

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

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Abstract

The self-control literature suggests three main models with contradictory predictions. By perceiving self-control as a knowledge, skill, or perishable resource, those models report a positive, neutral, and negative impact, respectively, of an initial self-control act on subsequent self-control ability. Using biometric data to monitor compliance enabled us to develop a unified self-control model, reconciling the diverging results in the literature. We find evidence of a dual impact of an initial self-control act 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 reducing 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. As a major factor in our daily lives, self-control has been extensively researched in several disciplines, which have looked at it from different perspectives. For instance, 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). Moreover, 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, debt, and productivity (Gathergood and Weber, 2014; Shah et al., 2012; Bucciol et al., 2011).

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). Particularly, a formal model of self-control has been introduced in the framework of intertemporal choice theory, where an individual faces an internal conflict between a completely selfish or myopic self and another self concerned with lifetime utility (Thaler and Shefrin, 1981; Gul and Pesendorfer, 2001; Fudenberg and Levine, 2006). Moreover, self-control has been modeled as two sub-selves within the same individual competing for opposite objectives. In this regard, the individual sub-selves can be thought of as different regions in the brain (Benabou and Pycia, 2002).

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, “*ego or resource depletion model*” views 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 second model views self-control as a “*knowledge structure*”, where this knowledge is accessed following any initial self-control act, and it serves as motivation for improving self-control ability in the short-run (Baumeister et al., 1998). Finally, the third model, the “*strength model*”, considers self-control as a *skill* that slowly develops through repeated practice, implying that improvements in self-control would 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). The initial act of self-control in all three models need not be related to subsequent self-control acts (Vohs and Heatherton, 2000; Bucciol et al., 2011). 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 “*ego or resource depletion model*”; the idea that self-control relies on a limited amount of psychological and physical resources. 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, or 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 and test 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 (“*resource depletion*”). 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 their 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 introduces a brief overview of biometric measures, including EEG. Section 3 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 EEG and Approach/Withdrawal Behavior

Davidson’s motivational model of approach-withdrawal behavior rests on the premise that the left- and right-frontal regions of the brain are part of two separate neural systems responsible for moderating approach and avoidance motivations, respectively (Davidson, 1995, 2004). Based on an extensive literature, increased relative activity in the left frontal region has been shown to be indicative of engagement or approach towards a stimulus, while increased relative activity in the right frontal region has been shown to be associated with disengagement or withdrawal from a stimulus (Coan and Allen, 2004; Demaree et al., 2005; Harmon-Jones et al., 2006). In this regard, several studies have used EEG data to capture asymmetries in the activation of the left- and right- frontal brain regions, reporting evidence that such asymmetries served as predictors of higher monetary risk taking behavior (Pizzagalli et al., 2005), reduced punishment in ultimatum games (Knoch et al., 2010), and increased propensity to purchase products (Ravaja et al., 2013). Specifically, the frontal asymmetry index (FAI) is calculated by subtracting the natural log of the alpha power in the

left frontal region from the natural log of the alpha power in the right frontal region (Coan and Allen, 2004). Higher values of this index simply reflect relative approach behavior, while lower values signal withdrawal behavior.

3 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_1 is a function of past self-control exertion in a previous task at time period T_0 . 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_1} with SE_{T_0} .

$$SA_{T_1} = f(SE_{T_0}, x) \tag{1}$$

where x is all other factors that affect SA_{T_1} .

3.1 Hypothesis 1 (The ego or resource depletion model).

There is an inversely proportional short-run relationship between SA_{T_1} and SE_{T_0} , with $\partial f / \partial SE_{T_0} < 0$.

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.

3.2 Hypothesis 2 (The knowledge structure model).

There is a directly proportional short-run relationship between SA_{T_1} and SE_{T_0} , with $\partial f / \partial SE_{T_0} > 0$.

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 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.

Clearly, the 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.¹ However, it is important to note a common factor between those models, namely, that all are restricted to modeling linear relationships between SA_{T_1} and SE_{T_0} . 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

¹A third model is the strength model, which implies no short-run relationship between SA_{T_1} and SE_{T_0} , with $\partial f / \partial SE_{T_0} = 0$. In this light, 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 today is not enough to significantly alter our self-control ability. Since the level of self-control ability was measure immediately after the initial self-control exertion, little can be said about the effects of the strength model. Further investigation over longer periods of time is needed to better understand the implications of this model.

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_1} and SE_{T_0} , which leads to hypothesis 3. 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.

3.3 Hypothesis 3 (A unified model of self-control).

There is a nonlinear, inverse parabolic relationship between SA_{T_1} and SE_{T_0} , with a self-control exertion threshold SE^ below which $\partial f/\partial SE_{T_0} > 0$, but beyond which $\partial f/\partial SE_{T_0} < 0$.*

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, overexertions have the opposite effect as they exhaust the individual and cripple his self-control ability.

4 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 were 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.

4.1 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 the purchasing decisions. Subjects 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). In the easy self-control condition, participants were presented with a 6 minute video consisting of motion pictures with varying shapes and colors, which acted as a distraction.² Participants in the hard self-control condition were shown the same video, however, it looped over 30 minutes. In both conditions, subjects 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. This self-control task, which is often used in the psychology literature, was particularly chosen for its ease of application with biometric equipment. Moreover, its validity is derived from the fact that focusing on the red dot bulls-eye and resisting the distractions in the video requires significant exertion of self-control. In order to maintain the attention of subjects, 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 subject's scalp and he or she was 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

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

depending on which treatment was being conducted. First, the participant received general instructions about the experiment. Then, depending on the assigned treatment, the subject was either presented with the 6 minute video, 30 minute video 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, the participant was endowed with \$5 and asked to choose whether he or she would like to purchase the presented product or keep the money.³ 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.⁴ Care was taken to ensure that the products were gender neutral in order to more accurately capture differences in the self-control capacities of males and females and avoid the confounding effect of gender differences in tastes and preferences. The market price of the products, which remained unknown to the participants, was \$10. The task was incentivized by using a bingo cage, at the end of the experiment, 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 or she chose not to purchase. Subjects' self-control capacities are exhibited in this task through their ability to resist the impulse buying urge and refrain from purchasing products. This is analogous to the case of an individual in the supermarket facing several temptations as he goes through the aisles looking for the grocery items he came to purchase. People often find themselves in this situation, where they have to exercise self-control by not purchasing all the extra items they like on store shelves.

³Similar to previous studies, subjects used the keyboard to make their decisions in order to minimize movements that can cause noise in the EEG data (Harmon-Jones and Allen, 1998).

⁴The participants were not told that the products were purchased at Walmart.

4.2 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 more withdrawal. 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 high resolution cameras, to track gaze direction (Ramsøy, 2015). The eye-tracking device enables to monitor the compliance rate with the self-control treatments. 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 or her eyes were properly captured by the eye tracker.

5 Results and Discussion

Table 1 presents summary statistics of the demographic and behavioral characteristics by treatment. A balance check showed that none of the means were significantly different across treatments, which means that randomization was valid *ex post*. Approximately half the subjects in each treatment were male. Moreover, most of the subjects considered themselves White or Hispanic, were nonsmokers, exercised regularly and reported family incomes lower than \$100,000.

Insert Table 1 here.

The purchasing rate, which represents the average proportion of purchases made by subjects, was calculated for each treatment. The subjects displayed self-control in the purchasing task by refraining from purchasing products.⁵ Data from the brain activations confirm that the purchasing task exhibited an asymmetric 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 treatment in Figure 1 panel A and broken down by gender in panel B.

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

⁵Previous research report a strong correlation between impulsive purchasing behavior and lack of self-regulation (Baumeister et al., 1994; Houser et al., 2008).

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. This is evident from the fact that the increase in self-control between the baseline and the easy self-control condition was larger for males than females, indicating that the 6 minute video was enough for men to access the knowledge structure while females required longer self-control exertions in the initial task before they could gain access to this knowledge for the purchasing task.

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 2, 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 (χ^2 test, $P = 0.95$) and the hard self-control treatment (χ^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*”.⁶

Insert Table 2 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 rate of “low-compliers” increased from the baseline to the easy and hard self-control conditions. This result aligns with the prediction of the knowledge structure hypothesis and is consistent with the result in Figure 1 (although the effect is stronger). In

⁶Robustness tests were also conducted for 70%, 80%, and 90% compliance rates. The results were similar.

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.⁷ 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 self-control 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 was 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.

⁷It may be argued that since individuals have different capacities for self-control, those with low compliance levels might be the ones with lower capacities, who depleted first and were forced to break compliance. However, this argument implies that subjects were consistently complying with the task at first and suddenly stop complying at some point during the video when they became depleted. This did not happen. Instead, subjects with low compliance levels were quite inconsistent in the way they complied during the task. Moreover, the experimenters were monitoring the subjects throughout the entire video and were careful to instruct them to return their gaze on the red dot bulls-eye immediately after they were observed not complying. Hence, it is reasonable to assume in this case that compliance is positively correlated with the level of self-control exertion.

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 panel B of Figure 3. 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 on self-control ability 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 min-

utes, and represents the total amount of time the subject spent complying with the initial self-control task.⁸ 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 3, 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 on purchasing decisions in the experiment. It is noteworthy to mention another interpretation of the results; one which attributes the observed effects solely to the *resource depletion* model with the claim that subjects show

⁸Subjects were constantly reminded to keep their attention on the red dot bullseye whenever they looked away from it. Thus, they were not given the chance to rest during the self-control exertion task.

high levels of self-control while they are making use of this resource and low levels once they are depleted. However, this interpretation would predict that a moderate initial act of self-control should not enhance nor impede the self-control ability of the individual since he is merely using up a resource he already possesses. Only when this resource is used up would we expect to see a significant decrease in the subject's self-control ability. Since subjects displayed significantly higher self-control levels following a moderate initial act of self-control, there is stronger evidence suggesting some sort of motivation effect along the lines of the *knowledge structure* model.

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 impulse 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 impulse 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 on average smokers have lower self-control ability, and are more likely to impulse 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 > \$100,000) were found to have higher self-control ability, and a lower propensity to impulse 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 noteworthy 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 for 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 results presented so far are used to validate and are supported by the brain frontal asymmetry index (FAI) 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. This result is in line with FAI findings by Ravaja et al. (2013). More importantly, the difference in the index value between purchases and non-purchases was large in the baseline condition, where it was significantly higher for purchases. This indicates that subjects were displaying higher approach towards purchases in the baseline condition where no self-control is exerted. In contrast, there was no significant difference in the index value between purchases and non-purchases in neither of the self-control conditions. This suggests that the approach behavior towards purchases disappeared following the self-control treatments of 6 and 30 minute videos, which is supportive of the knowledge structure model. Following the self-control tasks, the subject's enhanced ability to control themselves caused them to display less approach towards purchases compared to non-purchases, which in turn caused the difference in the brain FAI to fade. While the FAI has only recently been used in the literature to assess approach/withdrawal behavior, its comparison with our results provides evidence that it is a valid indicator of this behavior. 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.

This result becomes clearer once we analyze the index values separately for high-compliers and low-compliers (Figure 5 panels 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 condition. 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. After being fatigued, high compliers in the hard self-control task revert back and manifest approach behavior towards impulse purchasing in the brain frontal asymmetry. 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.

6 Conclusions

Previous investigations of the effect of self-control on individual decision making have led to three opposing models. While the *“ego or resource depletion model”* argues that self-control is a limited resource, the *“knowledge structure model”* perceives it as a “switch” that is turned on following any initial self-control act. Conversely, the *“strength model”* views self-control as a skill that is slowly acquired through repeated practice over time. 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 measuring 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

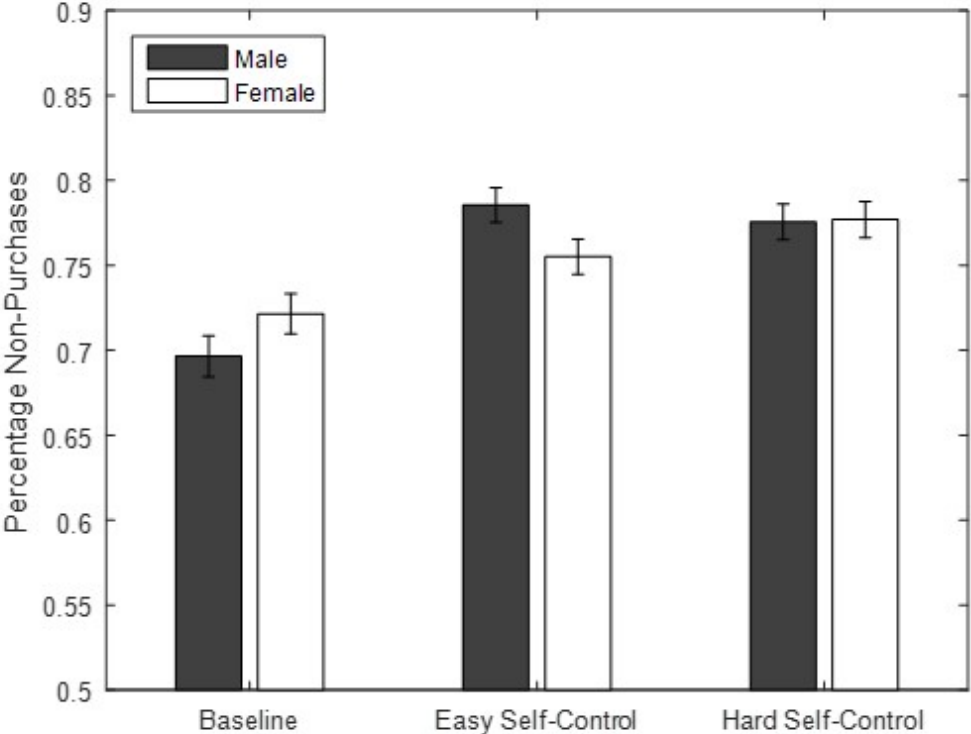


FIGURE 1: SELF-CONTROL LEVELS BY GENDER AND TREATMENT.

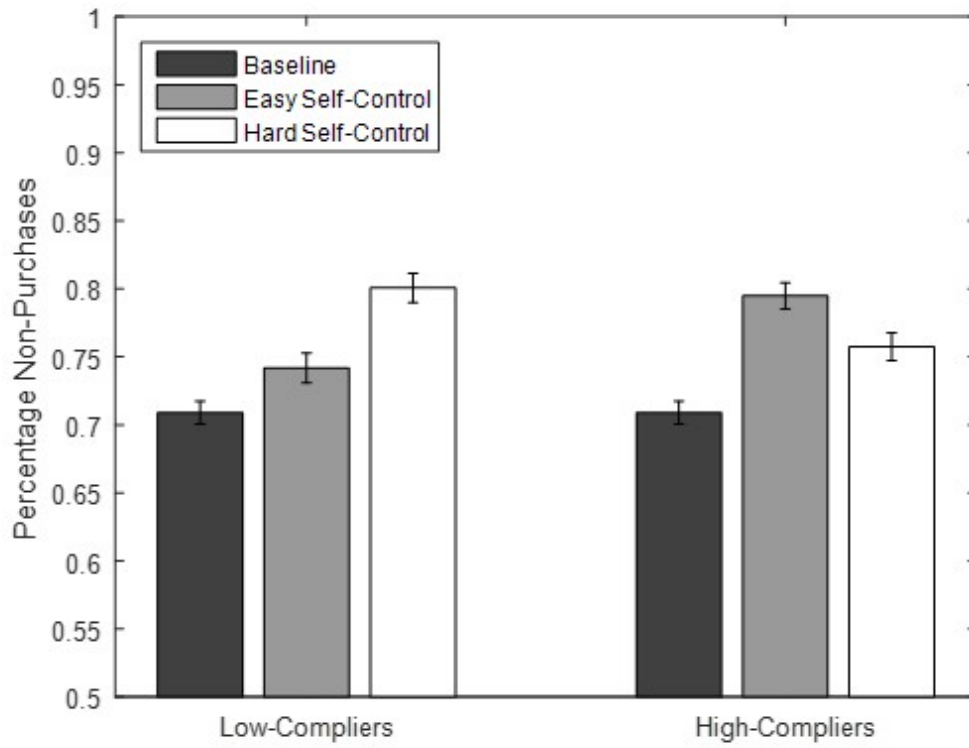


FIGURE 2: SELF-CONTROL LEVELS BY TREATMENT AND COMPLIANCE RATE.

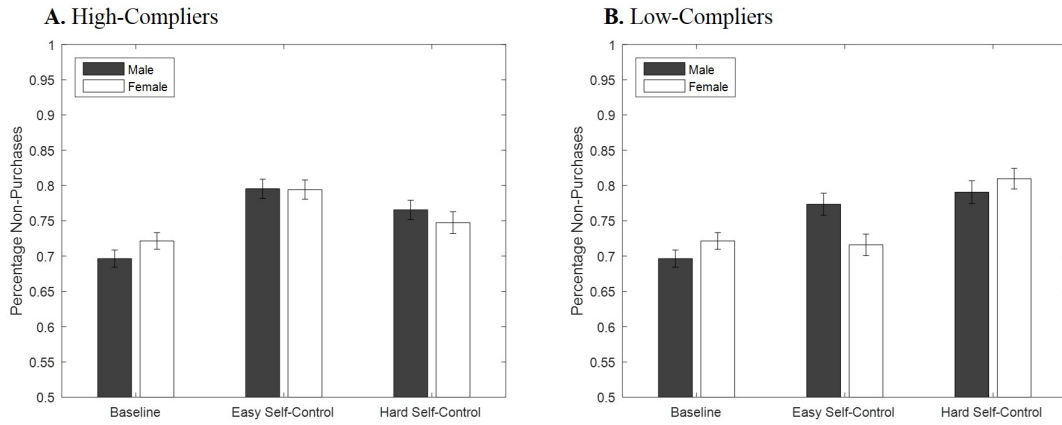


FIGURE 3: SELF-CONTROL BY COMPLIANCE LEVEL. (A) Self-control levels by treatment and gender for high-compliers. (B) Self-control levels by treatment and gender for low-compliers.

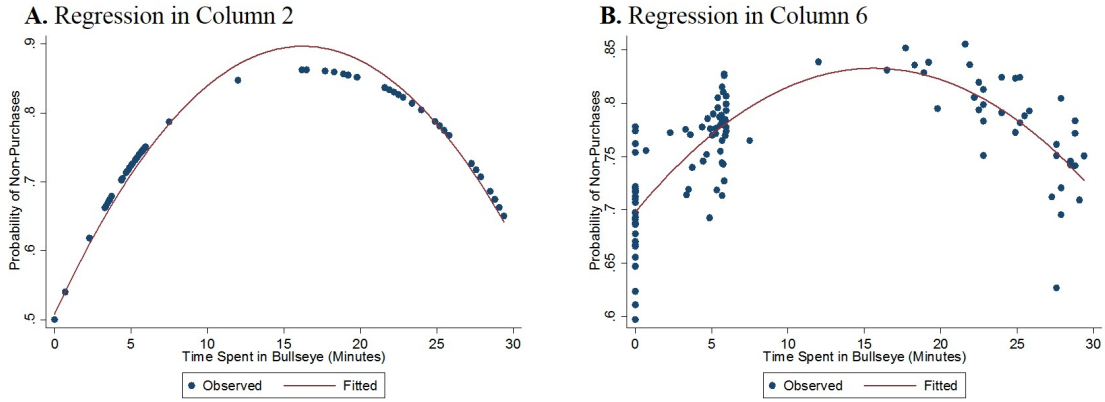


FIGURE 4: ESTIMATED PROBABILITY OF NO PURCHASE AS A FUNCTION OF INITIAL SELF-CONTROL TIME. (A) Estimated probability of no purchase calculated from Logit regression specification in column 2 of Table 2. (B) Estimated probability of no purchase calculated from Logit regression specification in column 6 of Table 2.

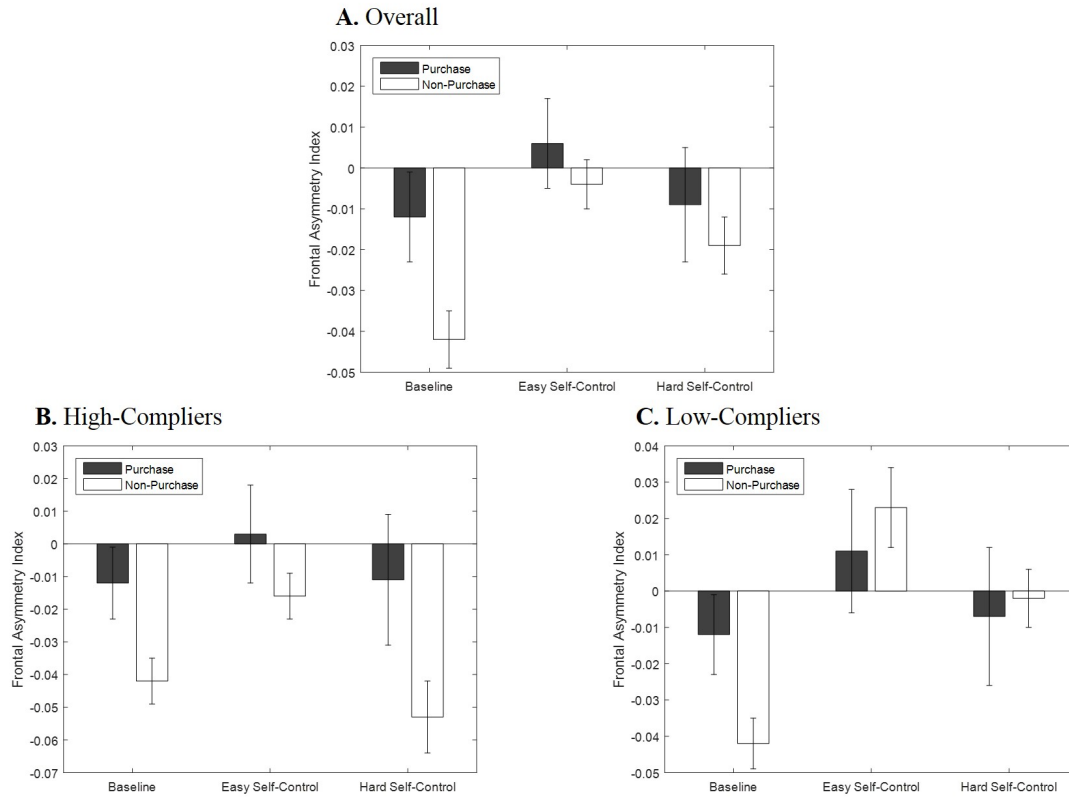


FIGURE 5: EFFECT OF SELF-CONTROL ON APPROACH BEHAVIOR. (A) Frontal asymmetry index by treatment and purchasing decision. (B) Frontal asymmetry index by treatment and purchasing decision for high-compliers. (C) Frontal asymmetry index by treatment and purchasing decision for low-compliers.

TABLE 1: BALANCE TEST ACROSS TREATMENT GROUPS

Variable	Mean	Mean	Mean
	(Std. Err.)	(Std. Err.)	(Std. Err.)
	Control	Easy Self-Control	Hard Self-Control
Male	0.47 (0.08)	0.47 (0.08)	0.51 (0.08)
Race: White	0.56 (0.08)	0.51 (0.08)	0.66 (0.08)
Hispanic	0.22 (0.07)	0.30 (0.07)	0.21 (0.06)
Asian/Pacific Islander	0.16 (0.06)	0.12 (0.05)	0.10 (0.05)
Other	0.06 (0.04)	0.07 (0.04)	0.03 (0.02)
Education: Freshman	0.39 (0.08)	0.37 (0.08)	0.34 (0.07)
Sophomore	0.14 (0.06)	0.16 (0.06)	0.22 (0.07)
Junior	0.28 (0.08)	0.14 (0.05)	0.24 (0.07)
Senior	0.19 (0.07)	0.33 (0.07)	0.27 (0.07)
Exercise: Rarely	0.08 (0.05)	0.16 (0.06)	0.15 (0.06)
Moderately	0.67 (0.08)	0.63 (0.07)	0.61 (0.08)
Frequently	0.25 (0.07)	0.21 (0.06)	0.24 (0.07)
Smoke	0.06 (0.04)	0.05 (0.03)	0.03 (0.03)
Hours of Sleep (previous night)	7.19 (0.29)	6.87 (0.17)	7.01 (0.22)
Weight (lbs)	150.83 (6.08)	164.91 (6.04)	159.18 (5.85)
Income (< \$40,000)	0.61 (0.08)	0.65 (0.07)	0.61 (0.08)
Income (\$40,000 – \$100,000)	0.25 (0.07)	0.14 (0.05)	0.12 (0.05)
Income (> \$100,000)	0.14 (0.06)	0.21 (0.06)	0.27 (0.07)
N	36	44	42

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

TABLE 2: 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 3: 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*** (0.002)	0.227*** (0.008)	0.215*** (0.008)	0.257*** (0.011)	0.094*** (0.010)	0.104*** (0.014)
Self-Control Time Squared		-0.007*** (0.000)	-0.07*** (0.000)	-0.008*** (0.000)	-0.003*** (0.000)	-0.003*** (0.001)
Male			0.504*** (0.040)	0.833*** (0.054)	0.002 (0.050)	0.072 (0.076)
Male x Time				-0.159*** (0.019)		-0.023 (0.021)
Male x Time Sq				0.005*** (0.001)		0.001 (0.001)
Medium Income					-0.163** (0.065)	-0.170*** (0.065)
High Income					0.123* (0.066)	0.119* (0.067)
Smoke					-0.194* (0.109)	-0.223** (0.112)
Sleep					0.095*** (0.011)	0.093*** (0.011)
Exercise					0.049** (0.020)	0.046** (0.020)
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%

Appendix

Instructions

[Screen 1]

WELCOME!

Thank you for participating in today's session. The session will proceed in several stages.

Stage 1: Video

Stage 2: Practice Task

Stage 3: Experiment

Stage 4: Receive payment and/or products

press Enter to continue...

Notes: This screen did not include the video stage for participants in the control group.

[Screen 2]

Video

This stage will proceed as follows:

1. You will see a video of approximately 6 minutes of duration.
2. Please, keep your eyes fixed at the stationary red dot at the bottom of the screen. Refrain from looking at everything else but the red dot.
3. If you get distracted and accidentally look elsewhere, please return your attention immediately to the red dot.

Press Enter to continue...

Notes: Participants in the control group were not presented with this screen.

Participants in the hard self-control condition were told the video will last 30 minutes.

[Screen 3]

This concludes this stage of the experiment.

Now we will proceed to the practice task.

Press Enter to continue...

[*Screen 4*]

Practice Task

This stage will proceed as follows:

1. You will be presented with 10 different products.
2. Each product is followed by a purchasing decision.
3. You will choose either to purchase the product or not by pressing the right cursor for yes or the left cursor for no.

Press Enter to continue...

[*Screen 5*]

This concludes this stage of the experiment.

Now we will proceed to the experiment stage.

Press Enter to continue...

[*Screen 6*]

Experiment

This stage will proceed as follows:

1. You will be presented with 80 products.
2. You will make a decision to either purchase the product or get \$5 in cash.
3. Press the right cursor (Yes) if you would like to purchase the product or press the left cursor (NO) if you would like to get the \$5 cash.

Press Enter to continue...

[*Screen 7*]

4. Your decisions are real. At the conclusion of this stage, four decisions will be randomly selected to be binding.

5. For each decision, if your answer was yes, you will receive the product. If your answer was no you will receive \$5 in cash.

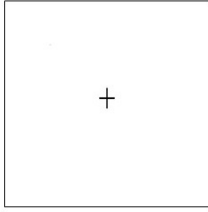
Let the monitor know when you are ready to continue...

[*Screen 8*]

This concludes this stage of the experiment.

You will now draw the four decisions that will be realized.

Let the monitor know when you are ready to continue...



Would you buy the product?

← NO → YES →

Product List

6.1 Food Products

Atkins chocolate chip protein bars; Ferrero Rocher chocolate; G2 Gatorade powder packs; Great value trail mix; Jack Links meat snacks; Jif creamy peanut butter; Kellogs rice Krispies treats bars; Kellogs special K protein shakes; Lipton indulge black tea; Nesquik chocolate powder; Old fashioned office snack hard pretzels; Pringles potato chips; Quaker chewy granola bars; Snickers variety mix; Spectrum organic virgin coconut oil; Starbucks french roast arabica coffee; The Bakery chocolate fudge cake; The Bites Company almond biscotti bites; Tree of life organic apricot fruit spread; Wonderful roasted unsalted pistachios.

6.2 Office Supplies

Belkin essential surge protector; Bostitch antimicrobial pencil sharpener; Brownline monthly planner; Casio fx-300MS calculator; Casemate wire mesh desk organizer; Eldon desk organizer; Expandable pocket file folder paper organizer; Expo dry erase markers; Honeywell table top air circulator fan; Mainstays metal desk lamp; Paper Mate felt tip pens; PNY 32GB USB; Sandisk 32GB USB; Sentry safe lock box; Sharpie fine permanent markers; Sharpie gel highlighters; Swingline desk stapler; Swingline hole puncher; Westcott scissors; X-ACTO electric pencil sharpener.

6.3 Health-Personal Care

Advil congestion relief coated tablets; Centrum chewables multivitamin supplement; Cetaphil moisturizing care; Crest pro-health multiprotection; Crest sensi-stop strips; Dove sensitive skin nutrient moisturizer; Dr. Scholl's foot powder; Eucerin daily protection moisturizing body lotion; Equate adult gummy multivitamins; Equate restore tears lubricant eye drops; Equate comfort gel lubricant eye drops; Equate fiber therapy supplement; Hawaiian Tropic clear mist spray sun screen; Nature made fish oil soft gels; Neutrogena sport sunscreen spray; Neutrogena ultra sheer sun screen; Olay ultra moisture beauty bars; Oral-B advanced vivid toothbrushes; Spring Valley calcium coated tablets ; Tums tropical fruit tablets.

6.4 Home Appliances

Brentwood electric coffee mug with wire car plug; Brita water pitcher; Contigo coffee mug; Contigo water bottle; La Crosse technology LED alarm clock; Energizer AAA 16 battery pack; Energizer LED metal light; Exco measuring spoon set; Forty-piece tool kit; French press coffee maker; Hand soap container; Hefty touch-lid trash can; Lysol neutra air fresh-matic; Pyrex 6-piece store value pack; Pyrex glass bakeware ; Rubbermaid large wire dish rack; Rubbermaid shaker bottle; Sauce server bowls; Salt and pepper condiment container; Sunbeam weight scale.