J Behav Med (2014) 37:81–93
DOI 10.1007/s10865-012-9470-9

Self-control and its relation to emotions and psychobiology: evidence from a Day Reconstruction Method study

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Received: February 21, 2012 / Accepted: November 1, 2012 / Published online: November 18, 2012

Abstract This study aimed to ascertain whether self-control predicts heart rate, heart rate variability, and the cortisol slope, and to determine whether health behaviors and affect patterns mediate these relationships. A sample of 198 adults completed the Self-Control Scale (Tangney in J Pers 72:271–322, 2004), and reported their exercise levels, and cigarette and alcohol use. Participants provided a complete account of their emotional experiences over a full day, along with morning and evening salivary cortisol samples and a continuous measure of cardiovascular activity on the same day. High trait self-control predicted low resting heart rate, high heart rate variability, and a steep cortisol slope. Those with high self-control displayed stable emotional patterns which explained the link between self-control and the cortisol slope. The self-controlled smoked less and this explained their low heart rates. The capacity to sustain stable patterns of affect across diverse contexts may be an important pathway through which self-control relates to psychophysiological functioning and potentially health.

Keywords Personality · Self-control · Cortisol · Heart rate · Heart rate variability · Affect variability · Day Reconstruction Method

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Introduction

There is now considerable evidence that personality is associated with health and longevity. In particular, recent research suggests that self-controlled children grow up to be healthy adults, and emotionally stable adults experience enhanced longevity (Moffitt et al., 2011; Terracciano et al., 2008). However, the psychological mechanisms and biological intermediaries that explain these links remain largely undocumented (Smith, 2006). To address this issue, in this study we tested the effects of trait self-control on psychobiological functioning, including the contribution of emotional patterns and health behaviors to explaining the psychobiological outcomes. Specifically, we examined measures of cardiovascular (i.e. heart rate and heart rate variability) and neuroendocrine (i.e. the diurnal cortisol slope) functioning and predicted that high levels of self-control would be associated with favorable patterns of psychobiological functioning.

Moreover, we anticipated that the self-controlled participants would behave in healthier ways, specifically exercising more and being less likely to drink alcohol or to smoke, as compared to people with lower trait self-control. We hypothesized that these healthy behaviors would, at least in part, explain a link between self-control and physiological functioning. Furthermore, cross-sectional and experimental intervention studies have demonstrated that high self-control is associated with emotional control and stability (e.g. Tangney et al., 2004; Oaten & Cheng, 2006). We therefore tested the hypothesis that high levels of trait self-control would reduce variability in emotional state. We reasoned that a trend toward stable patterns of affect may help explain the relationship between high self-control and adaptive patterns of cardiovascular and neuroendocrine functioning.

Self-control, health behavior and emotion

Personality traits are relatively stable dimensions of individual differences in cognitive, socioemotional and behavioral patterns. Early research aiming to evaluate the link between personality and health demonstrated that personality traits predict future health behaviors, well-being, and self-rated health (Hampson et al., 2006). However, relying on self-reported subjective and behavioral outcome measures to establish a link between personality and health can be problematic. This is largely because such self-report measures may reflect the same methodological variance as personality. Thus, people who say good things about their personality may also say good things about their health, but that could indicate a positive style of answering questions rather than objective differences in health. Furthermore, personality and social factors might influence perceptions and hence ratings of health without having any impact on objective physical health.

Recent evidence has, however, begun to reveal links between personality and objective physiological measures of cardiovascular disease and longevity (Friedman, 2008). Biological markers of healthy functioning and mortality rates have been shown to be predicted by personality traits such as childhood self-control (Moffitt et al., 2011; Martin et al., 2007) and dependability (Deary et al., 2008). The capacity to exert self-control is a remarkably adaptive trait that allows people to manage their own thoughts, impulses, emotional states, and behaviors. Inadequate self-control can contribute to disinhibited behavior patterns and can reduce the ability to stay on task, pursue goals, delay gratification, and follow socially prescribed rules (e.g., Baumeister et al., 2007). The pathways connecting poor self-control to poor health are complex and are likely to involve multiple psychological and biological channels (Smith, 2006). Our investigation focused on possible pathways involving emotional stability and health behaviors.

In the health domain, previous research has linked poor self-control to smoking, substance abuse, problem drinking, overeating patterns, and sexually impulsive behaviour (Moffitt et al., 2011). These behaviors, in turn, are bad for health. So we predicted that low self-control would be associated with more smoking and drinking, less exercise, and that these behaviors would contribute to poorer physical health.

Another possible route linking self-control to health involves emotional stability. Prior work has provided some evidence linking high levels of self-control to high emotional stability ($r = 0.5$; Tangney et al., 2004). Improvements in self-control brought about by structured interventions designed to enhance self-control have sometimes led to an increase in emotional control (Oaten & Cheng, 2006). Meanwhile, there is some evidence that a lack of emotional control is predictive of negative health outcomes (e.g. Suls & Bunde, 2005). Accordingly, we hypothesized that self-control may promote health by regulating and stabilizing emotion.

There are several ways that high self-control could reduce fluctuations in negative affect and possibly stabilize positive affect (e.g. Larsen, 2000). First, the regulation of affect has been compared to the operation of a thermostat where discrepancies from one's favoured 'set-point' are monitored and noted. Strategies such as selecting certain situations, distracting oneself or concentrating on an alternative can then be implemented to return one's emotional state to its preferred level (Chow et al., 2005; Gross & Thompson, 2007). Second, people with high self-control may be less likely than others to experience wide fluctuations in affect. This is because the highly self-controlled are competent in organizing and planning activities, problem solving, self-presentation, active coping, controlling thoughts, and persistently engaging with tasks, as well as being able to regulate their own emotional states (Baumeister et al., 2007). Third, the highly self-controlled almost by definition have fewer experiences than other people of self-control failure. Such failures can bring surges of negative affect, because they involve doing things that violate personal or societal standards for behavior, thereby bringing negative consequences such as guilt, regret, and interpersonal conflict (Tice et al., 2001). Whilst negative emotional feedback is functional in that it serves as a deterrent for future self-defeating behavior (Baumeister et al., 2007), those with poor self-control may avoid such feelings by seeking out transient immediate pleasures that boost positive feelings temporarily (Tice et al., 2001; Oaten & Cheng, 2005). A pervasive pattern of self-control failure and blocking out the ensuing negative feelings through momentarily effective methods seems an unlikely recipe for a long, healthy life.

Taken together, the evidence suggests that low levels of self-control and poor management of self-regulatory resources can lead to more changeable patterns of affect. Intraindividual variability in affect has been demonstrated to be a stable trait (Eid & Diener, 1999). Low variability (high stability) of emotion is thought to reflect successful maintenance of psychological functioning, good personality integration, and high ego strength. Several studies have linked diminished psychosocial resources to greater variability in affect (Kuppens et al., 2007). We suggest that diminished intrapsychic resources such as self-control could have a substantial effect on patterns of emotion which may in turn influence psychophysiological processes (e.g. neuroendocrine, immune, inflammatory, and cardiovascular functioning) and health (Gallo et al., 2005).

Self-control and psychobiological functioning

Examining objectively measured psychobiological variables may assist in specifying the mechanisms that connect self-control, affect, and health (Martin et al., 2007). For instance, recent research has identified heart rate variability, a reliable predictor of cardiovascular morbidity and mortality, as a potential physiological index of a person's trait capacity to inhibit prepotent responses. Baseline heart rate variability has been shown to predict how long participants tend to persist on an unsolvable anagram task (Reynard et al., 2011). Furthermore, heart rate variability appears to vary with self-regulatory effort, particularly efforts directed at emotional control (Segerstrom & Nes, 2007; Appelhans & Luecken, 2006; Geisler & Kubiak, 2009). Thus, it is likely that both between and within-person variation in the self-regulatory abilities are indexed by the interaction of sympathetic and parasympathetic systems, as evidenced by measures of heart rate variability (Geisler & Kubiak, 2009).

Self-regulatory capacities are possibly linked to heart rate variability as a result of the colocalization of autonomic and self-control systems in the brain (Segerstrom & Nes, 2007). Specifically, the central autonomic network overlaps considerably with neural areas involved in self-control such as the medial prefrontal cortex, anterior cingulate, and amygdala (Appelhans & Luecken, 2006). This network activates the vagus nerve which influences cardiovascular activity. Vagal parasympathetic activity can be indexed by the beat-to-beat variation in heart rate, with the high frequency component of this variability gauging the most rapid changes in heart rate (Lane et al., 2009). This quick modulation of heart rate acts as potentially the purest metric of cardiac vagal tone. However, the high frequency range of the heart rate variability spectrum has shown correlations of 0.9 and above with other measures such as the standard deviation of inter-beat-intervals, calling into question the added value of such metrics in distinguishing self-regulatory influences (Allen et al., 2007). In general, the broad set of measures of heart rate variability commonly utilized by researchers appear to correlate very strongly ($r = 0.7$–0.97). For instance, the root mean square of differences between inter-beat-intervals and the standard deviation of inter-beat-intervals have demonstrated correlations of 0.93 at rest and 0.83 during mental arithmetic (Allen et al., 2007).

As in the case of heart rate variability, low heart rate may reflect the activity of the cortical control centres through which self-control operates. Prospective studies have linked high (fast) heart rate to hypertension in young people and to myocardial infarction and mortality in older adults (e.g. Palatini et al., 2006). Hence it is plausible that the health benefits of good self-control could be mediated by low heart rate. We therefore hypothesized that self-control may engage the vagus nerve, putting a brake on heart rate and increasing heart rate variability.

In addition to linkages between self-control and cardiovascular activity, recent research suggests that high levels of self-control may be related to adaptive patterns of neuroendocrine functioning (Taylor et al., 2008; Urry et al., 2006). In terms of neuroendocrine biomarkers, there is particularly strong evidence linking flat diurnal cortisol slopes with adverse health outcomes (e.g. cancer, fatigue, post-traumatic distress) and early mortality (e.g. Saxbe, 2008). Cortisol levels peak approximately 30 min after waking and then decline across the day, but they decline faster for some people than for others. People with flat cortisol slopes show a slow rate of decline in cortisol output over the day with evening levels not differing substantially from morning levels. For people with the more typical steep cortisol slope, cortisol output declines quickly from elevated morning levels to substantially reduced evening levels.

High levels of activity in the prefrontal cortex, a brain area heavily implicated in self-control, during an emotion regulation task have been shown to predict a steep cortisol slope over the course of a day (Urry et al., 2006; Cunningham-Bussel et al., 2009; Taylor et al., 2008). The activity of the prefrontal cortex may dampen amygdala reactivity to emotive stimuli and in this way prevent high levels of emotional reactivity and the associated cortisol output. Hence another prediction would be that those low in self-control may have difficulty controlling their emotions which may in turn lead to a flat cortisol slope. In this way, the rate of decline in cortisol could help mediate some of the health impact of self-control.

The present investigation

The current study had several goals. First, we sought to show that self-control would have positive relationships to health markers, specifically that high self-control would predict high variability of heart rate, low heart rate, and a steep cortisol slope. Second, we looked for mediation by health behaviors and emotional patterns. We included participant's reports of exercise and cigarette and alcohol consumption. To measure affect we used the Day Reconstruction Method (Kahneman et al., 2004), a survey that incorporates memory priming techniques to assist in the recall of experiences of the previous day. We hypothesized that a link between self-control and the psychobiological process examined would be mediated principally by health behaviors and less volatile patterns of affect.

Method

Study participants

Data were collected from 204 participants, recruited via email from the Trinity College Dublin student population. Participants were requested to take part in the study on three consecutive days: to complete baseline physiological tests and receive instruction on the study procedures (day 1), to provide ambulatory monitoring data during a normal working day (day 2), and to complete an online questionnaire which included health behaviors and a day reconstruction measure (day 3). The day reconstruction survey requested that participants recount the activities and feelings of a seamless series of episodes from the previous day which corresponded with the day when participants provided psychophysiological data. Those who took part were compensated with either research credits or a cash incentive of 25 euro. The drop-out rate was 3 % (6 participants), leaving 198 participants. The demographic characteristics of participants are detailed in Table 1. Cortisol samples were provided by 186 participants, 159 of which were fully usable, with the remaining participants removed due to an incomplete sampling diary, or missing, inappropriately timed, or unanalyzable samples. All participants provided resting heart rate data and 186 participants provided fully usable ambulatory cardiovascular activity data with the remaining 12 participants removed due to the presence of excessive artifactual measurement error in their heart rate and heart rate variability data (e.g. excessive number of outlier measurements, repeated loss of signal). Each participant received verbal and written information detailing what the study entailed and gave informed consent. The study was approved by the Trinity College Dublin, School of Psychology Research Ethics Committee.

Measures

Ambulatory measurement of heart rate

Heart rate was measured with the Suunto Memory Belt, a lightweight (61 g) heartbeat interval recorder, worn around the chest, with a capacity to record 200,000 beat-to-beat intervals (Suunto memory belt, Suunto Oy, Vantaa, Finland). This commercially available heartbeat interval recorder has been shown to align closely with measurements from the 1,000 Hz 3-lead ECG BIOPAC MP35 data acquisition unit (Biopac Systems, Santa Barbara, CA) (Daly et al., 2010). The research nurses instructed participants on how to apply electrode gel to the heartbeat

Table 1 Descriptive statistics for self-control levels, demographic characteristics, health behaviors, affect levels, and biological variables

Variable	N	Min	Max	M/%	SD
Self-Control Scale score	198	18	59	39.56	8.45
Demographics					
Age	198	18	49	23.39	6.26
Female (%)	198	0	1	66 %	
Father's education[a]	198	1	4	3.41	0.88
Health behavior					
Smoking[b]	198	1	6	1.28	0.8
Exercise frequency[c]	198	1	5	3.29	1.32
Alcohol consumption on study day (%)	198	0	1	27 %	
Emotion					
Positive affect	194	0.18	5.55	3.57	0.8
Negative affect	187	0.00	3.88	1.43	0.82
Affect variability	191	0.10	4.56	2.07	0.7
Biological variables					
Body mass index (kg/m^2)	198	13.5	45.2	23.22	3.9
Resting heart rate (bpm)	198	43	115.00	74.27	11.9
Ambulatory heart rate (bpm)	186	63.6	106.3	82.26	8.74
SDNN[d]	186	66.65	343.73	142.14	41.64
Cortisol slope (magnitude of hourly decline in μg/dL)	159	−0.05	0.18	0.061	0.037

[a] From education 1 = primary education, to 4 = third level/university

[b] From 1 = 0 cigarettes per day, 6 = 31 or more cigarettes per day

[c] From 1 = never, to 5 = 4 or more times per week

[d] Standard deviation of inter-beat-intervals

recorder and the operating procedures for the device. Outlier and artifactual readings were isolated and removed from HR recordings prior to analysis. Outlier measurements were defined as measurements of heart rate outside the range of 40–150 beats/min (Daly et al., 2010) and accounted for less than 1 % of the data. The Kubios heart rate variability analysis package (Biosignal Analysis and Medical Imaging Research Group, Kuopio, Finland) was used to produce indices of heart rate (M = 82.3, SD = 8.7) and heart rate variability (standard deviation for the mean value of the time between heart beats) (M = 142.1, SD = 41.6), as shown in Table 1. Resting heart rate (M = 74.3, SD = 11.9) was also assessed using a professional blood pressure monitor when the participant was sitting quietly on a chair during the initial day of medical testing.

Salivary cortisol measurement

On the first day of the study the research nurses provided each participant with detailed verbal and written instructions on the saliva collection procedures. Salivary cortisol samples were collected using the Salivette sampling device (Sarstedt, 51582 Numbrecht, Germany); a centrifuge tube containing a sterile cylindrical cotton wool swab. For this study participants provided four saliva samples: two samples at 30 min post waking, and two 12 h after waking up. Participants were requested not to brush/floss their teeth, smoke, eat, or drink beverages (water was permitted up to 5 min prior to sampling), during the 30 min prior to saliva collection. They were asked to place each cotton swab in their mouth for at least 45 s and then place it in the centrifuge tube.

Due to the importance of accurately assessing the post-waking cortisol peak, participants were provided with a saliva sample collection diary which they were instructed to complete immediately upon waking. In this diary participants noted their waking time and added 30 min to note the exact time that the two samples would need to be collected. Participants were told to try their utmost to adhere to the allotted schedule but that if this was not possible then it was important to accurately report the time the sample was provided. Of the 186 participants who provided cortisol samples, six provided unusable samples, twelve failed to complete the diary and nine recorded times which were greater than 10 min before or after the expected peak-cortisol time and were not included in the cortisol analyses. The remaining 159 participants were deemed to be compliant with the salivary cortisol protocol, providing the 30 min samples approximately a minute and a half prior to the allotted time on average (M = −1.4, SD = 2.6).

Samples were returned to the laboratory the next day and stored at room temperature for a maximum of 1 week before being centrifuged and frozen at −80 °C. The average cortisol level of the saliva samples at 30 min after waking and at 12 h post-waking was computed for each participant. The average values for these samples were used to calculate the hourly decline in cortisol levels from morning to evening, with larger values indicating a more pronounced rate of decline over the course of the day (M = 0.061, SD = 0.037).

Self-control measure

The brief *Self-Control Scale* (Tangney et al., 2004) consists of 13 statements, rated on a 5 point scale from 1 (not at all like me) to 5 (very much like me). The 13 items are worded such that endorsement of 9 items is indicative of a reduced capacity for self-control (e.g. "I have a hard time breaking bad habits.") and an enhanced capacity for the other 4 items (e.g. "I am good at resisting temptation."), as detailed in "Appendix". The range of possible scores on the scale is 13–65 with higher scores signifying better self-control. The average score on the Self-Control Scale was 39.6 (SD = 8.45) with scores ranging from 18 to 59 and the scale showed a high degrîee of reliability (Cronbach's alpha = 0.83). In support of the validity and reliability of the Self-Control Scale, the scale has been shown to be predictive of more appropriate emotional responding, superior interpersonal skills and adjustment, better grade point averages, and has demonstrated high internal consistency and test–retest reliability (Tangney et al., 2004).

Health related variables

As part of an online questionnaire completed on the third day of the study participants endorsed items relating to their health behavior. Participants rated how often they engage in exercise (from 1 = never, to 5 = 4 or more times per week), how many cigarettes they smoked daily (from 1 = none, to 6 = over 30), and if they consumed alcohol on the day they provided affect and psychophysiological data. Participants exercised on average 2–4 times per month (M = 3.29, SD = 1.32), approximately 13 % of the sample was current smokers, and 27 % drank alcohol on the monitoring day. Trained research nurses measured each participant's body mass index (BMI) (M = 23.22, SD = 3.9), as shown in Table 1.

Assessment of affect

On the day after completion of the ambulatory procedures, participants returned the relevant data collection devices and completed a computer-assisted day reconstruction survey. The online survey follows a fixed format where participants recall the entire previous day from waking to sleep. The day is separated into morning, afternoon, and evening stages and subsequently each stage is broken down into a series of 'episodes'. Episodes are between 20 min and 2 h and participants provide episode-by-episode information about the subjective experiences linked with each episode as measured by 10 affect scales. The 10 scales were parsed into six items measuring positive affect (happy, calm, comfortable, affectionate, interested, confident), and four items assessing negative affect (impatient, depressed, stressed, irritated). Participants rated each emotion using response scales ranging from 0 (not at all) to 6 (very much). The adjectives used are similar to those used in other mood scales such as the PANAS or POMS and in previous day reconstruction studies (Kahneman et al., 2004).

On average participants provided affect ratings for approximately 11 episodes recounted from their day. Collated averages of each person's positive affect (M = 3.57, SD = 0.8) and negative affect scores (M = 1.43, SD = 0.82) were calculated based on mean affect intensity levels across all reported episodes. The mean within-person standard deviation in each affect item over the reported episodes was computed. Variability in positive affect items (M = 1, SD = 0.38) was found to be closely related to variability in negative affect (M = 1.07, SD = 0.42), (r = 0.53, $p < 0.0005$). The deviation scores for positive and negative affect variability were therefore summed to produce an overall index of total affect variability (M = 2.07, SD = 0.7).

Data analysis

Correspondence between self-control and heart rate, heart rate variability, and the cortisol slope were firstly assessed using multiple linear regression adjusting for the inclusion of the participant's age and gender, and father's education (utilized as a measure of the participant's socioeconomic background). In addition, we controlled for each participant's BMI as body mass may be linked to both self-control and psychophysiological functioning.

Following this we selected potential mediating variables which may explain linkages between self-control and psychobiological functioning using guidelines outlined by Baron and Kenny (1986). Specifically, candidate variables for mediation analysis were required to be predicted by the independent variable, self-control. In addition, mediating variables must account for substantial variation in the dependent variable examined.

Potential mediating variables were analysed using a non-parametric bootstrapped approach to multiple mediation (Preacher & Hayes, 2008), employed in order to empirically test the role of health behaviors and affect patterns in mediating between self-control and the psychobiological variables examined. This resampling approach allows the unique contributions of several mediators to be gauged simultaneously. The SPSS macro accompanying the article by Preacher and Hayes (2008) does not assume that indirect effects are normally distributed. Rather, for each analysis 5,000 samples are obtained from the original data in order to produce an empirical estimation of the sampling distribution of the indirect effects. This distribution is then used to calculate point estimates and bias-corrected and accelerated confidence intervals for each indirect effect. Mediation is present when the lower and upper values for the bootstrap confidence intervals are both either above or below zero. In this way, it is possible to generate estimates for a large array of mediators and adjust for the presence of other mediators without making distributional assumptions that characterize prior tests (e.g. the Sobel test).

Results

Self-control and psychobiology

A correlation matrix detailing the unadjusted relationships between self-control and the key study variables is shown in Table 2. We utilised linear regression analyses to test the association between trait self-control and the psychobiological measures. The demographic factors age, gender and father's education, and the participant's BMI were included in the regression. In line with predictions, self-control was positively related to heart rate variability ($B = 0.8$, $SE\ B = 0.37$; t = 2.19, $p < 0.05$), and inversely related to resting heart rate ($B = -0.24$, $SE\ B = 0.1$; t = −2.35, p < 0.05), and showed negative non-statistically significant link to ambulatory heart rate ($B = -0.122$, $SE\ B = 0.077$; t = 1.58, $p = 0.12$). High trait self-control was also predictive of a steeper cortisol slope ($B = 0.0008$, $SE\ B = 0.0004$; t = 2.16, $p < 0.05$), as can be seen in Table 3. Thus, trait self-control successfully predicted several biological measures relevant to health.

Emotion and mediation

Mediation involves identifying a relation whereby an independent variable causes a mediating variable which in turn causes a dependent variable (Baron & Kenny, 1986). Therefore we next aimed to determine whether affect patterns and health behaviors were associated with both self-control and psychobiological functioning.

The first phase of the mediation analysis examined the relation between trait self-control and the intensity of positive or negative affect and overall variability in affect. High levels of self-control were unrelated to negative feelings but successfully predicted high levels of positive

Table 2 Correlation matrix detailing relationships between study variables

	Self-control	Age	Female	Father educ.	Pos. affect	Neg. affect	Aff. var.	Smoke	Exercise	Alco.	Resting HR	Ambul. HR	SDNN[a]
Age	0.156*												
Female	0.082	0.127											
Father's education	−0.051	−0.325**	−0.087										
Positive affect	0.175*	0.049	0.088	−0.066									
Negative affect	−0.050	−0.099	0.083	−0.109	−0.377**								
Affect variability	−0.277**	−0.148*	0.068	0.070	−0.226**	0.330**							
Smoke	−0.192**	0.212**	−0.077	−0.172*	−0.137	0.141	0.092						
Exercise	−0.011	−0.203**	−0.141*	0.112	0.068	−0.142	0.002	−0.212**					
Alcohol	−0.065	−0.047	−0.178*	−0.001	0.097	0.001	0.022	0.067	0.038				
Resting HR	−0.150*	0.112	0.149*	−0.153*	0.099	0.074	−0.027	0.231**	−0.298**	−0.103			
Ambulatory HR	−0.106	−0.027	0.194**	−0.115	0.062	0.144	0.126	0.157*	−0.244**	0.062	0.650**		
SDNN[a]	0.144*	−0.058	−0.006	0.158*	−0.005	−0.122	−0.102	−0.178*	0.135	−0.057	−0.416**	−0.602**	
Cortisol slope	0.170*	0.156	0.127	−0.164*	0.163*	−0.141	−0.261**	−0.032	−0.025	0.081	−0.015	−0.082	−0.024

* Correlation is significant at the 0.05 level (2-tailed)

** Correlation is significant at the 0.01 level (2-tailed)

[a] Standard deviation of inter-beat-intervals

affect ($B = 0.016$, $SE\ B = 0.007$; $t = 2.3$, $p < 0.05$) and were strongly related to low variability in affect ($B = -0.022$, $SE\ B = 0.006$; $t = -3.74$, $p < 0.001$). Adjusting for mean positive and negative affect levels did not appear to affect the link between self-control and affect variability ($B = -0.02$, $SE\ B = 0.006$; $t = -3.5$, $p < 0.001$). Multiple regression analyses showed that positive affect was not related to heart rate, heart rate variability or to the cortisol slope, which effectively ruled out positive affect as a mediator of the benefits of self-control.

Affect variability also failed to predict heart rate or heart rate variability. However, affect variability strongly predicted flat cortisol slopes, or smaller hourly declines in cortisol ($B = -0.014$ $SE\ B = 0.004$; $t = -3.36$, $p < 0.001$). The inclusion of both average positive and negative affect levels in the regression did little to attenuate the relationship between affect variability and the cortisol slope ($B = -0.012$ $SE\ B = 0.004$; $t = -2.65$, $p < 0.01$). Because affect variability was predicted by self-control and predictive of the daily drop in cortisol (see Fig. 1), it was considered as a potential mediator of the link between self-control and the magnitude of the diurnal decline in cortisol levels.

Bootstrapped mediation analyses showed that entering affect variability into the analysis diminished the relationship between self-control and the cortisol slope. Self-control was no longer a significant predictor of the cortisol slope ($B = 0.0005$ $SE\ B = 0.004$; $t = 1.49$, $p = 0.14$). An examination of the indirect effect showed that the bias-corrected and accelerated confidence intervals were above zero (Lower = 0.0001, Upper = 0.0005) and that the magnitude of the indirect effect of affect variability ($Z = 2.15$, $p < 0.05$), was such that the null hypothesis of no mediation could be rejected.

Health behavior and mediation

Next, we tested whether engaging in more or less favourable health behaviors may help mediate association between self-control and psychobiological functioning. Regression analysis, controlling for demographic variables and BMI showed that high self-control scores were associated with low levels of cigarette consumption ($B = -0.021$, $SE\ B = 0.007$; $t = -3.13$, $p < 0.01$). Exercise and alcohol consumption were unrelated to self-control levels and for this reason were not considered for further mediation analyses.

High levels of cigarette smoking were not related to the cortisol slope but were predictive of undesirable forms of cardiovascular activity, specifically a high resting heart rate ($B = 3.17$, $SE\ B = 1.06$; $t = 2.98$, $p < 0.01$) and low heart rate variability ($B = -8.53$, $SE\ B = 4.04$; $t = -2.11$, $p < 0.05$). We therefore utilized bootstrapped mediation to test smoking as a mediator between self-control and these measures of cardiovascular activity. Entering smoking into the regression model marginally diminished the association between self-control and resting heart rate ($B = -0.24$, $SE\ B = 0.1$; $t = -2.35$, $p < 0.05$, reduced to $B = -0.18$, $SE\ B = 0.1$; $t = -1.76$, $p < 0.1$), and smoking remained as a significant predictor of heart rate ($B = 2.74$, $SE\ B = 1.08$;

Table 3 Summary of regression analysis assessing self-control as a predictor of heart rate, heart rate variability, and the cortisol slope

Variable	Resting HR (N = 196)		Ambulatory HR (N = 185)		SDNN[a] (N = 186)		Cortisol slope (hourly decline) (N = 154)	
	B (SE)	β	*B* (SE)	β	*B* (SE)	β	*B* (SE)	β
Self-control	−0.24* (0.1)	−0.17	−0.12 (0.08)	−0.12	0.8*(0.37)	0.16	0.0008*(0.0004)	0.16
Age	0.09 (0.15)	0.05	−0.1 (0.1)	−0.07	−0.29 (0.5)	−0.04	0.0004 (0.0006)	0.07
Female	4* (1.8)	0.16	3.67** (1.4)	0.17	0.5 (6.5)	0.01	0.008 (0.006)	0.06
Father educ.[b]	−1.45 (1)	−0.11	−1.28 (0.77)	−0.13	7.57*(3.62)	0.16	−0.004 (0.003)	−0.11
BMI	0.3 (0.23)	0.1	0.03 (0.19)	−0.02	0.44 (0.9)	0.04	0.001 (0.001)	0.08

** $p < 0.01$, * $p < 0.05$

[a] Standard deviation of interbeat intervals

[b] From education 1 = primary education, to 4 = third level/university

t = 2.53, $p < 0.05$). The indirect effect estimates indicated that smoking could be considered a mediator between self-control and heart rate (Z = −2.04, $p < 0.05$; Lower confidence interval = −0.14, Upper confidence interval = −0.016). In addition, smoking slightly attenuated the link between self-control and heart rate variability ($B = 0.8$, $SE\ B = 0.37$; t = 2.19, $p < 0.05$, reduced to $B = 0.67$, $SE\ B = 0.37$; t = 1.8, $p < 0.1$). However, smoking levels remained only as a marginal predictor of heart rate variability in analyses that included self-control ($B = -7.04$, $SE\ B = 4.1$; t = −1.72, $p < 0.1$) and the indirect effect estimate was also marginally statistically significant (Z = 1.84, $p < 0.1$).

Discussion

The present results indicate that the benefits of self-control are more than skin deep or, more precisely, more than merely enhancing subjective reports and perceptions of health. Self-control was associated with several biological markers of cardiovascular and endocrine health. Specifically, high trait self-control predicted having a slower heart rate, higher variability in heart rate, and a steeper rate of decline in cortisol across the day. The present study also found some effects of self-control that are not directly biological. People with high self-control were less likely than others to be regular smokers. They had more positive affect and pleasant emotions overall. They showed greater emotional stability in the sense of less variation in affect across the day.

Perhaps most important, we identified interlinkages between self-control, several cardiovascular and neuroendocrine markers, and emotional and behavioral patterns. The strongest mediation effect was the pathway running from high self-control through low affective variability to the cortisol slope. Apparently, one important consequence of having high trait self-control is that it stabilizes the person’s emotional state, which in turn contributes to a faster and more thorough reduction in cortisol levels over the day.

We also examined three health behaviors: exercise, cigarette smoking, and alcohol consumption. For these, we relied on self-reports, which may not be entirely reliable, especially insofar as people may seek to give socially desirable answers. We found self-reported exercise and alcohol consumption had no significant associations with self-control. In contrast, being a smoker was associated with low self-control, and smoking mediated the link between self-control and heart rate.

Self-control and psychobiology

Our data are quite compatible with several strands of recent research examining personality and health. Self-controlled people have been shown to live longer than other people, and the activation of brain areas implicated in self-regulation has been linked to adaptive patterns of cardiovascular and neuroendocrine function (e.g. Deary et al., 2008; Segerstrom & Nes, 2007; Cunningham-Bussel et al., 2009). In a similar vein, and in keeping with our predictions, we found that highly self-controlled people had low and variable heart rates and a substantial decline in cortisol from morning to evening.

It could be that self-control predicts ambulatory cardiovascular activity because diligent people have patterns of physical activity that differ from those of less disciplined persons. It should be noted, however, the relationship between high self-control and low heart rate was found even when participants were monitored sitting quietly in a chair during baseline medical testing. Hence the biological effects of self-control were at least partly independent of current physical activity. Self-control was also unrelated to exercise frequency in this sample. The adaptive patterns of cardiovascular activity amongst those high in self-control are therefore unlikely to be due to individual differences in patterns of activity or fitness levels.

A flat overall cortisol slope could result, at least in part, from the numerous stressors people encounter on a daily

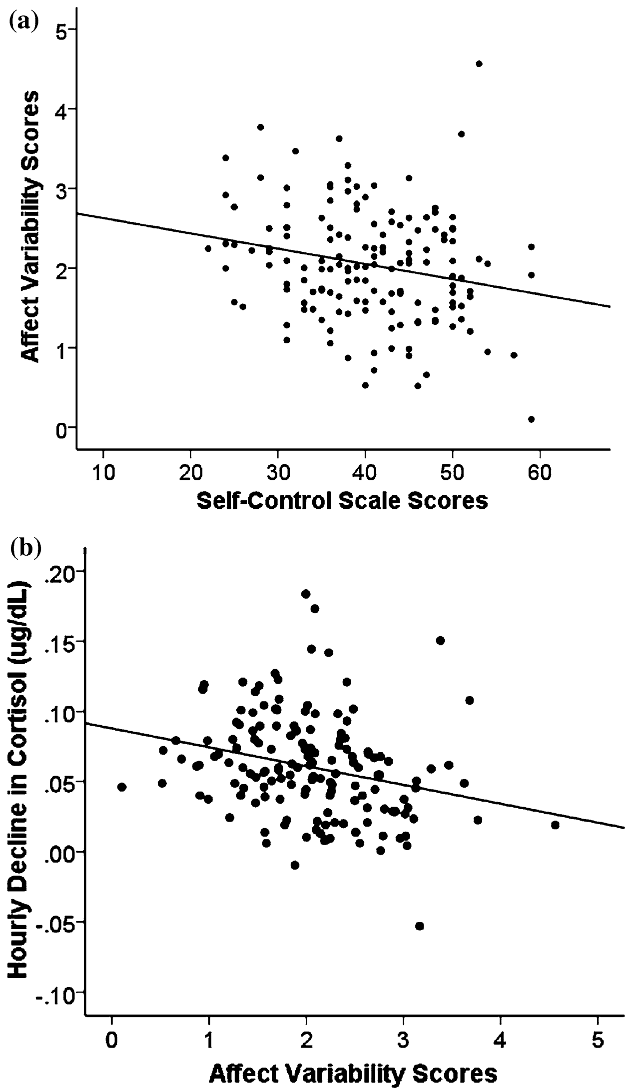

Fig. 1 **a** Affect variability scores as a function of Self-Control Scale scores, and **b** hourly decline in cortisol levels as a function of affect variability scores

basis (Adam et al., 2006). That is, the normal and healthy pattern is for cortisol to decline across the day from its morning high, but among some people, stressful events may reduce or prevent this decline. Good self-control may enable people to deal with such common stressors and to cope with internal stressors such as disturbing thoughts. These advantages may help explain why, in the present sample, people with high self-control did not seem to succumb to stress-related upsurges in cortisol throughout the day but instead showed a rapid decline in cortisol from morning to evening. In particular, the present study indicated that the affective stability was decisive in enabling people with high self-control to benefit from the steep decline in cortisol. Apparently, in response to whatever stressors arise, good self-control enables the person to avoid the worst emotional turmoil, which thereby facilitates adaptive neuroendocrine functioning.

Emotional stability and psychobiology

Rapid fluctuations in affect are a reliable feature of psychopathology and may be due, at least in part, to a poor ability to repair negative feelings or sustain positive emotion (Kuppens et al., 2007). Those with sufficiently high levels of self-control have a good deal of self-regulatory resources at their disposal and may use these resources to implement strategies to maintain optimal levels of affect.

In particular, our finding that emotional stability accounted for some of the benefits of high self-control represents a new direction in the research literature. Whilst previous reports have linked affect variability to psychological disorder, depression, and neuroticism, researchers have not given much consideration to possible links between fluctuations in affect and poor self-control. There is some evidence that impulsivity predicts high levels of mood variability ($r = 0.39$; McConville & Cooper, 1999) and that practicing self-control exercises can enhance the ability to control emotion (Oaten & Cheng, 2006). But most writings about the benefits of self-control have focused on cognitive and performance effects.

Our results suggest that the improvement in self-control may have health benefits (e.g., Tang et al., 2007). In particular, cortisol levels might be reduced quickly among those with high self-control. In terms of a mechanism, an improvement in self-control may make daily stressors less frequent and improve the person's ability to deal effectively with stressors, thus reducing emotional reactivity and in turn cortisol output.

Health behavior mediation

In line with previous studies, we showed a link between low self-control and an elevated risk of current smoking (Bogg & Roberts, 2004). Smokers had substantially elevated heart rate and reduced heart rate variability levels, presumably due to sympathetic nervous system activation induced by nicotine. In line with health behavior models that map the link between personality and health (Smith, 2006), our mediation analysis suggested that the raised likelihood of smoking among those with poor self-control may explain the link between self-control and resting heart rate. Thus, it appears that self-control may stabilise emotion and reduce one's likelihood of smoking, which can both in turn yield psychophysiological benefits. Examining the influence of self-control on emotional factors and health behaviors and how these affect biological intermediaries will help further the understanding of the complex pathways between self-control and health.

Self-control and emotional stability

The link we identified between high self-control and stable patterns of affect warrants further comment. In contrast to this pattern, readers might infer that affect variability should be more likely to be observed among those high in self-control rather than those with poor self-control. This is because changeability in affect might reflect a dynamic ability of the psychological system to react flexibly to different situations. We argue that high levels of self-control allow rapid adjustment of affect levels from moment to moment, not unlike a thermostat that can adjust quickly to changing environments (Chow et al., 2005). Thus, a continuous record of one's emotions might show relatively brief, minor fluctuations from and back to a 'set-point' among those with high self-control, indicating the robustness of regulatory mechanisms. For people low in self-control, on the other hand, contextual events may cause changes in affect that persist for several minutes or longer before the emotional state can return to its baseline equilibrium level. This would explain why those with poor self-control reported quite different levels of intensity of emotion from one (approximately hourly) episode to the next in the current study.

In addition it could be argued that changes in negative affect are likely to be characteristic of poor self-control, whereas fluctuations in positive affect are unlikely to reflect such impulsivity. However, in the current study and several previous reports there was a strong correspondence between variability in negative and positive emotions, sharing approximately 25 % of variance (e.g. McConville & Cooper, 1999). Those with highly variable negative feelings appear to typically experience large fluctuations in positive affect too. Researchers in the area of emotion regulation have continually emphasized that people need to be able to manage positive as well as negative emotions (Gross & Thompson, 2007). There are numerous contexts in daily life where restricting the expression of positive affect is necessary. It thus seems to be the case that self-control could be required to sustain stable level of positive as well as negative affect.

Limitations and issues for further research

The present research showed self-control to predict adaptive patterns of psychobiology, which appeared to result from engaging in positive health behavior (i.e., not smoking) and having stable patterns of emotion. A large body of research supports a model whereby personality produces a risk to health through inducing or preventing adverse health behaviors and dysfunction in physiological systems such as the hypothalamic pituitary adrenal-axis or the autonomic nervous system (e.g. O'Donnell et al., 2008; Martin et al., 2007). We followed this model of interpretation throughout the current research. However, the cross-sectional nature of the data collected precludes a causal examination of the direction of the relationships between self-control, emotion and behavior, and psychobiology. For example, it is possible that those with a constitutional disposition toward low levels of physiological responsiveness may tend to develop stable patterns of affect which in turn can facilitate self-regulation (Smith, 2006; Tice et al., 2001). Future prospective studies, possibly including experimental manipulations and multi-wave real-time diary studies examining both the trait and state operation of self-control, may help establish the direction of causality. In addition, by measuring biological system functioning on multiple days such studies could estimate 'trait' levels of cardiovascular and neuroendocrine system functioning and evaluate systematic changes in the day-to-day levels of these variables (Adam et al., 2006). The current study is restricted in this regard as cortisol levels and cardiovascular activity were only measured on a single day. In particular, a growing body of research points to the situational determinants of intra-individual variability in cortisol levels, as gauged by fluctuations occurring on a day-to-day level (e.g. Almeida et al., 2009). Utilizing average levels or latent trait estimates of cortisol levels over several days is likely to produce a more robust estimate of hypothalamic–pituitary–adrenal axis functioning and how this is affected by both self-control and important mediating factors.

Furthermore, the current study relied on self-reported participant assessments of the accuracy of the timing of saliva samples. A combination of 'smart cap' salivettes and actigraphy for movement assessment is likely to be the most accurate way to produce an objective account of when saliva samples were provided. Yet, whilst these methods can identify when a sample is opened or when the person wakes, there is still inherent uncertainty relating to when the sample was actually provided (Almeida et al., 2009).

The health behavior measures used in the current study were self-reported and as such were likely to be only modestly related to objectively recorded behavior patterns. For instance, prior research in the physical activity domain has found that participants reports are at best moderately correlated with accelerometer data ($r = 0.24$–0.47, as illustrated in Welk et al., 2007), whereas other behaviors such as reported alcohol consumption and smoking appear to demonstrate closer links to objective measures (Patrick et al., 1994; Del Boca & Darkes, 2003). In particular, the current study would have benefitted from objective high-frequency movement data which could have been used to precisely delineate the interlinkages between self-control, affect, movement, and cardiovascular activity. However, the relative independence of self-control and exercise levels in this sample coupled with our observation that self-control predicts heart rate at rest, suggests that the pattern of results observed may be robust to the effects of movement.

Future studies would also benefit from testing a broader sample of participants. It is likely that by restricting the current study to university students we observed a narrow range of health behaviors and self-control levels. However, this restriction of range may imply that the relationships observed in the current study are likely to hold in a representative sample of the same cohort where ceiling effects are less of an issue. A greater concern is that the results identified in this sample of mostly healthy young people may not generalize to more vulnerable populations such as the elderly or those suffering with chronic illness. However, old age and illness could perhaps be considered as contexts where possessing high levels of self-control is all the more valuable. For example, managing chronic illness requires people to persist with invasive regimes of medication and various therapies as well as consistently regulating anxiety-provoking thoughts about the trajectory of one's illness (Segerstrom et al., 2007).

Future research could combine detailed trait measures of self-control with functional imaging and real-time tracking of emotion and biological processes to answer numerous questions arising from the current research: Do people with high levels of trait self-control engage key brain areas such as the ventromedial and medial prefrontal cortex during tasks where the regulation of affect is required? Are the people who successfully control their emotions in the laboratory capable of doing so just as well in everyday life? And do the neural activation patterns observed in the laboratory explain individual differences in daily levels of cardiovascular and neuroendocrine function? As numerous forms of psychopathology have been shown to be characterised by both variability in affect and detrimental patterns of psychobiological functioning (e.g. Peeters et al., 2006) future studies could also examine the role of self-control in explaining such associations.

Conclusions

The present findings suggest several answers as to how self-control produces health benefits. People with good self-control have lower heart rates than others, partly due to their healthy behavior of not smoking. High self-control contributes to good endocrine function in the sense of a steep decline in stress (cortisol) hormones across the day, in this case mainly because of the emotional stability. The link between self-control and high heart rate variability could not be fully explained by any of our mediation tests and remains for further research to investigate. All these effects were found even after controlling for age, gender, parental education, and BMI. Thus, the benefits of self-control were independent of several factors that have been known to contribute to health-related outcomes. Future studies will assist in determining whether poor self-control heralds a trajectory of ill-health and early mortality. Such research will also delineate the impact of self-control on health behavior and patterns of emotion in order to explain changes in psychobiological functioning and the associated downstream health-effects.

Appendix

Self-Control Scale (Tangney et al., 2004)

Using the scale provided, please indicate how much each of the following statements reflects how you typically are (1 = Not at all, 5 = Very much).

1. I am good at resisting temptation.
2. I have a hard time breaking bad habits.
3. I am lazy.
4. I say inappropriate things.
5. I do certain things that are bad for me, if they are fun.
6. I refuse things that are bad for me.
7. I wish I had more self-discipline.
8. People would say that I have iron self-discipline.
9. Pleasure and fun sometimes keep me from getting work done.
10. I have trouble concentrating.
11. I am able to work effectively toward long-term goals.
12. Sometimes I can't stop myself from doing something, even if I know it is wrong.
13. I often act without thinking through all the alternatives.

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