher composite EF was also associated with less use of suppression between people (see Table 7). Stronger set-shifting and verbal fluency were significantly associated with less suppression, and may be the components driving this effect (Table S8). Last, higher composite EF was associated with more physical activity within people (see Table 8). No EF components were statistically associated with physical activity, however, suggesting a combination of EF components may be necessary.

In the domain of subjective self-regulation, better total subjective self-regulation was significantly associated with more positively valenced repetitive thought between and within people (see Table 4), less total repetitive thought between people (see Table 5), and better self-rated health between people (see Table 10). Higher mean levels of all subjective self-regulation subscales were significantly associated with more positively valenced repetitive thought (with the exception of Organization of Materials); less total repetitive thought; and better self-rated health (with the exception of Inhibition) (Supplemental Table S9). Therefore, most facets of subjective self-regulation may be needed for these particular psychological and physical health outcomes. Within people, stronger emotional control, working memory, and ability to shift, plan, monitor tasks, and organize materials were significantly associated with more positively valenced repetitive thought (Supplemental Table S10), suggesting these domains may drive the overall within-person association. Better total subjective self-regulation was also associated with more physical activity between people (see Table 8). Of the subjective self-regulation subscales, the Initiate subscale was significantly associated with higher physical activity (Table S9), suggesting the ability to begin tasks or activities without external prompting may be especially important for physical activity. Better total subjective self-regulation was associated with lower BMI between people, but higher BMI within people (see Table 9). The ability to self-monitor and initiate were significantly associated with lower BMI between people (Table S9), and the ability to plan was significantly associated with higher BMI within people (Table S10). In addition, better self-regulation was associated with higher waist circumference within people (Table S5), although this relationship was not statistically significant. However, the task monitor subscale was significantly associated with higher waist circumference within person (Table S10). Last, better subjective self-regulation was associated with higher use of reappraisal within people (see Table 6). The ability to organize materials was significantly associated with higher reappraisal within person and may be the component driving this effect. Overall, the Initiate subscale (from the meta-cognition subdomain of the BRIEF) had the most consistent relationships with psychological and physical health.

## Discussion

Cognitive, physiological, and subjective indices of self-regulation have all been proposed to predict better health. The present study described the associations among indices over time and tested their correlations with upstream conscientiousness and downstream psychological and physical health between and within older adults. In this sample of healthy older adults, there were modest and few associations between self-regulation indices, but each index was indeed linked to psychological and/or physical health.

Evidence, mostly from younger adults, suggests that EF, HRV, and subjective self-regulation can all index self-regulatory ability (Hansen, Johnsen, & Thayer, 2003; Holzman & Bridgett, 2017; Thayer et al., 2009). However, there were small to medium associations between EF and subjective self-regulation ( $r_s=.21-.30$ ) at two of the three waves in the present study, and across waves, correlations between HRV and subjective self-regulation ( $r_s=.06-.20$ ) and HRV and EF ( $r_s= -.05 -.02$ ) were small and not statistically significant. The results parallel recent evidence suggesting low associations among self-regulation indices in general (Saunders et al., 2018) and in older adults specifically. For example, investigations of HRV

and EF using MIDUS II data (a middle-age and older adult sample) reported no significant associations between multifaceted EF and HRV after accounting for age, sex, and education (Kimhy et al., 2013; Mann et al., 2015). Additionally, subjective self-regulation (assessed via the BRIEF) did not significantly correlate with standardized neuropsychological tests of EF in older adults (including processing speed, working memory, verbal fluency, set-shifting, and cognitive inhibition; Meltzer et al., 2017; Rabin et al., 2006). One interpretation to explain the overall lack of strong association between the indices may be because the aging process itself changes how the indices relate to each other. Older adults may have more practice and experience over a lifetime of self-regulatory opportunities and demands; thus, consequent to experience, they may optimize or automatize self-regulatory efforts, even though resources (including neurobiological resources) may become more limited (Jopp & Smith, 2006). This speculation requires empirical corroboration. An additional consideration is that although subjective self-regulation and EF demonstrated good reliability in the current study, the high within-person variability of HRV ( $ICC=.27$ ) may suggest its lower reliability, potentially attenuating its associations with other variables of interest.

Self-regulation indices correlated with different psychological and physical health outcomes at both the stable between-person level (i.e., across all study waves) and at the dynamic within-person level (i.e., regarding changes across study waves). Better EF predicted less total repetitive thought and less use of emotional suppression between people. Emotional suppression is an effective strategy to reduce behavioral signs of emotion, but generally has minimal impact on the experience of negative emotion (Gross, 1998). Older adults with better average EF may more easily pursue goal-directed behavior and regulation and strategically use less suppression because it does not change emotions in a desirable way. However, within people, better EF predicted *more* use of suppression; one possibility is that the within-person changes reflect inhibition capacity required for both EF and suppression. Last, better EF was associated with higher physical activity within people. This finding parallels within- and between-person results in older adults (Daly, McMinn, & Allan, 2015; McAuley et al., 2011) and suggests that state-level increases in EF may be sufficient to initiate positive health behaviors that are not evident at the stable between-person level. Importantly, however, this association is bidirectional: physical activity may also feed back to the self-regulatory constellation and improve EF in a virtuous spiral (Best et al., 2014; Colcombe & Kramer, 2003; Daly, McMinn, & Allan, 2015).

Within people, higher HRV was associated with more use of reappraisal, consistent with similar findings at a between-person level in younger adults (e.g., Gyurak & Ayduk, 2008). Notably, there were no substantial associations between HRV and any other cognitive or psychological health outcome within or between people (e.g., repetitive thought). One consideration is that HRV may be especially sensitive to situational aspects of participants' activities and health; indeed, about 30–50% of the variance of a single HRV measurement can be explained by occasion-specific effects (Bertsch et al., 2012). An alternative explanation is that with increasing age, HRV may reflect neurological inhibition less and general cardiovascular health more, and as such be a weaker correlate of cognitive or psychological processes. Age-related decrease in neural control of heart rate has been observed: inactivation of the prefrontal cortex resulted in heart rate increases in younger but

not older patients (Thayer et al., 2009). One alternative measure of cardiovascular autonomic regulation that does not appear to be affected by age and is associated with markers of executive function (inhibition, shifting, updating, and context maintenance) is the QT variability index (Stenfors et al., 2016).

Subjective self-regulation was associated with both psychological and physical health. Consistent with literature on attentional control and cognitive change (e.g., Oschner & Gross, 2005), older adults who reported fewer difficulties in self-regulation also reported more positive and less total repetitive thought between people and more use of reappraisal within people. Older adults' ability to direct attention toward goal-relevant behavior in everyday life may promote better control over emotions and repetitive thought valence as well as the ability to inhibit repetitive thought in general. However, self-regulation may not play as large a role in directing repetitive thought purpose in older adults, which encompasses searching to solving content. In terms of health behavior and physical health, older adults who, on average, reported fewer difficulties in self-regulation engaged in more physical activity and had lower BMI and better self-rated health. These findings are consistent with better self-regulatory ability and strength associating with better health behaviors and physical health in undergraduate populations (Ginis & Bray, 2010, Tangney et al., 2004). Last, at waves when participants reported higher than average subjective self-regulation (specifically the ability to plan), they also had higher BMI. We speculate that this association could be due to the effect of higher physical activity on increasing muscle mass. Indeed, BMI is inversely associated with the presence of sarcopenia, or age-related muscle loss, in older adults (Han et al., 2015). This possibility remains to be tested, however, and there are alternate explanations for this unexpected association; participants may mistakenly believe they are doing well at self-regulation when in fact they are not, or participants may be self-regulating well but in other areas of life. Selection bias may also play a role such that older adults with both high BMI and low self-regulation may be dropping out of the study earlier, leaving high BMI participants who report high self-regulation; however, this explanation may be less tenable given that dropout was not predicted by subjective self-regulation. Neither waist circumference nor blood pressure were associated with composite self-regulation indices between or within people. In the current sample, average mean arterial pressure (97.28 mmHg) was considered borderline high (i.e., between 93.3 – 106.6 mmHg) and average waist circumference for men (103.5 cm) and women (91.5 cm) also fell within the 'high risk' category; therefore, restriction of range was not an issue. Other measurements of body composition in older adults (e.g., DEXA scan) may also be useful in future investigations of associations between self-regulation and physical health. Overall, subjective self-regulation was the most consistent predictor of health, perhaps because it is a final common pathway (i.e., reflecting the effects of neurobiology, motivation, and experience on self-regulatory behavior). Efforts to improve self-regulation in older adults may consider capitalizing on multiple ways to promote better self-regulatory abilities.

Self-regulation was not strongly related to dyadic cohesion. Reliability was not an issue, as the dyadic cohesion measure demonstrated adequate reliability between and within people. One possibility is that self-regulation is a more distal predictor of interpersonal outcomes and operates through a series of interconnected mechanisms (e.g., specific behavioral and emotional processes), which may more strongly predict interpersonal functioning in older

adults. Additionally, the interdependent nature of relationships should be considered: partners' abilities in self-regulation may be potent predictors of each other's relationship outcomes, over and above individuals' own effects on their outcomes (Reed, Butler, & Kenny, 2013).

The upstream personality trait of conscientiousness, which demonstrated adequate reliability, was associated with subjective self-regulation, suggesting that people who view themselves as more conscientious also perceive fewer self-regulatory difficulties. We did not find associations between conscientiousness and the EF composite or HRV, which is mostly consistent with previous research (Brouwer et al., 2015; Shepherd, Mulgrew, & Hautus, 2015; Unsworth et al., 2009; Williams, Suchy, & Kraybill, 2010). In the exploratory analyses, higher conscientiousness tended to be associated with better working memory (assessed via Letter Number Sequencing), but this effect was not statistically significant. Of the Big Five personality factors, conscientiousness typically has the strongest relationship to outcomes such as healthy behaviors and longevity (e.g., Friedman et al., 1993; Ozer & Benet-Martinez, 2006; Roberts et al., 2007). In the current study, higher conscientiousness was related to better intrapersonal psychological and physical health outcomes. Moreover, the relationships between conscientiousness and more positively valenced repetitive thought, more physical activity, and better self-rated health were partially mediated by better subjective self-regulation. Subjective self-regulation was stable over time and may therefore be a focus for future research on individual differences and psychological and physical health in older adults.

Strengths of the current study included the multi-method assessment (neuropsychological evaluations, physiological assessments, and subjective self-report), the large age range within older age (60–93 years), and the longitudinal design that allowed the examination of both between- and within-person changes in self-regulation over time. However, the present study was observational and therefore reverse causality and bi-directionality are also possible: poorer health may also compromise self-regulatory capacity. Additionally, although the sample is demographically representative of the local population of older adults, there was low representation of racial and ethnic minorities, limiting generalizability. The sample also included relatively healthy older adults; it will be important to cross-validate these findings and examine the structure and health correlates of self-regulation in clinical samples of older adults with psychological and/or physical health challenges (e.g., Combs et al., 2018). A final consideration is that the convenience sampling and study design, which involved participants being willing to be interviewed semi-annually over 5 years, may further limit the representativeness of the data. The study protocol was tailored so that participants were visited in their homes, negating the need for participants to navigate to a laboratory, arrange transportation, etc. However, the dropout and missing data analyses suggest that efforts to retain particularly older participants and those with lower executive function would also be beneficial.

Several measurement considerations are worth noting for future research. As in the current investigation, similar methods of measurement (e.g., self-report) will likely yield stronger associations between and within participants over time; therefore, mixed methods designs that capture a variety of self-regulation measures (questionnaire, laboratory, behavioral) are

ideal to provide converging evidence. Additionally, our analyses were limited to examining *resting* HRV and blood pressure as indicators of self-regulation and physical health, respectively. HRV reactivity (i.e., in response to a challenging stimuli or acute psychological stress) has also been investigated as an indicator of self-regulation (e.g., Butler et al., 2006) and may interact with resting HRV to associate with outcomes of better self-regulation. Similarly, we would expect better self-regulation to be associated with well-regulated blood pressure reactions to acute stress, which plays a role in predicting the development of hypertension and cardiovascular disease (Chida & Steptoe, 2010). In terms of emotion regulation, older adults in particular may use strategies other than those measured by the Emotion Regulation Questionnaire, including situation selection and attentional deployment (Urry & Gross, 2010). Furthermore, future research that parses out the effects of specific emotion regulation strategies in older adults is warranted; for example, older adults are more successful than younger adults at using positive reappraisal but are less successful at using detached reappraisal (Shiota & Levenson, 2009). A final consideration is that our sample of older adults differed in age at study entry; thus, the 5-year study represents, for example, one participant's change from 62 to 67 years old and another participant's change from 83 to 88 years old. Given this, and the issue that five years may not provide sufficient time to capture meaningful health and developmental change in older adults of varying ages, we did not examine whether wave 1 predicted wave 10 data, nor did we examine time-structured longitudinal changes in within-person coupling over time. Intraindividual variability is clearly an area of exciting inquiry, however, and we direct interested readers to Diehl, Hooker, and Sliwinski (2015).

## Conclusions

The goals of the present study were to examine the structure of self-regulation and its correlates with upstream conscientiousness and downstream psychological and physical health between and within older adults over time. Indices of self-regulation (EF, HRV, and subjective self-reports) were modestly related, yet separable components. The results suggest that the aging process itself may change how the indices relate to each other and that older adults may rely less on neurobiological resources and more on practice and experience for self-regulatory efforts. Additionally, self-regulation indices differentially predicted psychological health, positive health behaviors, and physical health, with subjective self-regulation being the most consistent predictor of all domains. Moreover, the associations between self-regulation and health were characterized by both stable between-person differences and dynamic within-person fluctuations. Last, subjective self-regulation mediated the relationships between conscientiousness and psychological (repetitive thought valence) and physical health (self-rated health). Ultimately, subjective self-regulation may be a particularly important and final common pathway from upstream influences on self-regulation (e.g., personality, neurobiological, motivational, and experiential) to health in older adults. Strengthening self-regulation by targeting its indicators separately, and in particular promoting better self-regulatory function, may yield the most robust health for older adults.

## Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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**Figure 1.**  
Visualization of waves (1–10) completed per participant.

**Table 1:**

Number of observed person-waves, reasons for missingness, and number of dropouts.

Wave	Person-Waves		Reason for Missing Person-Waves							N dropouts prior to wave
	Observed	Missing	Skipped	Lost data	Due in future	Wanted to drop	Lost contact	Moved/too ill	Died	
1	149	0	0	0	0	0	0	0	0	0
2	140	9	1	0	0	4	1	3	0	8
3	133	16	4	1	0	5	3	3	0	3
4	128	21	2	0	0	6	5	6	2	8
5	119	30	5	0	0	8	7	7	3	6
6	106	43	6	3	0	11	8	10	5	9
7	89	60	12	3	1	17	10	12	5	10
8	78	71	7	4	11	18	12	14	5	5
9	63	86	1	2	29	21	12	16	5	5
10	41	108	7	3	40	22	13	18	5	4
Sum 1–10	1,046	444	45	16	81	112	71	89	30	58

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**Table 2:**

Descriptive statistics for study variables.

	Mean (SD)	Range	ICC
Conscientiousness	3.83 (0.46)	2.50 – 5.0	--
EF Composite	0.55 (0.11)	0.13 – 0.79	0.78
Trail Making Test (part A – part B)	0.73 (0.15)	0 – 1	0.56
Controlled Oral Word Association	0.43 (0.15)	0 – 1	0.80
Letter Number Sequencing	0.61 (0.15)	0 – 1	0.46
Digit Span backward	0.48 (0.18)	0 – 1	0.68
Digit Span sequencing	0.49 (0.14)	0 – 1	0.47
HF-HRV (ms <sup>2</sup> )	4.77 (1.64)	0.92 – 11.36	0.27
Subjective Self-Regulation (BRIEF)	174.48 (18.95)	97 – 210	0.81
Repetitive Thought Valence	0 (2.10)	-6.20 – 8.41	0.48
Repetitive Thought Purpose	0 (1.87)	-5.63 – 6.36	0.47
Repetitive Thought Total	0 (4.38)	-16.53 – 11.14	0.69
Reappraisal	4.91 (0.90)	1 – 7	0.53
Suppression	3.88 (1.11)	1 – 7	0.64
Dyadic Cohesion	12.32 (3.35)	0 – 20	0.52
Physical Activity	91.09 (48.47)	0 – 288.11	0.48
Physical Activity (sqrt transformed)	9.17 (2.63)	0 – 16.97	0.49
BMI	27.11 (5.30)	16.06 – 49.99	0.95
BMI (log transformed)	3.28 (0.19)	2.78 – 3.91	0.96
Waist circumference (cm)	96.92 (14.79)	59 – 161.50	0.83
Mean Arterial Pressure (mm Hg)	97.28 (12.33)	63.67 – 150.83	0.41
Systolic Blood Pressure (mm Hg)	138.15 (19.99)	83 – 214.50	0.42
Diastolic Blood Pressure (mm Hg)	76.84 (10.55)	42 – 122	0.38
Self-Rated Health	3.65 (0.86)	1 – 5	0.63

*Note.* ICC = intraclass correlation coefficient; EF = executive function; HF-HRV = high frequency heart rate variability; BRIEF = Behavior Rating Inventory of Executive Function; BMI = body mass index.

**Table 3:**

Correlations between latent variables within waves 1, 3, and 5.

		<u>Subjective</u>		<u>EF</u>	
		<i>r</i>	<i>p</i>	<i>r</i>	<i>p</i>
EF	Wave 1	.04	.67		
	Wave 3	.21	.033		
	Wave 5	.30	.004		
HRV	Wave 1	.06	.67	.02	.87
	Wave 3	.03	.83	-.04	.78
	Wave 5	.20	.13	-.05	.68

*Note.* Horizontal rows depict correlations between latent variables within each wave. Correlations are standardized completely. EF = executive function; HRV = heart rate variability.



**Table 4:**

Results of multilevel models predicting repetitive thought valence (N=147, n=1017)

	<b>Null Model</b>	<b>Model 1</b>	<b>Model 2</b>	<b>Model 3</b>	<b>Model 4</b>
	<b><math>\gamma</math> (SE)</b>	<b><math>\gamma</math> (SE)</b>	<b><math>\gamma</math> (SE)</b>	<b><math>\gamma</math> (SE)</b>	<b><math>\gamma</math> (SE)</b>
Fixed effects					
Intercept	-0.030 (0.132)	-0.29 (0.23)	0.055 (0.151)	-0.022 (0.12)	-0.16 (0.25)
Age at study entry		0.057 (0.029)	0.039 (0.0262)	0.045* (0.020)	0.058 (0.033)
Education		0.002 (0.058)	-0.002 (0.058)	0.020 (0.047)	0.047 (0.065)
Practice effects					
EF between		0.32 (0.321)			0.347 (0.362)
EF within		-1.15 (1.49)			-0.710 (1.73)
HRV between			-0.135 (0.130)		-0.077 (0.141)
HRV within			0.075 (0.046)		0.089 (0.070)
Subjective between					
Subjective within				<b>-0.044** (0.007)</b>	<b>-0.035** (0.010)</b>
Random effects					
Intercept SD	1.46	1.44	1.55	1.24	1.46
Residual SD	1.51	1.47	1.44	1.49	1.42
Model fit					
LL	-2005.6	-958.8	-1227.9	-1914.7	-589.1
AIC	4017.2	1933.6	2469.8	3843.4	1202.3

*Note.* Higher repetitive thought valence is more negative and less positive content. Results (Models 3 and 4) remain unchanged when excluding the observations that had inconsistent subjective self-regulation scores. EF = executive function; HRV = heart rate variability; LL = log likelihood; AIC = Akaike information criterion.

\*  $p < .05$ .

\*\*  $p < .001$ .

**Table 5:**

Results of multilevel models predicting repetitive thought total (N=147, n=1017).

	Null Model	Model 1	Model 2	Model 3	Model 4
	$\gamma$ (SE)	$\gamma$ (SE)	$\gamma$ (SE)	$\gamma$ (SE)	$\gamma$ (SE)
Fixed effects					
Intercept	0.146 (0.308)	1.32* (0.48)	0.313 (0.329)	0.269 (0.286)	4.88* (2.01)
Age at study entry		-0.10 (0.062)	0.005 (0.057)	-0.029 (0.049)	-0.061 (0.065)
Education		-0.185 (0.126)	-0.291* (0.128)	-0.171 (0.114)	-0.191 (0.130)
Practice effects					
EF between		-2.06* (0.690)			-2.35* (0.722)
EF within		<b>-9.58* (3.19)</b>			-6.12 (3.45)
HRV between			-0.278 (0.280)		-0.072 (0.278)
HRV within			-0.124 (0.075)		0.056 (0.112)
Subjective between				<b>-0.086** (0.017)</b>	<b>-0.087** (0.020)</b>
Subjective within				-0.019 (0.010)	-0.034 (0.025)
Random effects					
Intercept SD	3.58	3.38	3.55	3.23	3.16
Residual SD	2.39	2.20	2.35	2.37	2.22
Model fit					
LL	-2528.5	-1201.9	-1571.6	-2431.1	-750.07
AIC	5063.0	2419.7	3157.2	4876.2	1524.1

Note. Results (Models 3 and 4) remain unchanged when excluding the observations that had inconsistent subjective self-regulation scores. EF = executive function; HRV = heart rate variability; LL = log likelihood; AIC = Akaike information criterion.

\*  $p < .05$ .

\*\*  $p < .001$ .

**Table 6:**

Results of multilevel models predicting reappraisal (N=148, n=1024).

	Null Model	Model 1	Model 2	Model 3	Model 4
	$\gamma$ (SE)	$\gamma$ (SE)	$\gamma$ (SE)	$\gamma$ (SE)	$\gamma$ (SE)
Fixed effects					
Intercept	4.91 <sup>**</sup> (0.058)	5.08 <sup>**</sup> (0.093)	4.90 <sup>**</sup> (0.062)	4.93 <sup>**</sup> (0.060)	5.02 <sup>**</sup> (0.103)
Age at study entry		-0.015 (0.012)	-0.010 (0.011)	-0.004 (0.010)	-0.007 (0.014)
Education		-0.018 (0.024)	-0.018 (0.024)	-0.019 (0.024)	-0.022 (0.027)
Practice effects		-0.20 (0.13)			-0.10 (0.15)
EF between		-0.61 (0.62)			-0.63 (0.72)
EF within		0.87 (0.64)			1.40 (0.90)
HRV between			-0.025 (0.053)		0.004 (0.059)
HRV within			0.007 (0.020)		<b>0.059<sup>*</sup> (0.029)</b>
Subjective between				0.001 (0.003)	-0.003 (0.004)
Subjective within				<b>0.006<sup>*</sup> (0.003)</b>	0.006 (0.006)
Random effects					
Intercept SD	0.65	0.61	0.64	0.66	0.63
Residual SD	0.62	0.58	0.61	0.61	0.58
Model fit					
LL	-1112.3	-519.8	-701.1	-1073.5	-337.3
AIC	2230.5	1055.6	1416.2	2161.0	698.6

Note. Model 3 results remain unchanged when excluding the observations that had inconsistent subjective self-regulation scores. EF = executive function; HRV = heart rate variability; LL = log likelihood; AIC = Akaike information criterion.

\*  $p < .05$ .

\*\*  $p < .001$ .

**Table 7:**

Results of multilevel models predicting suppression (N=148, n=1024).

	Null Model	Model 1	Model 2	Model 3	Model 4
	$\gamma$ (SE)	$\gamma$ (SE)	$\gamma$ (SE)	$\gamma$ (SE)	$\gamma$ (SE)
Fixed effects					
Intercept	3.89 ** (0.077)	3.83 ** (0.122)	3.87 ** (0.082)	3.89 ** (0.077)	3.79 ** (0.13)
Age at study entry		0.036 * (0.015)	0.036 * (0.014)	0.033 * (0.013)	0.049 * (0.017)
Education		0.011 (0.032)	-0.021 (0.032)	-0.007 (0.031)	-0.010 (0.032)
Practice effects		0.033 (0.17)			0.11 (0.18)
EF between		<b>-2.46 * (0.81)</b>			<b>-3.03 ** (0.88)</b>
EF within		0.15 (0.72)			<b>3.23 * (1.10)</b>
HRV between			0.031 (0.070)		0.035 (0.072)
HRV within			-0.031 (0.021)		-0.032 (0.037)
Subjective between				-0.005 (0.004)	0.003 (0.005)
Subjective within				0.001 (0.003)	-0.002 (0.008)
Random effects					
Intercept SD	0.89	0.83	0.88	0.87	0.87
EF within SD	-	-	-	-	3.96
HRV within SD	-	-	-	-	0.14
Subjective within SD	-	-	-	-	0.04
Residual SD	0.67	0.65	0.65	0.67	0.55
Model fit					
LL	-1233.1	-599.4	-777.8	-1187.6	-385.0
AIC	2472.3	1214.7	1569.6	2389.1	812.0

Note. EF = executive function; HRV = heart rate variability; LL = log likelihood; AIC = Akaike information criterion.

\*  $p < .05$ .

\*\*  $p < .001$ .

**Table 8:**

Results of multilevel models predicting physical activity (N=149, n=948).

	Null Model	Model 1	Model 2	Model 3	Model 4
	$\gamma$ (SE)	$\gamma$ (SE)	$\gamma$ (SE)	$\gamma$ (SE)	$\gamma$ (SE)
Fixed effects					
Intercept	9.12 <sup>**</sup> (0.166)	10.61 <sup>**</sup> (0.699)	9.79 <sup>**</sup> (0.603)	9.97 <sup>**</sup> (0.533)	10.19 <sup>*</sup> (0.797)
Gender		-0.689 (0.381)	-0.549 (0.361)	-0.537 (0.320)	-0.481 (0.435)
Age at study entry		-0.115 <sup>*</sup> (0.036)	-0.101 <sup>*</sup> (0.031)	-0.114 <sup>*</sup> (0.027)	-0.125 <sup>*</sup> (0.041)
Education		0.050 (0.075)	0.050 (0.070)	0.038 (0.064)	0.034 (0.082)
Practice effects		-0.585 (0.409)			-1.03 <sup>*</sup> (0.461)
EF between		1.05 (1.91)			-1.19 (2.20)
EF within		<b>4.94<sup>*</sup> (2.22)</b>			<b>6.40<sup>*</sup> (3.17)</b>
HRV between			-0.054 (0.155)		-0.115 (0.179)
HRV within			-0.006 (0.064)		-0.041 (0.099)
Subjective between				<b>0.022<sup>*</sup> (0.009)</b>	<b>0.034<sup>*</sup> (0.013)</b>
Subjective within				0.012 (0.008)	0.001 (0.022)
Random effects					
Intercept SD	1.83	1.78	1.76	1.66	1.73
Residual SD	1.89	1.90	1.89	1.90	1.91
Model fit					
LL	-2086.5	-1000.7	-1284.5	-2019.9	-625.1
AIC	4179.1	2019.3	2585.0	4055.9	1276.2

Note. Gender is coded 1=males, 2=females. Results (Models 3 and 4) remain unchanged when excluding the observations that had inconsistent subjective self-regulation scores. EF = executive function; HRV = heart rate variability; LL = log likelihood; AIC = Akaike information criterion.

\*  $p < .05$ .

\*\*  $p < .001$ .

**Table 9:**

Results of multilevel models predicting body mass index (N=148, n=1035).

	Null Model	Model 1	Model 2	Model 3	Model 4
	$\gamma$ (SE)	$\gamma$ (SE)	$\gamma$ (SE)	$\gamma$ (SE)	$\gamma$ (SE)
Fixed effects					
Intercept	3.27 <sup>**</sup> (0.015)	3.36 <sup>**</sup> (0.058)	3.35 <sup>**</sup> (0.054)	3.36 <sup>**</sup> (0.051)	3.38 <sup>**</sup> (0.063)
Gender		-0.047 (0.032)	-0.043 (0.032)	-0.054 (0.031)	-0.056 (0.035)
Age at study entry		-0.004 (0.003)	-0.003 (0.003)	-0.002 (0.002)	-0.001 (0.003)
Education		-0.016 <sup>*</sup> (0.006)	-0.013 <sup>*</sup> (0.006)	-0.014 <sup>*</sup> (0.006)	-0.012 (0.007)
Practice effects		-0.018 (0.035)			-0.004 (0.037)
EF between		-0.034 (0.160)			0.101 (0.176)
EF within		-0.026 (0.045)			-0.048 (0.061)
HRV between			0.001 (0.013)		0.004 (0.014)
HRV within			0.001 (0.001)		0.001 (0.002)
Subjective between				-0.001 (0.001)	<b>-0.002<sup>*</sup> (0.001)</b>
Subjective within				<b>0.0005<sup>*</sup> (0.0002)</b>	0.0002 (0.0006)
Random effects					
Intercept SD	0.18	0.18	0.18	0.18	0.18
Subjective within SD	-	-	-	0.001	0.003
Residual SD	0.04	0.04	0.03	0.04	0.03
Model fit					
LL	1515.0	556.5	922.0	1469.41	289.7
AIC	-3023.9	-1094.9	-1827.9	-2918.8	-549.4

*Note.* Gender is coded 1=males, 2=females. Results (Models 3 and 4) remain unchanged when excluding the observations that had inconsistent subjective self-regulation scores. EF = executive function; HRV = heart rate variability; LL = log likelihood; AIC = Akaike information criterion.

\*  $p < .05$ .

\*\*  $p < .001$ .

**Table 10:**

Results of multilevel models predicting self-rated health (N=149, n=1040).

	Null Model	Model 1	Model 2	Model 3	Model 4
	$\gamma$ (SE)	$\gamma$ (SE)	$\gamma$ (SE)	$\gamma$ (SE)	$\gamma$ (SE)
Fixed effects					
Intercept	3.66 <sup>**</sup> (0.059)	3.72 <sup>**</sup> (0.219)	3.42 <sup>**</sup> (0.208)	3.41 <sup>**</sup> (0.183)	3.72 <sup>**</sup> (0.228)
Gender		0.059 (0.120)	0.158 (0.125)	0.150 (0.110)	0.071 (0.125)
Age at study entry		-0.024 <sup>*</sup> (0.011)	-0.021 (0.010)	-0.016 (0.009)	-0.026 <sup>*</sup> (0.12)
Education		0.042 (0.024)	0.052 <sup>*</sup> (0.024)	0.038 (0.022)	0.028 (0.024)
Practice effects		-0.257 <sup>*</sup> (0.130)			-0.277 <sup>*</sup> (0.133)
EF between		0.817 (0.604)			0.461 (0.636)
EF within		0.325 (0.555)			-0.117 (0.745)
HRV between			0.015 (0.053)		-0.054 (0.052)
HRV within			0.011 (0.016)		0.011 (0.024)
Subjective between				<b>0.016<sup>**</sup> (0.003)</b>	<b>0.016<sup>**</sup> (0.004)</b>
Subjective within				0.004 (0.003)	0.008 (0.005)
Random effects					
Intercept SD	0.68	0.61	0.65	0.61	0.55
Subjective within SD	-	-	-	0.014	-
Residual SD	0.52	0.51	0.50	0.50	0.48
Model fit					
LL	-976.2	-484.2	-607.0	-916.9	-291.6
AIC	1958.4	986.4	1229.9	1853.8	609.2

*Note.* Gender is coded 1=males, 2=females. Results (Models 3 and 4) remain unchanged when excluding the observations that had inconsistent subjective self-regulation scores. EF = executive function; HRV = heart rate variability; LL = log likelihood; AIC = Akaike information criterion.

\*  $p < .05$ .

\*\*  $p < .001$ .