# Self-Control: Skill, Knowledge, or Perishable Resource?

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**Abstract**

The effect of self-control on individual behavior has long been a subject of debate. Previous investigations have led to three main models of self-control, with contradictory predictions. By perceiving self-control as a knowledge, skill, and perishable resource, those models make assertions of a positive, neutral, and negative impact, respectively, of an initial act of self-control on subsequent self-control ability. Using biometric data enabled us to settle this controversy by developing a unified model of self-control that reconciles the diverging results in the literature. By monitoring actual compliance with an initial self-control task, our model overcomes the main limitation of assuming full compliance with the self-control treatment and restricting the analysis to linear relationships. The results suggest a dual impact of an initial act of self-control on subsequent self-control ability. Specifically, while an initial moderate self-control act enhances subsequent self-control ability, exerting self-control beyond a certain threshold causes fatigue and reduces subsequent self-control ability.

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# 1 Introduction

Every day, people struggle to make optimal decisions, and most of these decisions, including economic choices, require the exertion of self-control. Being such a major factor in our daily lives, self-control has been extensively researched in several disciplines, which have looked at it from completely different perspectives. On one hand, health researchers have linked lack of self-control with psychiatric disorders and unhealthy behaviors, such as overeating, smoking, unsafe sex, and noncompliance with medical regimes (Junger and van Kampen, 2010; Tangney et al., 2004; Vohs et al., 2008). On the other hand, sociologists state that low self-control predicts unemployment (Moffitt et al., 2013), while criminologists consider self-control as the main cause of criminal actions (Gottfredson and Hirschi, 1990) and economists argue that self-control predicts overspending and debt (Gathergood and Weber, 2014; Shah et al., 2012).

The economic theory of self-control has been characterized mainly by the existence of "two-self" system models, which are based on the idea of simultaneous conflict between short-run and long run preferences (McIntosh, 1969). A systematic and formal model of self-control was first proposed by Thaler and Shefrin (1981), who incorporated the concept of self-control in a theory of intertemporal choice. This model views the individual as an organization that resembles an internal conflict between a completely selfish or myopic self (managers of a firm) and a self who is concerned with lifetime utility (owners). While this theory has been defined only for the consumption-saving problem, more general models have been applied to other situations. For example, Fudenberg and Levine (2006) proposed a "dual-self" model of impulse control, which presents a unified explanation for several behavioral irregularities, including time inconsistency (quasi-hyperbolic discounting) and Rabin's paradox of risk aversion. In particular, the authors explain the model as a game between two-selves sharing the same preferences, a short-run impulsive (myopic) self and a long-run patient self. The reduced form of this dual-self model can be seen as a close representation of the self-control model derived by Gul and Pesendorfer (2001). In the latter application, the authors presented a two-period model in which an individual first limits the available alternatives in his choice set (commitment), and then exerts self-control at the time of consumption (second period). That is, the individual exerts self-control by refraining from temptation and faces a penalty or self-control cost whenever the final decision is not the most tempting one. Building on the main results of the Gul-Pesendorfer model, Benabou and Pycia (2002) proposed a self-control theory that represents a costly interpersonal conflict, which resembles the psychologists view of multiple competing sub-selves with opposing objectives. In this regard, the individuals sub-selves can be thought of as different regions in the brain.

Despite scientific efforts to explain the role of self-control in individual decision-making, the underlying nature of self-control is still a subject of debate. In fact, there is a controversy in the literature surrounding the mechanism through which self-control affects individual behavior, with three competing models. The first model views self-control as a *"knowledge structure"*, which is accessed following any initial self-control act, hence improving self-control ability in the short-run (Baumeister et al., 1998). However, the second model, *"strength model"*, considers self-control as a *skill* that slowly develops through repeated practice, implying that improvements in self-control would only be noticed in the long-run (Muraven et al., 1999; Muraven and Baumeister, 2000; Oaten and Cheng, 2006; Gailliot et al., 2007; Oaten and Cheng, 2007; Hagger et al., 2010; Muraven, 2010; Wang et al., 2015). Finally, the third model, *"ego or resource depletion model"*, perceives self-control as a perishable resource, which is depleted following an initial self-control act, hence impeding self-control ability in the short-run (Muraven and Baumeister, 2000; Vohs and Heatherton, 2000; Muraven and Slessareva, 2003; Vohs and Faber, 2007; Mead et al., 2009; Barnes et al., 2011; Gino et al., 2011). The initial act of self-control in all three models need not be related to subsequent self-control acts. For example, exerting self-control by refraining from smoking, could alter subsequent self-control needed to exercise or eat healthy.

In consumer research and the economics literature, the conceptualization of self-control has been heavily influenced by the idea that self-control relies on a limited amount of psychological and physical resources (i.e., the resource depletion effect). However, this idea has been put under scrutiny by hundreds of recently published replication experiments that found insignificant small-study effects, concluding that the popular *resource depletion effect* has been overestimated, at least when measured in a laboratory setting (Carter et al., 2015; Carter and McCullough, 2014).

With partial evidence supporting each of the three competing self-control models, past research has provided contradictory assertions of a positive, neutral, and negative effect of self-control exertion on subsequent self-control ability, casting doubt on the true impact of self-control. The main purpose of this study is to utilize biometric data, including eye tracking and electroencephalogram (EEG), in order to address this longstanding dispute and provide a more definitive answer regarding the true impact of an initial act of self-control on subsequent self-control ability. Specifically, instead of assuming full compliance with the treatment, as is usually the case with experimental studies (Balke and Pearl, 1997; Manski, 1996), the eye-tracking device was used to measure the actual compliance rates of subjects with an easy and hard self-control task in a random assignment experiment. Obtaining individual-level quantitative measures of self-control enables us to model a dynamic relationship which allows for potential non-linear effects, as opposed to the more commonly used analysis of the average treatment effect. Using this more complete analysis can help us to shed more light on the dynamics surrounding the relationship between self-control exertion and subsequent self-control ability.

Our results highlight the importance and potential benefits of using biometric measures to complement experimental data. Moreover, we demonstrate how the sole dependence on the analysis of the average treatment effect might lead to erroneous and biased conclusions. By incorporating biometric data into the analysis, we develop a unified self-control theory that reconciles the contradictory predictions of the self-control models. We find evidence supporting a dual effect of an initial act of self-control on subsequent self-control ability, with a threshold level of self-control exertion in the initial task below which the effects of the *"knowledge structure"* are dominant, but beyond which subjects become fatigued and lose their ability to control themselves. Finally, we report a slight gender difference favoring males' ability to cope with self-control for a purchasing task, at least in the short-run.

The value of this study stems from the fact that it can be used to refine the current recommendations to conserve and enhance self-control ability. Furthermore, the findings presented here are valuable in informing policy makers on the optimal regimes and programs to follow when training individuals with self-control. Being aware of the existence of a fatigue threshold will help individuals better ration self-control capacities and achieve a more consistent state of self-control maintenance. The potential implications herein are vast, ranging from improvements in diet programs to the construction of more effective training systems for military members who require intensive levels of self-control. For instance, our unified self-control theory works well in explaining the apparent failure of many individuals in following their respective diet plans. Committing to the traditionally rigorous diet plans requires high levels of self-control. This means that although those plans might work well at first in helping people lose weight, they quickly deplete their self-control capacities, which reverses the effect of the program and usually leads to the individual gaining more weight than what was initially lost (Dragone, 2009; Rosin, 2012).

The rest of the paper is organized as follows: Section 2 includes a brief discussion of the main theoretical models surrounding the effect of an initial act of self-control on subsequent self-control ability. Details regarding the experimental design and procedures are described in section 3, followed by a discussion of the results in section 4. Finally, section 5 highlights the main findings and concludes the paper.

# 2 Theoretical Framework

In this section, we present the main theoretical self-control models implied by past research and propose a unified model which is backed by the results of this study. For this purpose, we will adhere to the framework where self-control in time period $t$ is a function of past self-control exertion at time period $t-1$. That is, let $SA_t$ and $SE_t$ denote self-control ability and self-control exertion in time period $t$, respectively. The three main self-control models can then be viewed as simple restrictions on the function that links $SA_t$ with $SE_{t-1}$.

$$SA_t = f(SE_{t-1}, x) \tag{1}$$

where $x$ is all other factors that affect $SA_t$.

## 2.1 Hypothesis 1 (The ego or resource depletion model).

*There is an inversely proportional short-run relationship between $SA_t$ and $SE_{t-1}$, with $\partial f/\partial SE_{t-1} < 0$.*

This first hypothesis is in line with research supporting the resource depletion model, which predicts a significant decrease in short-run self-control ability following an initial act of self-control. In this light, self-control ability is viewed as a limited resource that is drawn upon with every act of self-control that a person engages in. Hence, an initial act of self-control will drain this resource leaving very little self-control ability available for subsequent tasks. This is analogous to the muscle fatigue phenomenon, which is common among athletes who engage in strenuous exercise. Over-exercising, which requires tremendous amounts of energy, often exhausts the muscles causing difficulty, or even inability, to perform exercises that the athlete can easily complete in a well-rested state. In a similar fashion, this model predicts that engaging in an act of self-control will use up a high amount of energy, which in turn will exhaust the self-control ability of the individual leaving him incapable of controlling himself in the short-run.

## 2.2 Hypothesis 2 (The knowledge structure model).

*There is a directly proportional short-run relationship between $SA_t$ and $SE_{t-1}$, with $\partial f / \partial SE_{t-1} > 0$.*

This second hypothesis is implied by research supporting the knowledge structure model, which predicts an increase in short-run self-control ability following an initial act of self-control. Under this reasoning, self-control ability is perceived more like a *"switch"*, which is turned on following any initial act of self-control. Hence, upon engaging in an act of self-control, the individual is able to turn this switch on and gain access to the knowledge source that enhances his self-control ability in the short-run. This is analogous to accessing an old learned ability that was ignored and rusted over time, like the principle of riding a bicycle.

## 2.3 Hypothesis 3 (The strength model).

*There is no short-run relationship between $SA_t$ and $SE_{t-1}$, with $\partial f / \partial SE_{t-1} = 0$.*

This third hypothesis is consistent with research supporting the strength model, which predicts no change in short-run self-control ability following an initial act of self-control. Following this logic, self-control is viewed as a *"skill"* that needs to be nurtured and developed over time through repeated practice. Hence, significant improvements in self-control ability are only expected to materialize in the long-run, meaning that engaging in a single act of self-control during an experiment is not enough to significantly alter self-control ability. This is analogous to learning a new language for example. We would only expect to improve proficiency in a language by repeated practice and effort in trying to learn the language. On the other hand, it would be somewhat unreasonable to think that a single lesson today is enough to significantly improve proficiency in the language.

Clearly, the three self-control models, and the hypotheses implied by them, are contradictory and have thus far presented competing explanations and predictions of the effect of an initial act of self-control on subsequent self-control ability. However, it is important to note a common factor between those models, namely, that all are restricted to modeling linear relationships between $SA_t$ and $SE_{t-1}$. This is mainly due to the fact that previous investigations were centered on measuring average treatment effects, which implies that model specification includes a simple indicator variable of whether the individual engaged in an initial act of self-control. However, it is reasonable to conjecture that simply considering the average treatment effect fails to capture the full impact of an initial act of self-control on subsequent self-control ability, let alone reveal anything about the dynamics of this relationship. Using biometric tools to obtain a continuous measure of self-control exertion in the initial task, allows the consideration of potential nonlinear relationships between $SA_t$ and $SE_{t-1}$, which leads to hypothesis 4. This in turn allowed us to propose a unified self-control theory that reconciles the contradictory predictions and explanations of the three self-control models.

## 2.4 Hypothesis 4 (A unified model of self-control).

*There is a nonlinear, inverse parabolic relationship between $SA_t$ and $SE_{t-1}$, with a self-control exertion threshold $SE^*$ below which $\partial f / \partial SE_{t-1} > 0$, but beyond which $\partial f / \partial SE_{t-1} < 0$.*

This hypothesis, which is supported by the results of our study, combines elements from the *knowledge structure* and *resource depletion* models. It also explains the robust evidence found in the literature documenting support for each of those two contradictory models and serves as a first step towards settling the controversy regarding the true nature of self-control and the mechanism through which it operates. Intuitively, it implies that moderate exertions of self-control hold the benefit of improving the self-control ability of the individual as he gains access to the knowledge structure required to do so. However, overexertion have the opposite effect as they exhaust the individual and cripple self-control ability.

# 3 Experimental Design

A total of one hundred and nineteen right-handed individuals (57 males and 62 females) participated in a between-subject experiment, where they were randomly assigned to one of three treatments: 1) baseline condition, 2) easy self-control condition, and 3) hard self-control condition. Subjects were undergraduate students at Texas A&M University, who ranged from 18 to 26 years of age (M = 20 years). The data was collected over the period from September, 2015 through May, 2016 and the study was approved by the Institutional Review Board of Texas A&M University.

## 3.1 Experimental Setup

While participants in all treatments completed a purchasing task, those in the two self-control conditions were asked to perform a self-control task by sitting through a video prior to making any purchasing decisions.[1] The video lasted 6 minutes and 30 minutes for participants in the easy and hard self-control conditions, respectively, and it consisted of motion pictures with varying shapes and colors, which acted as a distraction.[2] Participants were asked to exercise self-control throughout the video by fixing their gaze on a red dot bulls-eye that appeared at the bottom of the screen while the video was playing. In order to maintain the subjects attention, background music with varying frequencies played throughout the video.

Upon arriving to the assigned session, the participant filled out an informed consent form, after which he completed a short demographic/behavioral survey. Electrodes were then attached to the subjects scalp and they were seated on a chair in front of a computer with an eye-tracking device and a web camera. Each session lasted between 60 to 90 minutes depending on which treatment was being conducted. First, the participant received general instructions about the experiment. Then, depending on the assigned treatment, the subject

[1]Participants in the baseline condition were not presented with a video prior to the purchasing task. This was done in order to avoid any confounding effects of self-control and fatigue, which has been shown to be highly correlated with diminished self-control ability (Vohs et al., 2014; Baumeister et al., 2007).

[2]The choice of pictures varying in shapes and colors was designed to be gender neutral in order to avoid asymmetrical effects of participants.

was either presented with one of the two self-control tasks or went straight to the purchasing task.

The purchasing task included 80 trials, preceded by 10 practice ones. Each trial consisted of a fixation point presented for 2 seconds (s), followed by a stimulus (product image) (6s), a choice decision, and an inter-stimulus (6s). In each choice decision, participants were endowed with $5 and asked to choose whether they would like to purchase the presented product or keep the money. The 80 products used were exact images taken from Walmart's website and they spanned the categories of food, office supplies, health-personal care, and home appliances. The market price of the products was $10. The task was incentivized by using a bingo cage, at the end of the session, to randomly select 4 out of the 80 purchasing decisions to be binding. In each of the binding decisions, the subject received the actual product if he chose to purchase it or $5 in cash if he chose not to purchase.

## 3.2 Data Acquisition and Preprocessing

The participant was fitted with a proper size headset (B-Alert X10, Advanced Brain Monitoring, Inc.) with 9 electrodes to record brain activity from the prefrontal (F3, F4, FZ), central (C3, C4, CZ), and parietal (P3, P4, POZ) cortices. An electrode impedance test was performed to ensure proper conductivity of the electrodes (impedance$< 20k\Omega$). Moreover, to guarantee the accuracy of the EEG data collection, a metric benchmark consisting of three choice, one psychomotor, and one auditory psychomotor vigilance task was created for each subject prior to the experiment. During data collection a 0.5 Hz high pass and 45 Hz low pass filters were used. The data collection was controlled by iMotions software and all signals were sampled at a rate of 256 Hz.

Data from the EEG was split into 80 epochs, one for each purchasing decision. Each epoch lasted 2.5 seconds, 0.5 seconds prior for baseline correction and 2 seconds post stimulus onset, and was used to determine approach behavior. This was done by calculating the frontal asymmetry index (FAI) using the mid-frontal sites (F3 and F4). Specifically, the natural log of the alpha power on the left (F3) was subtracted from the natural log of the alpha power on the right (F4) to calculate the FAI (Allen et al., 2004; Ravaja et al., 2013). Higher values of this index are associated with a greater activation in the left prefrontal cortex and more approach, while lower values are associated with a greater activation in the right prefrontal cortex and less approach. Moreover, subjects eye movement was recorded using a Tobii TX300 eye tracking device, which was embedded in the computer screen and uses near-infrared technology, along with a high resolution camera, to track gaze direction (36). iMotions software was also used to collect the eye-tracking data at a sampling rate of 120 Hz. The desk where the computer was placed was adjusted and a calibration test was completed for each participant to make sure that his eyes were properly captured by the eye tracker.

# 4 Results and Discussion

The purchasing rate, which represents the average proportion of purchases made by subjects, was calculated for each treatment. The subjects display self-control in the purchasing task by refraining from purchasing products. Data from the brain activations confirm that the purchasing task exhibited an asymmetrical activity in the prefrontal cortex signaling approach behavior towards purchasing the products. A *lower* purchasing rate therefore implies *higher* self-control in the subsequent purchasing task. Hence, the fraction of times that the participants did not purchase a product (i.e., one minus the purchasing rate) was used as the measure of self-control in the data analysis section. This measure, representing the level of self-control, is plotted by gender for the baseline and the two self-control treatments in Figure 1.

Insert Figure 1 here.

**Result 1.** *Simple analysis of the average treatment effect yields evidence in support of the knowledge structure model, where the initial self-control tasks seem to have enabled subjects* *to exert higher levels of self-control in the subsequent purchasing task.*

Clearly, there was a significant increase in self-control (drop in purchases) following the easy and hard self-control tasks compared to the baseline condition ($P < 0.035$). This initial analysis provides evidence favoring the "knowledge structure" model. In the absence of a biometrically refined measure of the magnitude of self-control exertion, the conclusion would be that the initial act of self-control enabled subjects to access the knowledge required to enhance subsequent self-control function in the purchasing task. Although this result holds true for both genders, males seem quicker at accessing this knowledge for purchasing decisions, since the increase in self-control between the baseline and the easy self-control condition was larger for males than females.

In order to understand the full impact of the initial act of self-control on purchasing decisions, the full self-control treatment compliance assumption was relaxed. In fact, as shown in Table 1, using eye tracking data reveals varying compliance rates with the initial self-control task. As expected, the compliance rate, shown as the percentage of the actual video time that the subjects kept their gaze on the red dot bulls-eye and away from the video, was slightly higher in the easy compared to the hard self-control condition. Moreover, the compliance levels of males and females were almost identical in the easy self-control treatment ($\chi^2$ test, $P = 0.95$) and the hard self-control treatment ($\chi^2$ test, $P = 0.93$). In each treatment, the median compliance rate was calculated and used as a threshold to split the subjects into *"high-compliers"* and *"low-compliers"*.[3]

Insert Table 1 here.

The added value of using biometric data becomes clear when we incorporate compliance rates into the analysis. Figure 2 breaks down the self-control results by compliance level. The self-control effect of "low-compliers" increases from the baseline to the easy self-control condition and the hard self-control condition. This result aligns with the prediction of the

[3]Robustness tests were also conducted for 70%, 80%, and 90% compliance rates. The results were similar.

knowledge structure hypothesis and it is consistent with the result in Figure 1 (although the effect is stronger). In contrast, the self-control rate of "high-compliers" increased from the baseline to the easy self-control condition but it was significantly lower ($P = 0.008$) in the hard compared to the easy self-control condition. This provides suggestive evidence of a possible non-linearity in the effect of self-control. There appears to be a certain threshold of self-control exertion in the initial task beyond which "resource depletion" dominates the "knowledge structure" as subjects fatigue and lose their ability to access their self-control function in the subsequent purchasing task. This leads us to our second result.

Insert Figure 2 here.

**Result 2.** *While assuming full compliance might lead to erroneously credit the knowledge structure model as the sole predictor of the effect, using biometric tools to refine the treatment compliance suggests a dual effect of self-control exertion on purchasing decisions.*

Looking at the results for low-compliers in Figure 2, it is clear that the self-control level significantly increased in both treatments compared to the baseline condition ($P < 0.02$), although the increase was larger in the hard self-control condition. The low compliance of subjects with the hard self-control task kept them below the fatigue threshold, in a region where the effect of the "knowledge structure" model was still dominant. Furthermore, while compliance rates were low in both treatments, the absolute level of self-control exerted in the 30 minute video is significantly higher than in the 6 minute video, which explains why the increase in self-control was more pronounced for low-compliers in the hard self-control task.

Results for high- and low-compliers are displayed by gender in Figure 3 panel A and B respectively. For high-compliers, the general effect of self-control is similar across genders, showing signs consistent with the "knowledge structure" model in the easy self-control and the "resource depletion" model in the hard self-control condition. However, two important gender differences need to be highlighted. First, the increase in self-control between the baseline and easy self-control conditions was more pronounced for males than females. Second, while the decrease in the level of self-control between the easy and hard self-control conditions was significant for females ($P = 0.022$), it was insignificant for males ($P = 0.123$).

**Result 3.** *When it comes to purchasing decisions, males are not only faster at acquiring the necessary knowledge that permits more self-control, they also fatigue slower than females.*

This conclusion is strengthened by the results from the subsample of low-compliers in Figure 3 panel B. While male low-compliers exhibited significantly higher levels of self-control in the easy self-control condition compared to the baseline ($P < 0.001$), the self-control levels of female low-compliers were almost identical in those two treatments, indicating that females require higher levels of self-control exertion before they can access the knowledge required to enhance their self-control ability for purchasing decisions. However, low-compliers from both genders displayed significantly more self-control ($P < 0.001$) in the hard self-control condition compared to the baseline, which is explained by the fact that even low compliance with the 30 minute video translates to an absolute level of self-control that is high enough to turn on the switch of knowledge.

Although the analysis presented so far carries strong results, it forgoes valuable information by grouping subjects into only two levels (high-compliers and low-compliers). In order to get a more continuous measure of the effect of self-control exertion on purchasing decisions, and a better understanding of the dynamics surrounding this relationship, several Logit regression specifications were estimated using the actual amount of initial self-control exertion ("initial self-control time") as the explanatory variable along with other control variables. The initial self-control time varies between zero and 30 minutes, and represents the total amount of time the subject spent complying with the initial self-control task. In addition, and based on the current evidence favoring non-exclusivity of the self-control models, a quadratic functional form (with respect to initial self-control time) was specified in order to account for potential non-linear effects.

As shown in Table 2, the specification in column 1 included initial self-control time as the only explanatory variable, while in column 2, the non-linear effect of self-control was investigated by including the quadratic form of the variable. The specification in column 3 controlled for gender, and the one in column 4 included interactions between gender and initial self-control time. Finally, the specifications in columns 5 and 6 controlled for demographic and behavioral characteristics.

The estimation results are consistent across all specifications and support the main hypothesis of a non-exclusive simultaneous effect of the self-control models. First, the dual nature of the effect of self-control is captured by the fact that the coefficient on *initial self-control time* was positive and significant, while the coefficient on the quadratic form of this variable was negative and significant across all specifications. This indicates that, at first, an initial act of self-control has a positive effect on the likelihood that subjects will refrain from purchasing products, supporting the *knowledge structure* model. However, subjects become fatigued as they exert self-control beyond a certain threshold, which leads to a decrease in their ability to control themselves and an increase in the likelihood of purchasing more products. In fact, when the calculated predicted probabilities of self-control (no purchase) from columns 2 and 6 were plotted as a function of initial self-control time in Figure 4 panel A and B respectively, it is clear that the fitted lines follow an inverted U curve. With a fatigue threshold consistently around 16 minutes, this stands as further support to the conclusion concerning the nature of the effect of self-control for purchasing decisions in the experiment. Moreover, the gender differences, observed in the previous analysis, are evident here from the fact that the coefficients on gender and the interaction between gender and initial self-control time squared were positive and significant. This strengthens the assertion that, in the short run, not only are males less inclined than females to purchase products at first, they also have higher fatigue thresholds and are able to maintain self-control for longer periods of time than females for purchasing decisions.

Regarding the effects of demographic and behavioral characteristics, columns 5 and 6 show that the coefficient on smoking was negative, while the coefficients on high income, sleep, and exercise were positive. The result concerning smoking is reasonable, as it implies that smokers have lower self-control ability, and are more likely to purchase products than non-smokers. Furthermore, the effect of sleep on self-control is not surprising since it is expected that people who slept more hours during the previous night are relatively more rested and have higher energy, which means that they were better conditioned to access the knowledge structure of self-control and fatigued less easily than those who slept fewer hours. The fact that high income individuals (annual income $> \$150,000$) were found to have higher self-control ability, and a lower propensity to purchase products, is in line with evidence from past research that poor individuals have a higher tendency to overspend (Dobbie and Skiba, 2013). As for the result surrounding the effect of exercise on self-control, it is interesting to find that people who exercise regularly have a higher self-control ability since this carries some implications on the possible long-run effects of self-control. Although further investigation regarding the relationship between self-control and exercising is needed, one plausible explanation of this result is that people who exercise regularly exert self-control more frequently and, over the long-run, might have developed a skill to control themselves better than those who do not exercise regularly. This idea is in line with recent findings by Wang et al. (2015) who in a natural experiment found that self-control can develop in adult populations as a result of exercising routine behaviors in commonly occurring environments.

The robustness of the results presented so far is further demonstrated by looking at the brain frontal asymmetry index calculations, which were averaged separately for purchases and non-purchases as shown in Figure 5 panel A. First, the index values were consistently higher for purchases than non-purchases, which intuitively indicate that subjects displayed more approach behavior for purchased products. More importantly, the difference in the index value between purchases and non-purchases was substantially higher in the baseline compared to the easy and hard self-control conditions. In fact, the difference is statistically insignificant for both self-control conditions. This suggests that the approach behavior towards purchases, which was very pronounced in the baseline condition, disappeared following the 6 and 30 minute videos, which is supportive of the knowledge structure model. Following the self-control tasks, the subjects enhanced ability to control themselves caused them to display less relative approach towards purchases compared to non-purchases, which in turn caused the difference in the frontal asymmetry index to fade. This brings us to result 4.

**Result 4.** *Self-control, and lack thereof, is manifested in the brain through approach/withdrawal behavior. This is captured by the frontal asymmetry index calculations, which further support the notion of a unified self-control model.*

The picture becomes clearer once we analyze the results separately for high-compliers and low-compliers in Figure 5 panel B and C respectively. Although the difference in the frontal asymmetry index between purchases and non-purchases is insignificant for high-compliers in the easy self-control condition, it is significant in the hard self-control task. This result is consistent with the previous findings surrounding the interplay between the knowledge structure and resource depletion models. It implies that while access to the knowledge structure has boosted the self-control ability of high-compliers in the easy self-control task, high-compliers in the hard self-control task were fatigued due to excessive amounts of self-control exertion. Moreover, results for low-compliers in Figure 5 panel C conform to this reasoning. Here, the difference in the frontal asymmetry index between purchases and non-purchases is insignificant in both self-control conditions. This is explained by the fact that the level of self-control exerted by low-compliers in the hard self-control condition was in fact lower than the fatigue threshold, which meant that they were still in the knowledge structure domain and were exercising higher self-control compared to subjects in the baseline condition.

# 5 Conclusions

Previous investigations of the effect of self-control on individual decision making have led to three opposing models. The use of biometric data, including eye tracking and brain activity, not only added an interesting perspective to the results, but also helped us consider potential non-linear relationships by incorporating actual compliance rates into the analysis. By using the eye tracker to determine compliance time of each subject with the self-control task, we overcome the major difficulty faced in experimental research, namely dealing with compliance with the treatment. This, in turn, can help avoid resorting to suboptimal methods such as intent to treat and randomized encouragement designs.

It was clearly shown that the conclusion supporting the knowledge structure as the sole predictor of the effect of self-control, arrived at in the absence of biometric measures, was ultimately erroneous. In fact, using eye tracking to account for the compliance rates, this study found evidence pointing towards the conclusion that the self-control models are not mutually exclusive and are actually operating simultaneously. That is, while the effect of the knowledge structure might be dominant at first, following an initial act of self-control, excessive self-control exertion during this act could drain the subjects resources and lead to fatigue, after which the resource depletion effect becomes dominant. This result was robust across various specifications and was further supported by analysis of approach behavior using the brain frontal asymmetry index. The difference in the results by compliance rates may explain why recent criticism of the resource depletion model may not always result in the theoretical predictions.

In conclusion, this article provides strong evidence in favor of a dual impact of self-control on subsequent purchasing decisions. It is possible that the balance between the knowledge structure and resource depletion might play a part in providing the individual with the experience required to develop a skill that enhances his self-control ability in the long-run. Yet, not much could be ascertained here since this effect could only materialize over long periods of time. Perhaps a field experiment, over a longer time period, could provide more suitable grounds for further investigation of the mechanism through which the strength model is related to knowledge structure and resource depletion. The importance of the findings reported in this article is that they can be used to design potential programs and policies to initiate and maintain self-control in the short-run. Being aware of the existence of a fatigue threshold would enable people to conserve short-run self-control ability by avoiding over exertions that lead to exhaustion.

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# Figures and Tables

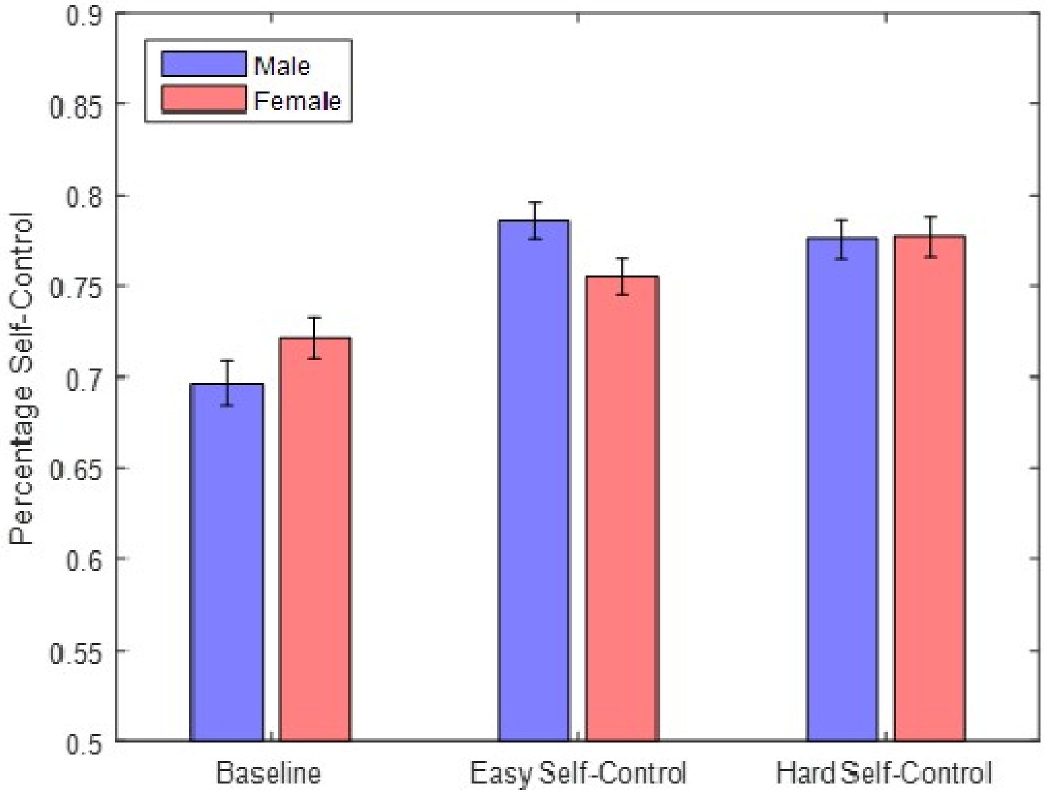


Figure 1: Self-control levels by gender and treatment.

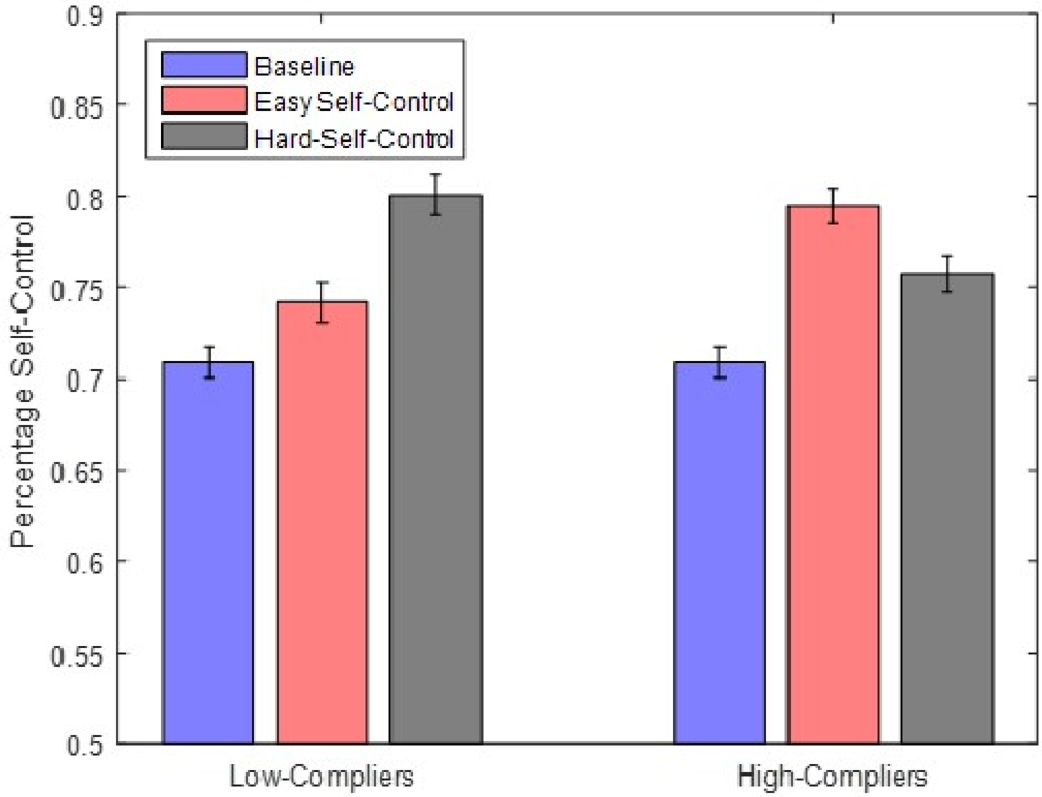


Figure 2: Self-control levels by treatment and compliance rate.

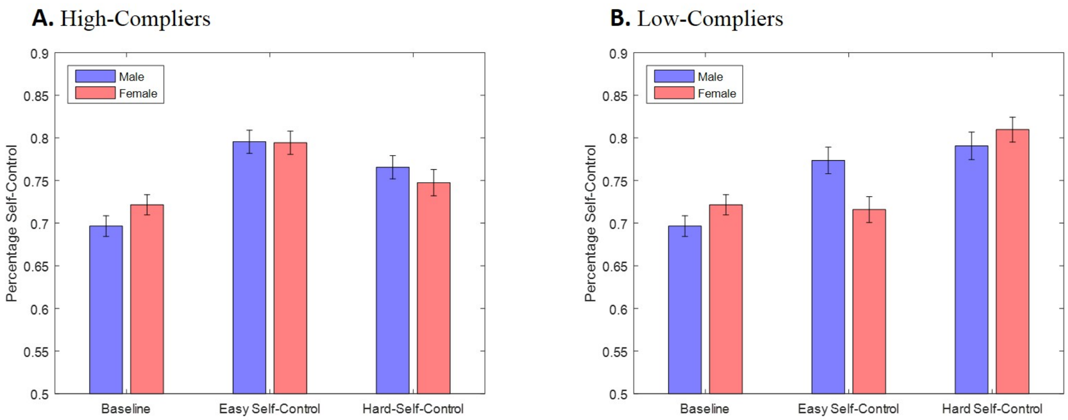


Figure 3: (A) Self-control levels by treatment and gender for high-compliers. (B) Self-control levels by treatment and gender for low-compliers.

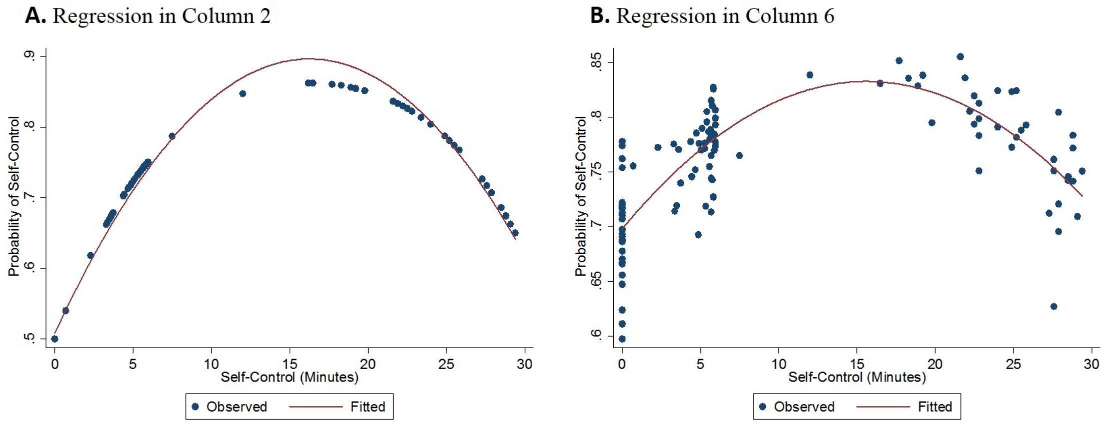


Figure 4: Estimated probability of no purchase as a function of initial self-control time. (A) Estimated probability of no purchase calculated from Logit regression specification in column 2 of Table 2. (B) Estimated probability of no purchase calculated from Logit regression specification in column 6 of Table 2.

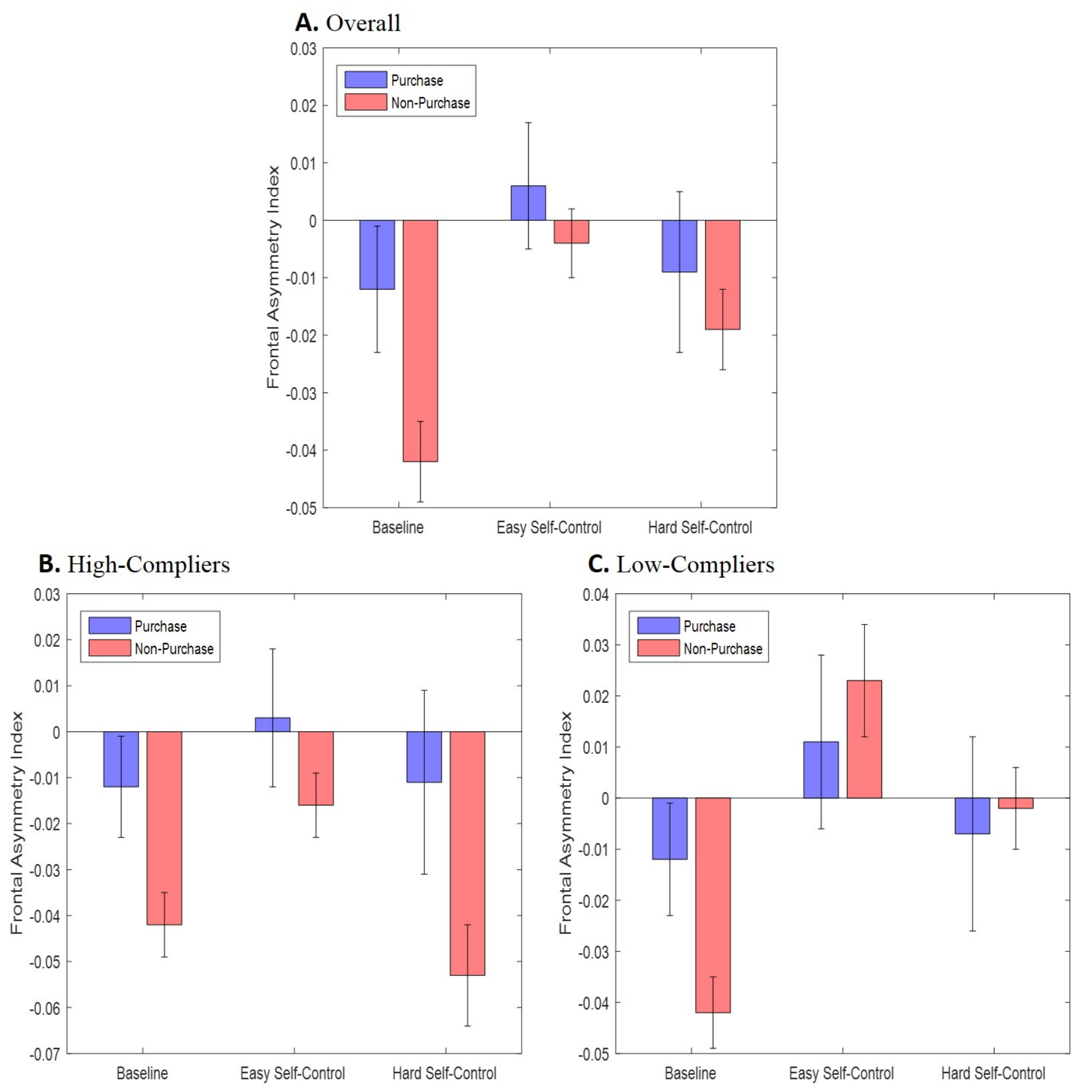


Figure 5: Effect of self-control on approach behavior. (A) Frontal asymmetry index by treatment and purchasing decision. (B) Frontal asymmetry index by treatment and purchasing decision for high-compliers. (C) Frontal asymmetry index by treatment and purchasing decision for low-compliers.

Table 1: Self-control Compliance by Treatment and Gender

| | Easy Self-Control Treatment | | |
|---|---|---|---|
| Self-Control Compliance | Total n = 44 | Male n = 20 | Female n = 24 |
| 90% or more | 26 | 13 | 13 |
| 80% - 89% | 8 | 3 | 5 |
| Less than 79% | 10 | 4 | 6 |
| | **Hard Self-Control Treatment** | | |
| Self-Control Compliance | Total n = 42 | Male n = 21 | Female n = 21 |
| 90% or more | 14 | 8 | 6 |
| 80% - 89% | 8 | 4 | 4 |
| Less than 79% | 20 | 9 | 11 |

Table 2: Logit Regressions of the Effect of Self-Control on Purchasing Decisions

| **Variable** | **Coefficient** (Std. Err.) | **Coefficient** (Std. Err.) | **Coefficient** (Std. Err.) | **Coefficient** (Std. Err.) | **Coefficient** (Std. Err.) | **Coefficient** (Std. Err.) |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Self-Control Time | 0.058*** | 0.227*** | 0.215*** | 0.257*** | 0.094*** | 0.104*** |
| | (0.002) | (0.008) | (0.008) | (0.011) | (0.010) | (0.014) |
| Self-Control Time Squared | | -0.007*** | -0.07*** | -0.008*** | -0.003*** | -0.003*** |
| | | (0.000) | (0.000) | (0.000) | (0.000) | (0.001) |
| Male | | | 0.504*** | 0.833*** | 0.002 | 0.072 |
| | | | (0.040) | (0.054) | (0.050) | (0.076) |
| Male x Time | | | | -0.159*** | | -0.023 |
| | | | | (0.019) | | (0.021) |
| Male x Time Sq | | | | 0.005*** | | 0.001 |
| | | | | (0.001) | | (0.001) |
| Medium Income | | | | | -0.163** | -0.170*** |
| | | | | | (0.065) | (0.065) |
| High Income | | | | | 0.123* | 0.119* |
| | | | | | (0.066) | (0.067) |
| Smoke | | | | | -0.194* | -0.223** |
| | | | | | (0.109) | (0.112) |
| Sleep | | | | | 0.095*** | 0.093*** |
| | | | | | (0.011) | (0.011) |
| Exercise | | | | | 0.049** | 0.046** |
| N | 9,920 | 9,920 | 9,600 | 9,600 | 9,440 | 9,440 |
| AIC | 12,416 | 11,828 | 10,947 | 10,858 | 10,436 | 10,438 |
| BIC | 12,423 | 11,842 | 10,969 | 10,894 | 10,493 | 10,510 |
| Log-likelihood | -6,206.97 | -5,911.83 | -5,470.58 | -5,424.24 | -5,209.82 | -5,209.06 |

Significance levels : $*$ : 10% $**$ : 5% $***$ : 1%