Personality and Individual Differences 152 (2020) 109572

Contents lists available at ScienceDirect

Personality and Individual Differences

journal homepage: www.elsevier.com/locate/paid

Cognitive control moderates the health benefits of trait self-regulation in young adults

Jonathan G. Hakun[a,b,c,*], Margaret A. Findeison[b]

[a] Department of Neurology, The Pennsylvania State University, Penn State Milton S. Hershey Medical Center, Hershey, PA 17033, USA
[b] Department of Psychology, The Pennsylvania State University, State College, PA 16801, USA
[c] The Center for Healthy Aging, The Pennsylvania State University, State College, PA, 16801, USA

ARTICLE INFO

Keywords:
Working memory capacity
Cognitive control
Executive function
Self-rated health
Self-regulation
Conscientiousness

ABSTRACT

Separate lines of epidemiological research suggest that individuals with high trait self-regulation (e.g. conscientious individuals) and individuals with higher cognitive ability (e.g. executive control/intelligence) each tend to enjoy superior health and well-being outcomes. However, it remains largely unexplored whether these personological and cognitive contributions to physical health are shared, independent, or interdependent. In the current study, we examined associations between trait self-regulation, cognitive control, self-reported physical health, and subjective well-being. A domain-general model revealed little shared variance between trait self-regulation and cognitive control but revealed significant unique relationships between each predictor and physical health. Results of a latent moderation analysis suggested that cognitive control moderated the contribution of self-regulation to health but not subjective well-being. This moderation effect was characterized by a strengthened relationship between trait self-regulation and health with decreases in cognitive control. Together, our results suggest that self-regulation and cognitive control may independently contribute to health outcomes in young adults and that self-regulation may be increasingly important for individuals lower in cognitive control.

1. Introduction

Separate lines of research suggest that individuals with a trait orientation toward self-regulation (e.g. conscientiousness, self-control) and individuals with stronger higher-order cognitive ability (e.g. intelligence, cognitive control) each enjoy superior health and well-being outcomes (Batty, Deary, & Gottfredson, 2007; Deary, Weiss, & Batty, 2011; Friedman, 2008; Gottfredson & Deary, 2004; Kern & Friedman, 2008; Kiecolt-Glaser, McGuire, Robles, & Glaser, 2002; Leon, Lawlor, Clark, Batty, & Macintyre, 2009; Sabia et al., 2010; Terracciano, Löckenhoff, Zonderman, Ferrucci, & Costa, 2008). While these benefits are often presumed to be conferred through common behavioral mechanisms (e.g. participation in healthy behaviors and avoidance of risky behaviors), it remains unknown whether the contributions of individual differences in self-regulation and cognitive ability to health and well-being are shared, independent, or interdependent (Bogg & Roberts, 2004; Deary et al., 2011; Hofmann, Schmeichel, & Baddeley, 2012). In the current study, we investigated associations between trait self-regulation, cognitive control, self-rated health, and well-being outcomes in college-aged young adults.

At a broad level, self-regulation involves the alignment of one's thoughts, emotions, and behavior with personal standards and long-term goals (Bandura, 1991; Baumeister & Heatherton, 1996; Carver & Scheier, 1982; Hofmann et al., 2012). Self-regulation is multi-faceted and refers to a broad range of psychological processes that influence decision making and behavior throughout the course of daily life (Baumeister & Heatherton, 1996; Nigg, 2017). Evidence accumulated over the past few decades suggests that inventory-based measures of personality, impulse control, and emotion regulation may validly capture the tendency to self-regulate and that each are predictive of positive health and well-being outcomes (Friedman, 2008; Gross & Muñoz, 1995; Martin, Friedman, & Schwartz, 2007; Mauss & Gross, 2004; Moffitt et al., 2011; Roberts, Walton, & Bogg, 2005; Tangney, Baumeister, & Boone, 2004). These positive outcomes are thought to be, at least in part, derived through a combination of participation in healthy behaviors and avoidance of risk factors for poor health (Bogg & Slatcher, 2015; Bogg & Roberts, 2004; DeSteno, Gross, & Kubzansky, 2013; Lodi-Smith et al., 2010). In addition, successful self-regulation of thought and emotion may have a direct effect on physical health by reducing stress-related physiological responses (e.g., promoting immunological function, faster recovery from illness; Bogg & Slatcher, 2015; Cacioppo & Berntson, 2012). In the current study, we took a

* Corresponding author at: Department of Neurology, The Pennsylvania State University, Penn State Milton S. Hershey Medical Center, Hershey, PA 17033, USA.
E-mail address: jgh5196@psu.edu (J.G. Hakun).

https://doi.org/10.1016/j.paid.2019.109572
Received 3 May 2019; Received in revised form 25 July 2019; Accepted 20 August 2019
Available online 30 August 2019

domain-general approach to individual differences in trait self-regulation by estimating a latent self-regulation factor indicated by conscientiousness, self-control, and negative emotion reappraisal.

The proposed links between cognitive ability and health outcomes include pathways held in common with trait self-regulation (e.g. participation in healthy behaviors and avoidance of risky ones) as well as possible advantages related to privileged access to education, resources, and health-care (through increased occupational attainment, socioeconomic status (SES); Deary et al., 2011; Gottfredson & Deary, 2004). Despite the recent increased attention to the role of cognitive control in successful self-regulation of healthy behaviors (Hall & Fong, 2015; Hall, Fong, Epp, & Elias, 2008; Hofmann et al., 2012; Hofmann, Friese, & Wiers, 2008; McAuley et al., 2011), it remains unknown whether individual differences in cognitive control and trait self-regulation are correlated constructs (although see Moutafi, Furnham, & Paltiel, 2004, 2005). Moreover, and central to the focus of the current study, few studies have examined whether previously established links between cognitive ability and trait self-regulation with health and well-being are shared, independent, or interdependent.

Consistent with our domain-general approach to measuring trait self-regulation, we experimentally measured cognitive control as a domain-general construct indicated by performance on multiple storage-plus-processing ("complex") working memory span tasks, a construct often referred to as 'working memory capacity' (WMC; Conway et al., 2005; Kane et al., 2004; Redick et al., 2012; Turner & Engle, 1986). WMC is a well-established marker of individual differences in cognitive control and is indicated by performance across complex span tasks covering multiple stimulus domains (e.g. visual and verbal; Kane et al., 2004; Kane, Conway, Hambrick, & Engle, 2007; Kane & Engle, 2002; Redick, 2013). WMC is highly associated with individual differences in fluid intelligence (Conway, Kane, & Engle, 2003; Kyllonen & Christal, 1990; Redick, 2013) and is a strong predictor of goal maintenance (McVay & Kane, 2009; Redick, 2013; Unsworth, Redick, Spillers, & Brewer, 2012); each of which has been posited to support engagement in behaviors that promote physical health (Hall & Fong, 2015; Hofmann, Friese, & Roefs, 2009; Hofmann, Friese, & Wiers, 2008).

We first examined the fit of latent variables to observed self-report and behavioral measures as well as associations between WMC, trait self-regulation, health, and well-being in a confirmatory factor analysis. In view of identifying domains of physical health with sufficient variance among a sample of younger adults (college students), a latent factor of Physical health was modeled indicated by recent cold history (e.g., frequency of recent colds), perceived vulnerability to illness (e.g. likelihood of getting sick when stressed), and self-rated health. In addition, subjective well-being was modeled as a latent factor indicated by self-reported happiness, positive and negative affect, and life satisfaction. After examining the covariance structure between WMC, trait self-regulation, health and well-being, we fit a latent moderation structural equation model to examine whether the contributions of trait self-regulation and WMC to health and well-being were interdependent.

2. Methods

2.1. Participants

A total of 145 younger adults (age M = 19.3; age SD = 1.5; age range = 18–26) participated in the study. Participants were recruited from Pennsylvania State University's psychology undergraduate research pool. All participants provided written informed consent and received course credit for their participation. All experimental procedures were approved by Pennsylvania State University's Institutional Review Board for the ethical treatment of human participants.

2.2. Materials and procedure

2.2.1. Experimental measures

Participants completed two automated complex span tasks (Operation Span and Symmetry Span). The Operation Span task measures the ability to store information in verbal working memory while processing a secondary equation judgment task. Similarly, the Symmetry Span task measures the ability to store information in visual working memory while processing a secondary symmetry judgment task. Each automated task contained self-guided instructions, practice, and timing parameters customized to the participant (for a full description of the development, parameters, and reliability of these automated procedures, see Conway et al., 2005; Redick et al., 2012). Both Operation Span and Symmetry Span were scored according to the partial-trial scoring method (Conway et al., 2005). The partial-trial scoring method involves counting each item recalled in the correct order from memory regardless of whether all items within a trial were recalled.

2.2.2. Working memory capacity (WMC)

Operation Span task (*OSpan*): OSpan involved memorizing a single letter at a time while performing interleaved arithmetic operations. After memorizing a set of letters and completing the interleaved arithmetic operations, participants were asked to recall all of the letters memorized throughout the current trial in order. Trials randomly varied in set-size. Set sizes (# of total letters tested on each trial) ranged from 3 to 7 with three repetitions of each set size throughout the task. The total number of item-operation pairs was 75.

Symmetry Span task (*SSpan*): involved memorizing highlighted locations in a 4 × 4 matrix one at a time while performing interleaved symmetry judgments on 8 × 8 mosaic pattern stimuli that were either symmetrical or non-symmetrical along the vertical axis. After memorizing a set of locations and completing the interleaved symmetry judgments, participants were asked to recall all of the spatial locations from the 4 × 4 matrices memorized throughout the current trial in order. Trials randomly varied in set-size. Set sizes (# of total locations tested on each trial) ranged from 2 to 5 with three repetitions of each set size throughout the task. The total number of location-symmetry pairs was 42. For a depiction of OSpan and SSpan procedures and stimuli see Fig. 1.

2.3. Self-report measures

2.3.1. Markers of trait self-regulation (self-regulation)

Conscientiousness (*C*): The NEO-FFI C sub-scale (α = 0.83), was used to measure trait C (Costa & McCrae, 1992). Participants responded to items from the NEO-FFI such as "I have a clear set of goals and I work toward them in an orderly fashion". Responses to C sub-scale items were summed to generate a total C score.

Self-Control (*SC*): The Self-Control Scale (α = 0.86) was used to measure trait SC (Tangney et al., 2004). Participants responded to items from the Self-Control Scale such as "I am able to work efficiently towards long-term goals" and "I often act without thinking through all the alternatives". Responses to the Self-Control Scale items were summed to generate a total SC score.

Emotional Reappraisal (*ER*): The Emotional Regulation Questionnaire cognitive reappraisal sub-scale (α = 0.84), was used to measure trait ER (Gross & John, 2003). Participants responded to items from the Emotional Regulation Questionnaire such as "When I want to feel a more positive emotion, I change the way I'm thinking about the situation". Responses to the cognitive reappraisal sub-scale items were summed to generate a total ER score.

2.3.2. Self-reported health (health)

Recent Cold History (*Colds*): A single item "How many colds did you catch over the previous 12 months" was adapted from measures used in

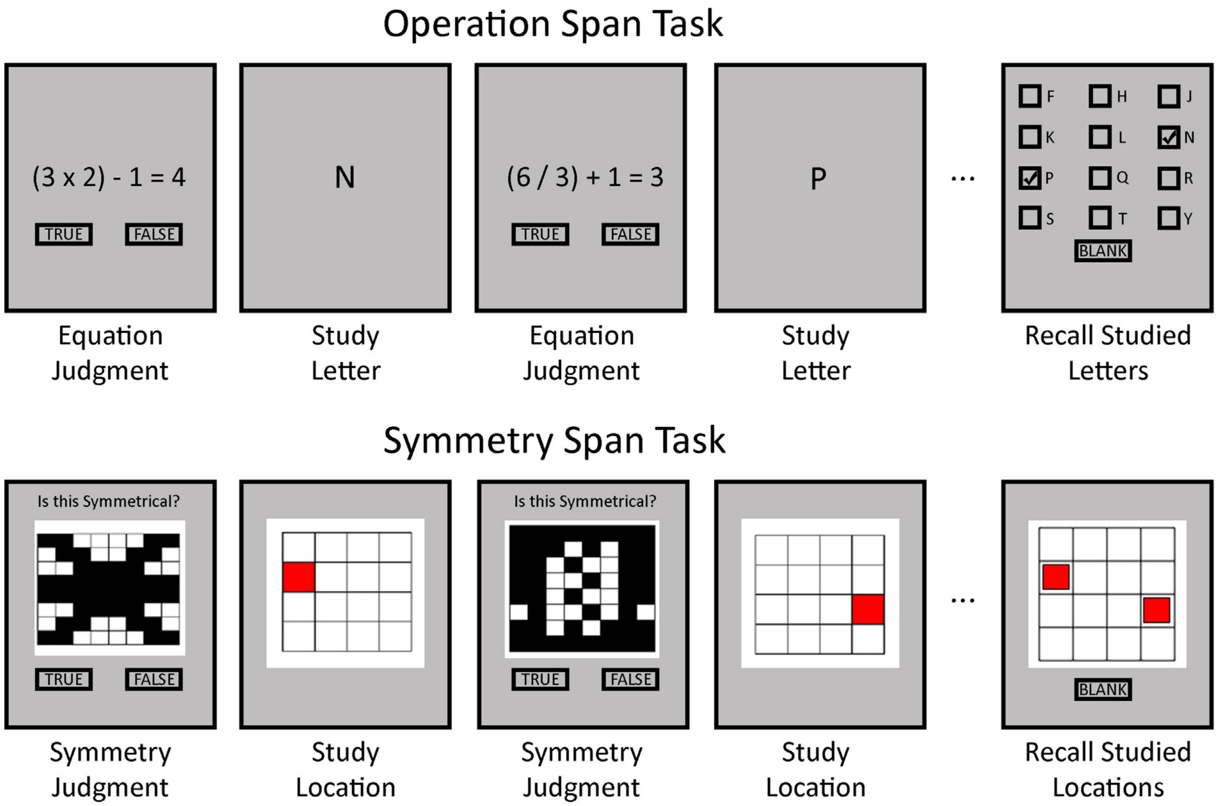

Fig. 1. Operation span and symmetry span tasks. (TOP) Overview of the procedure and stimuli for the Operation Span task. Participants alternated between true/false judgments made on presented equations and study of letter memoranda (3 to 7 iterations per trial). At the end of each trial, a recall screen appeared and participants were instructed to recall as many studied letters as possible from the current trial, in order, using the blank button to indicate a forgotten letter. (BOTTOM) Overview of the procedure and stimuli for the Symmetry Span task. Participants alternated between symmetry judgments made on presented visual patterns and study of individual location memoranda (2 to 5 iterations per trial). At the end of each trial, a recall screen appeared and participants were instructed to recall as many studied locations as possible from the current trial, in order, using the blank button to indicate a forgotten location.

the The Common Cold Project (Cohen, 2016) and used to measure participants' frequency of colds over the past year.

Perceived Vulnerability to Illness Scale (PVI): Perceived Vulnerability to Illness Scale (α = 0.61) was adapted from measures used in The Common Cold Project (Cohen, 2016) and used to measure participants' perceived likelihood of becoming sick. Participants responded to items such as “I am more likely to get sick when I am stressed”. Responses to the Perceived Vulnerability to Illness Scale items were summed to generate a total PVI score.

Self-Rated Health (SRH): The WHO Self-Rated Health measure (World Health Organization, 2002) was used to assess participants' self-rated health. Participants responded to a single item “In general, how would you rate your health today”.

2.3.3. Subjective well-being (SWB)

Happiness (Happy): The Subjective Happiness Scale (α = 0.87) was used to measure participants' happiness (Lyubomirsky & Lepper, 1999). Participants responded to items on the Subjective Happiness Scale such as “Compared to most of my peers, I consider myself: [not very happy–very happy].” Responses to the Subjective Happiness Scale items were summed to generate a total Happy score.

Positive and Negative Affect Schedule (PANAS): Positive and Negative Affect Schedule was used to measure participants' positive (Pos-A; α = 0.85) and negative affect (Neg-A; α = 0.82; (Watson, Clark, & Tellegen, 1988)). Participants indicated the extent to which they ‘generally feel this way’ in response to each affective word. Responses to positive (Pos-A) and negative affective (Neg-A) words were separately summed to generate positive and negative affect scores.

Satisfaction with Life (SWL): The Satisfaction with Life Scale (α = 0.80) was used to measure participants' life satisfaction (Diener, Emmons, Larsen, & Griffin, 1985). Participants responded to items from the Satisfaction with Life Scale such as “In most ways my life is close to ideal” and “If I could live forever, I would change almost nothing”. Responses to the Satisfaction with Life Scale were summed to generate a total SWL score.

2.4. Statistical analyses

Confirmatory factor analyses and Latent Moderation Structural Equation Modeling (LMS) Analysis used the Mplus software package (version 8.0; Muthén and Muthén, 1998-2017) using maximum likelihood estimation (CFA) and numerical integration (LMS). For all questionnaire-based measures, individual inventory summary scores served as indicators of the respective latent factors (scoring descriptions for each measure are provided above). For behavioral measures (OSpan and SSpan), total recalled memory items for each task using the partial-trial scoring method (described above) served as indicators of the WMC factor. Factor goodness of fit was evaluated using chi-square fit statistics, root mean square error of approximation (RMSEA), standardized root mean squared residual (SRMR), and comparative fit indices (CFI). Non-significant chi-square values, RMSEA values equal to or lower than 0.08, SRMR equal to or lower than 0.08, and CFI above 0.9 generally serve as indications of good fit (Hu & Bentler, 1999; Kline, 2005). All fit indices were considered when determining goodness of fit. Procedures for assessing model fit improvement for LMS described by Maslowsky, Jager, and Hemken (2015) were followed.

Table 1
Correlations between manifest variables.

Variable	1	2	3	4	5	6	7	8	9	10	11	12
1. OSpan	–											
2. SSpan	0.36*	–										
3. C	−0.03	0.10	–									
4. SCS	0.04	0.08	0.68*	–								
5. ER	0.01	0.10	0.24*	0.30*	–							
6. SRH	0.16	0.04	0.13	0.26*	0.14	–						
7. Colds	0.15	0.08	0.01	0.21*	0.17*	0.27*	–					
8. PVI	0.12	0.11	0.20*	0.29*	0.15	0.17*	0.43*	–				
9. SWL	0.09	0.10	0.42*	0.42*	0.35*	0.15	0.05	0.22*	–			
10. PA	0.00	0.06	0.42*	0.43*	0.21*	0.06	0.01	0.14	0.41*	–		
11. NA	0.02	−0.16	−0.25*	−0.31*	−0.36*	−0.06	−0.07	−0.23*	−0.38*	−0.15	–	
12. Happy	0.03	0.13	0.36*	0.40*	0.32*	0.13	0.21*	0.31*	0.61*	0.45*	−0.50*	–

Notes: Colds, PVI, and SRH are scored such that higher scores reflect fewer colds per year, lower perceived vulnerability to illness, and higher self-reported health. OSpan = Operation Span, SSpan = Symmetry Span, C = Conscientiousness, SCS = Self-control Scale, ER = Emotional Reappraisal, SRH = Self-rated Health, Colds = Recent Colds History, PVI = Perceived Vulnerability to Illness, SWL = Satisfaction with Life, PA = Positive Affect, NA = Negative Affect, Happy = Subjective Happiness Scale.

* $p < 0.05$

3. Results

3.1. Descriptive statistics

3.1.1. Correlations between observed indicators

Significant correlations between all indicators of hypothesized factors were observed with the exception of a non-significant trend between PA and NA ($r = 0.15$, $p = 0.08$; see Table 1). See Table 2 for descriptive statistics for each indicator.

3.2. CFA of WMC, self-regulation, health, and SWB

Results of a four-factor CFA measurement model of WMC, Self-regulation, Health and SWB indicated good fit (X^2 [46] = 77.326, $p = 0.005$, RMSEA = 0.065, 90% CI = 0.036–0.091; SRMR = 0.064; CFI = 0.925). In the measurement model, WMC and Self-regulation were not significantly correlated ($r = 0.08$, $p = 0.58$). A significant positive correlation between WMC and Health was observed ($r = 0.32$, $p = 0.03$). In addition, significant positive associations were observed between Self-regulation and Health ($r = 0.43$, $p < 0.001$), Self-regulation and SWB ($r = 0.65$, $p < 0.001$), and Health and SWB ($r = 0.42$, $p < 0.001$; Fig. 2).

Table 2
Descriptive statistics of indicators.

Variable	Mean	SD	Min-Max	Skewness	Kurtosis
OSpan	58.6	12.7	21–75	−0.99	0.28
SSpan	29.9	7.5	9–42	−0.62	−0.26
C	39.2	6.3	17–55	−0.38	0.60
SCS	117.2	16.3	74–172	0.10	0.55
ER	29.6	6.2	9–42	−0.29	0.50
SRH	2.2	1.0	1–5	0.70	0.16
Colds	2.6	1.1	1–5	0.59	−0.46
PVI	9.9	2.9	3–18	0.25	0.19
SWL	25.3	5.1	10–35	−0.39	−0.35
PA	35.6	6.6	16–50	−0.44	0.25
NA	20.1	6.4	10–35	0.45	−0.65
Happy	20.0	4.7	5–28	−0.84	0.87

Notes: OSpan = Operation Span, SSpan = Symmetry Span, C = Conscientiousness, SCS = Self-control Scale, ER = Emotional Reappraisal, SRH = Self-rated Health, Colds = Recent Colds History, PVI = Perceived Vulnerability to Illness, SWL = Satisfaction with Life, PA = Positive Affect, NA = Negative Affect, Happy = Subjective Happiness Scale.

3.3. LMS of WMC and self-regulation

Results of the four-factor CFA measurement model suggested that WMC and Self-regulation were uncorrelated, and thus, contributions of WMC and Self-regulation to Health were unshared. In order to examine whether relationships between WMC, Self-regulation, and Health were interdependent, we conducted a latent moderation analysis following a two-stage estimation procedure for latent moderated structural equation models (Klein & Moosbrugger, 2000; Maslowsky et al., 2015). We first estimated a structural model that did not contain the WMC*Self-regulation latent interaction term (*log-likelihood* = −5044.67). In a second step, we estimated a model that included the latent WMC*Self-regulation interaction term (*log-likelihood* = −5041.27). A chi-square test of differences in the log-likelihood of each model indicated a significant improvement of model fit with the inclusion of the latent WMC*Self-regulation interaction term ($D = 6.796$, $df = 1$, $p = 0.009$; Fig. 3a). In the latent moderation model, a significant negative moderation effect of WMC on the Self-regulation-Health relationship was observed ($\beta = -0.40$, $p = 0.011$). This negative moderation effect was characterized by a significant effect of Self-regulation on Health for individuals -1SD below mean WMC (estimate = 0.90, $p < 0.001$) and no effect of Self-regulation on Health for individuals +1SD above mean WMC (estimate = 0.1, $p = 0.57$; Fig. 3b). See Table 3 for all factor loadings in the measurement model and all regression estimates in the LMS.

4. Discussion

In the current study, we investigated how cognitive control and trait self-regulation relate to individual differences in self-reported physical health and subjective well-being. In addition, we examined whether these relationships were shared, independent, or interdependent. Our results show that physical health is associated with individual differences in both cognitive control and trait self-regulation. For individuals with higher levels of cognitive control, however, the relationship between self-regulation and physical health was diminished (approaching zero at +1SD in WMC). Only self-regulation was associated with individual differences in subjective well-being. Unlike physical health, this relationship was not moderated by individual differences in cognitive control. Overall, our results suggest that cognitive and personological factors may make unique, separable contributions toward positive physical health outcomes in younger adults, and that the role of self-regulation may be magnified for individuals with lower cognitive control ability. Together, these findings advance and complement existing work in an emerging area of research on *differential* epidemiology

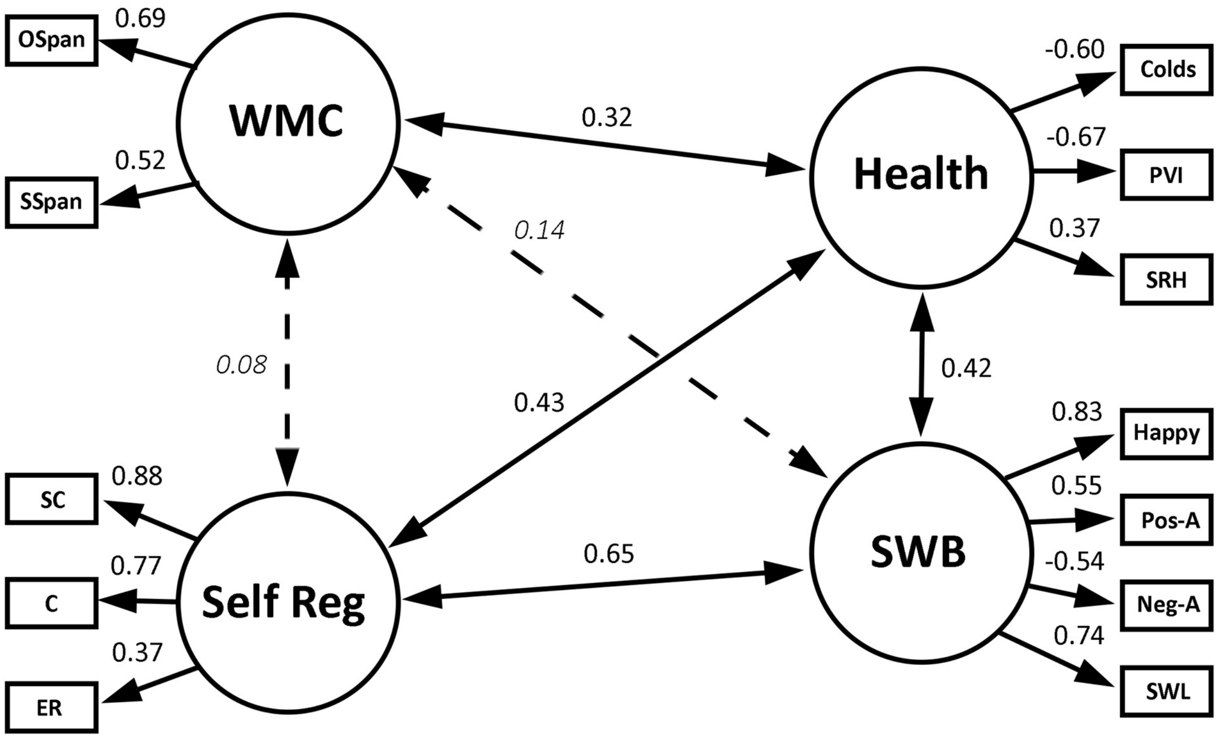

Fig. 2. Four-factor measurement model of WMC, self-regulation, health, and SWB. Significant associations were observed between WMC and Health, Self-Regulation and Health and SWB, and Health and SWB. No significant association was observed between WMC and Self-Regulation or WMC and SWB. All factor loadings are standardized. All estimates reflect standardized covariance (correlations) between factors. WMC = Working Memory Capacity, Self Reg = Self-regulation, Health = Self-rated Physical Health, SWB = Subjective well-being, OSpan = Operation Span, SSpan = Symmetry Span, C = Conscientiousness, SCS = Self-control Scale, ER = Emotional Reappraisal, SRH = Self-rated Health, Colds = Recent Colds History, PVI = Perceived Vulnerability to Illness, SWL = Satisfaction with Life, PA = Positive Affect, NA = Negative Affect, Happy = Subjective Happiness Scale.

(Deary et al., 2011).

Previous epidemiological evidence suggests that both cognitive and personological factors may contribute to health outcomes and mortality risk in middle-aged and older adults (Batty et al., 2007; Deary et al., 2011; Friedman, 2008; Gottfredson & Deary, 2004; Kern & Friedman, 2008; Kiecolt-Glaser et al., 2002; Leon et al., 2009; Sabia et al., 2010; Terracciano et al., 2008). Moreover, markers of these factors in early development (childhood/adolescence) have been shown to predict health and well-being outcomes in later-life (Batty & Deary, 2004; Moffitt et al., 2011; Sabia et al., 2010). Here, we show that these factors may manifest in health and well-being advantages detectable as early as young adulthood (e.g. college students). Exactly how individual

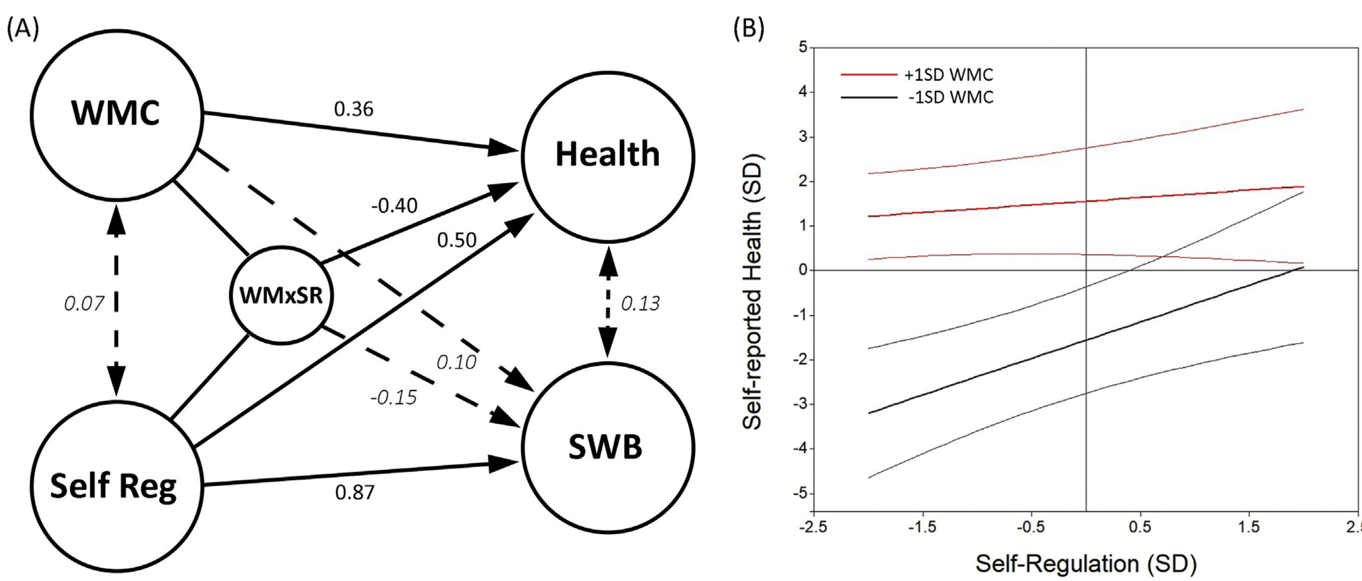

Fig. 3. WMC as a moderator of trait self-regulation & health. (A) A significant moderation effect of WMC on the relationship between Self-Regulation and Health was observed. (B) A significant effect of Self-Regulation on Health was observed for individuals -1SD below mean WMC. No relationship was observed for individuals +1SD above mean WMC. WMC = Working Memory Capacity, Self Reg = Self-regulation, Health = Self-rated Physical Health, SWB = Subjective well-being, WM × SR = WMC × Self Reg latent interaction term.

Table 3
Model factor loadings and regression estimates.

Estimate	Unstandardized	Standardized	Sig.
Measurement model factor loadings			
WMC			
OSpan	8.74	0.69	*
SSpan	3.87	0.52	*
Self-regulation			
SCS	14.27	0.88	*
C	4.78	0.77	*
ER	2.26	0.37	*
Health			
Colds	−0.69	−0.60	*
PVI	−1.98	−0.67	*
SRH	0.36	0.37	*
SWB			
Happy	3.87	0.83	*
Pos-A	3.60	0.55	*
Neg-A	−3.42	−0.54	*
SWL	3.80	0.74	*
Latent moderation structural model			
WMC & self-regulation	–	0.07	–
Health & SWB	–	0.13	–
WMC → Health	–	0.36	*
WMC → SWB	–	0.10	–
Self-regulation → Health	–	0.50	*
Self-regulation → SWB	–	0.87	*
WMC x Self-reg → Health	–	−0.40	*
WMC x Self-reg → SWB	–	−0.15	–

NOTE: * = significant estimates ($p < 0.05$); & = correlation; → = regression estimate; factor means were set to zero and variances set to one. OSpan = Operation Span, SSpan = Symmetry Span, C = Conscientiousness, SCS = Self-control Scale, ER = Emotional Reappraisal, SRH = Self-rated Health, Colds = Recent Colds History, PVI = Perceived Vulnerability to Illness, SWL = Satisfaction with Life, PA = Positive Affect, NA = Negative Affect, Happy = Subjective Happiness Scale.

trajectories in cognitive ability and self-regulation progress throughout young and middle adulthood toward shaping long-term physical health and well-being remains poorly understood and should be a point of focus in future studies.

The results of our latent moderation analysis suggest that if cognitive control were to be affected by contextual or developmental changes (e.g. decrease with increased age), we might expect an increased reliance on established patterns of self-regulation for these individuals toward achieving positive physical health outcomes. Such a pattern of change would be consistent with previous findings showing that indicators of trait self-regulation (e.g. conscientiousness) may increase over the adult lifespan (Roberts & Bogg, 2004). Critically, the moderation effect was observed exclusively for physical health and not subjective well-being, providing a boundary condition that shows the effect has some level of specificity for health outcomes and is not an artifact of subjective rating of each construct.

We interpret this specificity in context of recent self-regulation theories and experimental evidence including temporal self-regulation theory (Hall & Fong, 2007, 2015) and dual systems theory (Hofmann, Friese, & Strack, 2009; Hofmann, Friese, & Wiers, 2008) which point to individual differences in cognitive control as a source of self-regulatory capacity. The prediction of these theories is that higher executive control should facilitate goal maintenance (the ability to keep goals in the focus of attention), successful management of automatic impulses, and long-term planning. The net result of increased self-regulatory capacity should be superior health outcomes.

With respect to the direct effect of WMC on health outcomes, our data are consistent with these views. Recent studies show that individuals with stronger cognitive control exhibit behavior in experimental models of self-regulation that is more in line with self-reported standards (Hofmann, Gschwendner, Friese, Wiers, & Schmitt, 2008) and show greater adherence to intentions to perform healthy behaviors (e.g. exercise; Hall, Zehr, Paulitzki, & Rhodes, 2014). Individuals lower in cognitive control, on the other hand, were shown to behave in a more stereotyped or automatic manner, yielding to impulses and displaying less adherence to healthy behaviors (e.g. eat more potato chips; exhibit a bias toward provocative images; express implicit biases; lower adherence to exercise programs).

The results of our moderation analysis, however, are less in line with the predictions of these theories. The predictions of temporal self-regulation and dual process theories would be for individual differences in cognitive control to potentially magnify the health benefits of trait self-regulation. That is, for individuals who maintain a general orientation toward achieving goals, controlling their behavior, and regulating their emotions, increased cognitive control ability should help translate self-regulatory intentions into behavior (i.e. a positive moderation effect). However, given our study was focused on more distal health outcomes rather than the proximal performance of healthy behaviors, this finding may reflect the interaction of these cognitive and personological factors at a different timescale than what has been shown in experimental models. As such, our findings complement this previous work and may help bridge experimental and epidemiological lines on these topics.

Self-regulation of healthy behavior occurs over timescales from exceedingly brief (e.g. making a momentary choice to withhold an inappropriate action) to months or even years (e.g. losing a significant amount of weight). At the momentary timescale, higher cognitive control may provide the capacity to override potent drives or impulses, activate and enact a sub-goal (e.g. put on a pair of running sneakers), or rapidly weigh the utility of potential choices (i.e. factor in on decision-making processes). Over a longer timescale, however, higher cognitive control may act as more of a buffer against risk factors to poor health, placing a higher premium on well-established patterns of self-regulation for individuals who lack such a buffer. The potential sources of such a buffer may include the ability to strategically constrain the environment to avoid goal conflict and risky behaviors. Individuals higher in cognitive control (a well-established correlate of intelligence/reasoning ability; Conway et al., 2003) may leverage cognitive ability toward such ends, which represents an important area for future research.

Additionally, cognitive ability may either directly influence health outcomes (as a source of top-down self-regulation; Nigg, 2017) or serve as a measurement proxy for socioeconomic advantages conferred over the course of development (e.g., education, access to health care; for competing views on this see Batty et al., 2007). The general health status of younger adults who have been provided such a buffer throughout early development may depend less on self-regulation during younger adulthood than their peers. In this case, we might expect physical health to be less dependent upon the behavioral products of self-regulation at younger ages.

Our study has several limitations. As previously mentioned, our current sample was comprised of younger adults enrolled in a university. Thus, the disparity between individuals of high and low health does not necessarily reflect that of the general population. It is important to note, however, that the range observed in the recent cold history and self-rated health inventories reflected the full range possible in each scale. Second, while distinctions between cognitive and affective well-being have been proposed (Luhmann, Hawkley, Eid, & Cacioppo, 2012), here we modeled markers of each these dimensions of subjective well-being as a single factor. Alternative, more complex, models separating these dimensions did not fit the data better than the model presented here. Our current results also show that individual differences in cognitive control and self-regulation were uncorrelated. This finding is consistent with some studies of working memory and conscientiousness (Waris, Soveri, Lukasik, Lehtonen, & Laine, 2018), but inconsistent with recent studies predicting cognitive ability from facets of personality constructs (Moutafi, Furnham, & Crump, 2006). While the lack of a relationship between cognition and self-regulation may be related to the specific cognitive domain investigated (WMC/

cognitive control/intelligence), use of inventories that support separation of conscientiousness into multiple facets in future studies would help interpret this finding. Finally, it is important to note that the measures of trait self-regulation and physical health included in this study rely on self-report and, thus, must be taken to reflect subjective ratings of each construct. Future studies should examine whether the relationships observed remain under conditions of objective assessment of physical health and self-regulatory behavior.

5. Conclusions

Our current findings suggest that the positive health benefits of trait self-regulation and higher-order cognitive ability, often observed in epidemiological studies, are observable as early as young adulthood. In addition, our findings suggest that well-established patterns of self-regulation may be increasingly important for individuals lower in higher-order cognitive ability, which may be of translational significance for health interventions involving populations with cognitive/executive deficits (e.g., older adults, individuals with traumatic brain injury, individuals with neuropathology). Finally, our findings highlight the value of studying the interplay between cognitive and personological factors in predicting health outcomes.

Acknowledgements

This study was supported by the National Institute on Aging of the National Institutes of Health under award number K99AG056670. The content is solely the responsibility of the authors and does not necessarily represent the official views of these granting agencies.

References

Bandura, A. (1991). Social cognitive theory of self-regulation. *Organizational Behavior and Human Decision Processes, 50*(2), 248–287. https://doi.org/10.1016/0749-5978(91)90022-L.

Batty, G. D., & Deary, I. J. (2004). Early life intelligence and adult health. *BMJ, 329*(7466), 585–586. https://doi.org/10.1136/bmj.329.7466.585.

Batty, G. D., Deary, I. J., & Gottfredson, L. S. (2007, April 1). *Premorbid (early life) IQ and later mortality risk: Systematic review. Annals of epidemiology*Elsevierhttps://doi.org/10.1016/j.annepidem.2006.07.010.

Baumeister, R. F., & Heatherton, T. F. (1996). Self-regulation failure: An overview. *Source: Psychological Inquiry, 7*(1), 1–15. Retrieved from http://www.jstor.org/stable/1449145.

Bogg, T., & Roberts, B. W. (2004). Conscientiousness and health-related behaviors: A meta-analysis of the leading behavioral contributors to mortality. *Psychological Bulletin, 130*(6), 887.

Bogg, T., & Slatcher, R. B. (2015). Activity mediates conscientiousness' relationship to diurnal cortisol slope in a national sample. *Health Psychology, 34*(12), 1195–1199. https://doi.org/10.1037/hea0000243.

Cacioppo, J. T., & Berntson, G. G. (2012). The brain, homeostasis, and health: Balancing demands of the internal and external milieu. *The Oxford handbook of health psychology*Oxford University Presshttps://doi.org/10.1093/oxfordhb/9780195342819.013.0006.

Carver, C. S., & Scheier, M. F. (1982). Control theory: A useful conceptual framework for personality-social, clinical, and health psychology. *Psychological Bulletin, 92*(1), 111–135. https://doi.org/10.1037/0033-2909.92.1.111.

Cohen, S. (2016). *The common cold project: 5 studies of behavior, biology, and the common cold.* Inter-university Consortium for Political and Social Researchhttps://doi.org/10.3886/ICPSR36365.v1 distributor.

Conway, A. R. A., Kane, M. J., Bunting, M. F., Hambrick, D. Z., Wilhelm, O., & Engle, R. W. (2005). Working memory span tasks: A methodological review and user's guide. *Psychonomic Bulletin & Review, 12*(5), 769–786. https://doi.org/10.3758/BF03196772.

Conway, A. R. A., Kane, M. J., & Engle, R. W. (2003). Working memory capacity and its relation to general intelligence. *Trends in Cognitive Sciences, 7*(12), 547–552. https://doi.org/10.1016/j.tics.2003.10.005.

Costa, P. T., & McCrae, R. R. (1992). *Revised NEO personality inventory and NEO five-factor inventory: Professional manual.* Odessa, FL: Psychological Assessment Resources. Inc.

Deary, I. J., Weiss, A., & Batty, G. D. (2011). Intelligence and personality as predictors of illness and death. *Psychological Science in the Public Interest, 11*(2), 53–79. https://doi.org/10.1177/1529100610387081.

DeSteno, D., Gross, J. J., & Kubzansky, L. (2013). Affective science and health: The importance of emotion and emotion regulation. *Health Psychology, 32*(5), 474–486. https://doi.org/10.1037/a0030259.

Diener, E., Emmons, R. A., Larsen, R. J., & Griffin, S. (1985). The satisfaction with life scale. *Journal of Personality Assessment, 49*(1), 71–75. https://doi.org/10.1207/s15327752jpa4901_13.

Friedman, H. S. (2008, July 1). *The multiple linkages of personality and disease. Brain, Behavior, and Immunity.* Academic Presshttps://doi.org/10.1016/j.bbi.2007.09.004.

Gottfredson, L. S., & Deary, I. J. (2004). Intelligence predicts health and longevity, but why? *Current Directions in Psychological Science, 13*(1), 1–4. https://doi.org/10.1111/j.0963-7214.2004.01301001.x.

Gross, J. J., & John, O. P. (2003). Individual differences in two emotion regulation processes: Implications for affect, relationships, and well-being. *Journal of Personality and Social Psychology, 85*(2), 348–362. https://doi.org/10.1037/0022-3514.85.2.348.

Gross, J. J., & Muñoz, R. F. (1995). Emotion regulation and mental health. *Clinical Psychology: Science and Practice, 2*(2), 151–164. https://doi.org/10.1111/j.1468-2850.1995.tb00036.x.

Hall, P. A., & Fong, G. T. (2007). Temporal self-regulation theory: A model for individual health behavior. *Health Psychology Review, 1*(1), 6–52. https://doi.org/10.1080/17437190701492437.

Hall, P. A., & Fong, G. T. (2015). Temporal self-regulation theory: A neurobiologically informed model for physical activity behavior. *Frontiers in Human Neuroscience, 9*, 117. https://doi.org/10.3389/fnhum.2015.00117.

Hall, P. A., Fong, G. T., Epp, L. J., & Elias, L. J. (2008). Executive function moderates the intention-behavior link for physical activity and dietary behavior. *Psychology & Health, 23*(3), 309–326. https://doi.org/10.1080/14768320701212099.

Hall, P. A., Zehr, C., Paulitzki, J., & Rhodes, R. (2014). Implementation intentions for physical activity behavior in older adult women: An examination of executive function as a moderator of treatment effects. *Annals of Behavioral Medicine, 48*(1), 130–136. https://doi.org/10.1007/s12160-013-9582-7.

Hofmann, W., Friese, M., & Roefs, A. (2009). Three ways to resist temptation: The independent contributions of executive attention, inhibitory control, and affect regulation to the impulse control of eating behavior. *Journal of Experimental Social Psychology, 45*(2), 431–435. https://doi.org/10.1016/j.jesp.2008.09.013.

Hofmann, W., Friese, M., & Strack, F. (2009). Impulse and self-control from a dual-systems perspective. *Perspectives on Psychological Science: A Journal of the Association for Psychological Science, 4*(2), 162–176. https://doi.org/10.1111/j.1745-6924.2009.01116.x.

Hofmann, W., Friese, M., & Wiers, R. W. (2008). Impulsive versus reflective influences on health behavior: A theoretical framework and empirical review. *Health Psychology Review, 2*(2), 111–137. https://doi.org/10.1080/17437190802617668.

Hofmann, W., Gschwendner, T., Friese, M., Wiers, R. W., & Schmitt, M. (2008). Working memory capacity and self-regulatory behavior: Toward an individual differences perspective on behavior determination by automatic versus controlled processes. *Journal of Personality and Social Psychology, 95*(4), 962–977. https://doi.org/10.1037/a0012705.

Hofmann, W., Schmeichel, B. J., & Baddeley, A. D. (2012). Executive functions and self-regulation. *Trends in Cognitive Sciences, 16*(3), 174–180. https://doi.org/10.1016/J.TICS.2012.01.006.

Hu, L., & Bentler, P. M. (1999). Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. *Structural Equation Modeling: A Multidisciplinary Journal, 6*(1), 1–55. https://doi.org/10.1080/10705519909540118.

Kane, M. J., Conway, A. R. A., Hambrick, D. Z., & Engle, R. W. (2007). *Variation in working memory capacity as variation in executive attention and control.* Oxford University Press.

Kane, M. J., & Engle, R. W. (2002). The role of prefrontal cortex in working-memory capacity, executive attention, and general fluid intelligence: An individual-differences perspective. *Psychonomic Bulletin & Review, 9*(4), 637–671. https://doi.org/10.3758/BF03196323.

Kane, M. J., Hambrick, D. Z., Tuholski, S. W., Wilhelm, O., Payne, T. W., & Engle, R. W. (2004). The generality of working memory capacity: A latent-variable approach to verbal and visuospatial memory span and reasoning. *Journal of Experimental Psychology: General, 133*(2), 189–217. https://doi.org/10.1037/0096-3445.133.2.189.

Kern, M. L., & Friedman, H. S. (2008). Do conscientious individuals live longer? A quantitative review. *Health Psychology, 27*(5), 505–512. https://doi.org/10.1037/0278-6133.27.5.505.

Kiecolt-Glaser, J. K., McGuire, L., Robles, T. F., & Glaser, R. (2002). Emotions, morbidity, and mortality: New perspectives from psychoneuroimmunology. *Annual Review of Psychology, 53*(1), 83–107. https://doi.org/10.1146/annurev.psych.53.100901.135217.

Klein, A., & Moosbrugger, H. (2000). Maximum likelihood estimation of latent interaction effects with the LMS method. *Psychometrika, 65*(4), 457–474. https://doi.org/10.1007/BF02296338.

Kline, B.,. R. (2005). *Principles and practice of structural equation modeling* (2nd ed.). Guilford Press.

Kyllonen, P. C., & Christal, R. E. (1990). Reasoning ability is (little more than) working-memory capacity?!. *Intelligence, 14*(4), 389–433. https://doi.org/10.1016/S0160-2896(05)80012-1.

Leon, D. A., Lawlor, D. A., Clark, H., Batty, G. D., & Macintyre, S. (2009). The association of childhood intelligence with mortality risk from adolescence to middle age: Findings from the Aberdeen children of the 1950s cohort study. *Intelligence, 37*(6), 520–528. https://doi.org/10.1016/J.INTELL.2008.11.004.

Lodi-Smith, J., Jackson, J., Bogg, T., Walton, K., Wood, D., Harms, P., & Roberts, B. W. (2010). Mechanisms of health: Education and health-related behaviours partially mediate the relationship between conscientiousness and self-reported physical health. *Psychology and Health, 25*(3), 305–319. https://doi.org/10.1080/08870440902736964.

Luhmann, M., Hawkley, L. C., Eid, M., & Cacioppo, J. T. (2012). Time frames and the distinction between affective and cognitive well-being. *Journal of Research in Personality, 46*(4), 431–441. https://doi.org/10.1016/J.JRP.2012.04.004.

Lyubomirsky, S., & Lepper, H. S. (1999). A measure of subjective happiness: Preliminary reliability and construct validation. *Social Indicators Research, 46*(2), 137–155. https://doi.org/10.1023/A:1006824100041.

Martin, L. R., Friedman, H. S., & Schwartz, J. E. (2007). Personality and mortality risk across the life span: The importance of conscientiousness as a biopsychosocial attribute. *Health Psychology, 26*(4), 428–436. https://doi.org/10.1037/0278-6133.26.4.428.

Maslowsky, J., Jager, J., & Hemken, D. (2015). Estimating and interpreting latent variable interactions. *International Journal of Behavioral Development, 39*(1), 87–96. https://doi.org/10.1177/0165025414552301.

Mauss, I. B., & Gross, J. J. (2004). Emotion suppression and cardiovascular disease: Is hiding feelings bad for your heart? *Emotional expression and health: Advances in theory, assessment and clinical applications* (pp. 61–81). New York, NY, US: Brunner-Routledge.

McAuley, E., Mullen, S. P., Szabo, A. N., White, S. M., Wójcicki, T. R., Mailey, E. L., ... Kramer, A. F. (2011). Self-regulatory processes and exercise adherence in older adults: Executive function and self-efficacy effects. *American Journal of Preventive Medicine, 41*(3), 284–290. https://doi.org/10.1016/j.amepre.2011.04.014.

McVay, J. C., & Kane, M. J. (2009). Conducting the train of thought: Working memory capacity, goal neglect, and mind wandering in an executive-control task. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 35*(1), 196–204. https://doi.org/10.1037/a0014104.

Moffitt, T. E., Arseneault, L., Belsky, D., Dickson, N., Hancox, R. J., Harrington, H., ... Caspi, A. (2011). A gradient of childhood self-control predicts health, wealth, and public safety. *Proceedings of the National Academy of Sciences of the United States of America, 108*(7), 2693–2698. https://doi.org/10.1073/pnas.1010076108.

Moutafi, J., Furnham, A., & Crump, J. (2006). What facets of openness and conscientiousness predict fluid intelligence score? *Learning and Individual Differences, 16*(1), 31–42. https://doi.org/10.1016/j.lindif.2005.06.003.

Moutafi, J., Furnham, A., & Paltiel, L. (2004). Why is conscientiousness negatively correlated with intelligence? *Personality and Individual Differences, 37*(5), 1013–1022. https://doi.org/10.1016/j.paid.2003.11.010.

Moutafi, J., Furnham, A., & Paltiel, L. (2005). Can personality factors predict intelligence? *Personality and Individual Differences, 38*(5), 1021–1033. https://doi.org/10.1016/j.paid.2004.06.023.

Muthén, L. K., & Muthén, B. O. (1998-2017). *Mplus User's Guide. Eighth Edition.* Los Angeles, CA: Muthén & Muthén.

Nigg, J. T. (2017). Annual research review: On the relations among self-regulation, self-control, executive functioning, effortful control, cognitive control, impulsivity, risk-taking, and inhibition for developmental psychopathology. *Journal of Child Psychology and Psychiatry, 58*(4), 361–383. https://doi.org/10.1111/jcpp.12675.

Redick, T. S. (2013). Cognitive control in context: Working memory capacity and proactive control. *ACTPSY,* 145. https://doi.org/10.1016/j.actpsy.2013.10.010.

Redick, T. S., Broadway, J. M., Meier, M. E., Kuriakose, P. S., Unsworth, N., Kane, M. J., & Engle, R. W. (2012). Measuring working memory capacity with automated complex span tasks. *WMC Tasks European Journalof Psychological Assessment, 28*(3), 164–171. https://doi.org/10.1027/1015-5759/a000123.

Roberts, B. W., & Bogg, T. (2004). A longitudinal study of the relationships between conscientiousness and the social- environmental factors and substance-use behaviors that influence health. *Journal of Personality, 72*(2), 325–354. https://doi.org/10.1111/j.0022-3506.2004.00264.x.

Roberts, B. W., Walton, K. E., & Bogg, T. (2005). Conscientiousness and health across the life course. *Review of general psychology*Educational Publishing Foundationhttps://doi.org/10.1037/1089-2680.9.2.156.

Sabia, S., Guéguen, A., Marmot, M. G., Shipley, M. J., Ankri, J., & Singh-Manoux, A. (2010). Does cognition predict mortality in midlife? Results from the Whitehall II cohort study. *Neurobiology of Aging, 31*(4), 688–695. https://doi.org/10.1016/j.neurobiolaging.2008.05.007.

Tangney, J. P., Baumeister, R. F., & Boone, A. L. (2004). High self-control predicts good adjustment, less pathology, better grades, and interpersonal success. *Journal of Personality, 72*(2), 271–324.

Terracciano, A., Löckenhoff, C. E., Zonderman, A. B., Ferrucci, L., & Costa, P. T. (2008). Personality predictors of longevity: Activity, emotional stability, and conscientiousness. *Psychosomatic Medicine, 70*(6), 621–627. https://doi.org/10.1097/PSY.0b013e31817b9371.

Turner, M. L., & Engle, R. W. (1986). Working memory capacity. *Proceedings of the human factors and ergonomics society annual meeting. 30 (13)*. *Proceedings of the human factors and ergonomics society annual meeting* (pp. 1273–1277). . https://doi.org/10.1177/154193128603001307.

Unsworth, N., Redick, T. S., Spillers, G. J., & Brewer, G. A. (2012). Variation in working memory capacity and cognitive control: Goal maintenance and microadjustments of control. *The Quarterly Journal of Experimental Psychology, 65*(2), 326–355. https://doi.org/10.1080/17470218.2011.597865.

Waris, O., Soveri, A., Lukasik, K. M., Lehtonen, M., & Laine, M. (2018). Working memory and the big five. *Personality and Individual Differences, 130*, 26–35. https://doi.org/10.1016/J.PAID.2018.03.027.

Watson, D., Clark, L. A., & Tellegen, A. (1988). Development and validation of brief measures of positive and negative affect: The PANAS scales. *Journal of Personality and Social Psychology, 54*(6), 1063–1070. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/3397865.

World Health Organization (2002). *The world health report 2002: Reducing risks, promoting healthy life.* World Health Organization.