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SELF-REGULATION AND LIVER FUNCTION: EXPANDING AN ECOLOGICAL MODEL

Tory Anne Eisenlohr-Moul
University of Kentucky, toryanne@gmail.com

ABSTRACT OF THESIS

SELF-REGULATION AND LIVER FUNCTION:
EXPANDING AN ECOLOGICAL MODEL

Under conditions of high self-regulatory effort, peripheral organ systems have been found to slow, potentially to rearrange energetic priorities in favor of the brain. The present study tested an expansion of this model by exploring the possibility that alcohol metabolism (i.e., liver function) may slow during self-regulation. We also anticipated that high trait self-control would attenuate the effect of condition on metabolism. Twelve males aged 21-25 completed two conditions in counterbalanced order. During each session, the participant received 0.33 ml/kg of absolute alcohol for a target peak blood alcohol concentration (BAC) of 0.03 g%. Participants then performed tasks (self-regulatory tasks in the *high self-regulation condition* and identical tasks without a self-regulatory component in the *low self-regulation condition*) and BAC was measured throughout. Although there was no main effect of condition, trait self-regulation moderated the effect of condition on alcohol metabolism such that only those with lower trait self-control had slower alcohol metabolism under high self-regulatory effort. These results provide support for the hypothesis that liver function may indeed be altered by self-regulatory effort. In addition to suggesting the liver as a target organ for psychophysiological research, these data provide further support for slowing of peripheral systems during high self-regulatory demand.

KEYWORDS: Self-regulation, Ego Depletion, Ecological Models, Liver Function, Alcohol Metabolism.

Tory A. Eisenlohr-Moul
Student's Signature

March 25, 2011
Date

SELF-REGULATION AND LIVER FUNCTION:

EXPANDING AN ECOLOGICAL MODEL

By

Tory Anne Eisenlohr-Moul

Suzanne Segerstrom
Director of Thesis

David T. R. Berry
Director of Graduate Studies

March 25, 2011
Date

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THESIS

Tory Anne Eisenlohr-Moul

The Graduate School

University of Kentucky

2011

SELF-REGULATION AND LIVER FUNCTION: EXPANDING AN ECOLOGICAL MODEL

THESIS

A thesis submitted in partial fulfillment of the
requirements for the degree of Master of Science in the
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By

Tory Anne Eisenlohr-Moul

Lexington, KY

Director: Dr. Suzanne Segerstrom, Professor of Psychology

Lexington, KY

2011

For L.L.

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Chapter One: Introduction

Self-regulation

Self-regulation refers to internal guidance processes aimed at achieving a valued quality of experience, and to the flexibility and control necessary for adaptive behavior given different environmental demands. Self-regulation takes many forms, such as controlling thoughts, managing emotions, overcoming unwanted impulses, fixing attention, guiding behavior, and making choices (Baumeister, Vohs, & Tice, 2007). The large number of serious personal and societal problems that represent failures of cognitive, emotional, and behavioral self-regulation—emotional disorders such as anxiety and depression, substance abuse, violent behavior, overeating, and overspending, to name a few— highlight the importance of these processes.

Historically, an individual's ability to self-regulate has been labeled 'will power,' suggesting that a given person may have more or less self-regulatory 'strength'. While this manner of characterizing self-regulation fell out of fashion along with other psychoanalytic and psychodynamic concepts, it regained support in the 1990's when several research findings appeared consistent with a limited resource model of self-regulation. Today, a growing body of evidence supports the notion that self-regulation relies upon a limited energy source that may be depleted or fatigued in the short-term by self-regulatory efforts and that fatiguing these resources by performing a self-regulatory task predicts decrements in performance on a subsequent self-regulatory task (for meta analysis, see Hagger, Wood, Stiff, & Chatzisarantis, 2010). Many different tasks draw upon the same pool of self-regulatory resources and therefore fatigue self-regulatory strength. Some specific processes requiring self-regulatory resources include self-

presentation or impression management, kindness in response to a partner's bad behavior, restraining sexual behavior, interracial interactions and the suppression of prejudice, eating restraint among dieters, spending restraint, restraint of aggression after being provoked, making choices, and intelligent and logical decision-making (DeWall, Stillman, Baumeister, & Gailliot, 2007; Finkel & Campbell, 2001; Gailliot & Baumeister, 2007; Richeson & Shelton, 2003; Schmeichel, Vohs, & Baumeister, 2003; Vohs & Heatherton, 2000; Vohs, Baumeister, & Ciarocco, 2005; Vohs, Baumeister, Shmeichel, Twenge, Nelson, & Tice, 2008; Vohs & Faber, 2004). It is clear that within-person variation in self-regulatory resources has the potential to affect a wide variety of processes relevant to personal and societal wellbeing.

Ecological Models and Self-Regulation

Ecological models of the body postulate that, given different environmental demands, certain organ systems will take energetic priority at the expense of other, less immediately critical organ systems. The 'fight-or-flight' response serves as a particularly illustrative example: when the environment presents an imminent threat to survival, the cardiovascular system and the large muscles of the body take energetic priority, receiving a disproportionate amount of nutrient and oxygen-rich blood, which enables optimal functioning of crucial organs and muscles. However, this energetic shift comes at a cost to other parts of the body; blood is directed away from the digestive and reproductive systems, which take low energetic priority in the case of an imminent threat to survival.

Like the stressful circumstances in which the 'fight-or-flight' response occurs, self-regulatory demands may have physiological correlates. A few studies have attempted to determine the energetic priority given to various organs during self-

regulation and suggest that peripheral energy use may be downregulated in the presence of self-regulatory demand. Previous work demonstrates that the cellular branch of the immune system downregulates in response to both acute and chronic self-regulatory demands (Segerstrom, 2005; Segerstrom, 2006; Segerstrom, Castaneda, & Spencer, 2003). In addition, self-regulation has been associated with a slower heart rate and higher heart rate variability during a self-regulatory task compared to a control task (Segerstrom & Solberg Nes, 2007). These results are consistent with an ecological model in which the energetic demands of the brain take priority during self-regulation. It should be noted, however, that downregulation of these organs or systems is most likely to occur when the demands placed on them are of a mild to moderate nature; that is, if the processes they are engaged in take a higher priority than self-regulation, their functioning is less likely to be altered. If self-regulatory demand is capable of downregulating both immune response and heart rate, it seems possible that other energetically expensive organs, such as the liver, could also be downregulated by self-regulatory demand. If this were the case, a self-regulatory task might be expected to cause short-term decrements in the functioning of these organs, such as slowed metabolism of toxins by the liver.

While all body processes rely on the metabolism of glucose for fuel, the brain uses a disproportionately large amount, accounting for roughly 21% of the body's metabolism despite making up only 2% of the body's mass (Elia, 1992; Reivich & Alavi, 1983; Siesjö, 1978). Although this evidence is not without its critics (Kurzban, 2010), there is evidence that higher-order, goal-oriented functions such as self-regulation are among the most glucose-expensive of the brain's processes and may deplete levels of blood glucose more quickly than other mental tasks (Fairclough & Houston, 2004;

Gailliot et al., 2007). Whether or not blood glucose levels play a literal role in the short-term fluctuation of self-regulatory strength, it may be useful to measure fasting blood glucose for another reason. Fasting blood glucose provides some indication of an individual's metabolic regulation and health. A certain level of glucose in peripheral blood may indeed be necessary for self-regulation, but it may be equally interesting to estimate one's regulation of blood glucose and efficiency of glucose use, as these trait-like variables are likely to be proximally related to self-regulatory acts.

The liver consumes an amount of glucose roughly equal to that of the brain, accounting for approximately 21% of the body's metabolism (Elia, 1992). The liver serves a wide range of functions in the body, most notably the breakdown of toxic substances, the synthesis of protein, the production of catalysts for digestion, and the release of glycogen. Because liver function is energetically expensive, it is a logical target to be slowed in order to reduce peripheral glucose demand. One widely recognized task of the liver is to break down alcohol into less harmful substances following ingestion; the liver metabolizes 90% of ingested alcohol, with the remaining 10% metabolized by the stomach and kidneys. Previous research suggests that the liver metabolizes alcohol in a rigid linear fashion—about 15mg of alcohol per 100ml of blood per hour (Batt, 1989).

The purpose of this study is to examine the effects of self-regulatory tasks on liver function—specifically, on alcohol metabolism. Rate of alcohol metabolism has thus far been found to be relatively imperturbable; it is unaffected by factors such as physical exercise and ingestion of caffeine (Barnes, Cooke, King, & Passmore, 1965; Marczinski & Fillmore, 2006). However, no studies have examined possible effects of the energetic

demand of self-regulation on rate of alcohol metabolism. Therefore, the current study will attempt to address the question of whether the rate of alcohol metabolism can be slowed by self-regulatory demand following alcohol ingestion.

Individual Differences in Self-Regulation and Motivation

In addition to the within-person variability in self-regulatory strength, there is also between-person variability in self-regulatory strength and endurance. Some individuals self-regulate more effectively and consistently than others, a trait that appears to be stable over time (Mischel, 1974; Tangney, Baumeister, & Boone, 2004). Self-report measures of one's typical self-regulatory success predict both persistence on self-regulatory tasks (self-regulatory strength) and a relative resistance to self-regulatory fatigue (self-regulatory endurance). Measures such as these appear to capture some combination of innate capacity for self-control and the effects of self-regulatory practice, suggesting the possibility that self-regulatory processes can become less effortful with exercise. In addition, self-regulation may be more enjoyable and less demanding for individuals who enjoy a high level of self-regulatory success (Laran & Janiszewski, 2010).

Heart rate variability (HRV), a measure of parasympathetic control over the heart, indexes individual differences in innate capacity for and tendency toward self-regulation (Hansen, Johnson, & Thayer, 2003; Pu, Schmeichel, & Demaree, 2009). In contrast with questionnaires, which measure the effects of both capacity and practice, HRV is thought to capture self-regulatory capacity more purely by indexing the influence of neural structures that carry out self-regulatory processes (Thayer, Hansen, Saus-Rose, & Lane, 2009). Individuals with higher resting HRV have been shown to persist longer on an anagram task, even after being presented with a different self-regulation task (i.e., eating

carrots rather than cookies; Segerstrom & Solberg Nes, 2007). HRV was also higher during self-regulatory tasks than during control tasks, suggesting that phasic changes in HRV index self-regulatory effort.

Another possible indicator of metabolic health and efficiency is fasting blood glucose. In young, healthy populations, higher fasting blood glucose within the normal range could indicate more effective counter-regulatory (e.g., autonomic nervous system) processes to maintain blood glucose. In older or unhealthy individuals, higher fasting blood glucose and especially values above the normal range may indicate the development of insulin resistance characteristic of the early stages of Type II diabetes. In such samples, higher blood glucose may result in poorer self-regulatory abilities if cells cannot use available glucose efficiently. Therefore, the effect of fasting blood glucose on self-regulatory capacity is expected to be dependent on the sample and the obtained range of blood glucose levels.

Additionally, the degree of intrinsic motivation for one's self-regulatory efforts on a given task has been found to moderate the relationship between self-regulatory efforts and self-regulatory fatigue (as reflected in decrements in performance on a subsequent self-regulatory task). Those who engage in a self-regulatory task for intrinsic reasons (e.g., "it was fun to challenge myself") show less self-regulatory fatigue following that self-regulatory task (Muraven, 2008; Muraven, Rosman, & Gagne, 2007; Muraven, Gagne, & Rosman, 2008). In previous studies, this buffering effect has been shown to be mediated by both subjective vitality and feelings of autonomy. In addition to having a different subjective quality, intrinsically motivated self-regulation may actually require less effort and be experienced as more enjoyable (Laran & Janiszewski, 2010).

Hypotheses

Self-Regulatory Fatigue, Individual Differences, and Alcohol Metabolism

First, I predicted that when participants were forced to self-regulate following alcohol ingestion, their rate of alcohol metabolism would be slower than when they were not forced to self-regulate following alcohol ingestion. I also predicted that higher self-reported trait self-control, higher resting HRV, higher intrinsic motivation for self-regulatory tasks, and higher fasting blood glucose would attenuate the slowing effect of self-regulatory demand on alcohol metabolism.

Self-Regulatory Fatigue, Alcohol, Individual Differences, and Blood Glucose Levels

Second, I attempted to extend the finding that self-regulatory effort decreases blood glucose levels by examining whether this effect would be present even after the ingestion of alcohol (Gailliot et al., 2007). I predicted that, after ingesting alcohol, participants' blood glucose levels would decrease more during high self-regulatory demand than during low self-regulatory demand. Further, I predicted that higher resting HRV, self-reported trait self-control, and intrinsic motivation for self-regulatory tasks would attenuate these decreases in blood glucose.

Self-Regulatory Fatigue, Individual Differences, and Persistence

Third, I attempted to replicate and extend studies indicating that self-regulatory effort fatigues a limited resource, resulting in decrements in performance on a subsequent self-control task (e.g., Schmeichel, 2007). I predicted that, even after ingesting alcohol, participants would persist longer on a self-regulatory task following low self-regulatory demand than following high self-regulatory demand. Further, I attempted to replicate the findings that individual differences relevant to self-regulatory performance moderate the

effects of self-regulatory fatigue on subsequent self-regulatory performance (Segerstrom & Solberg Nes, 2007; Tangney, Baumeister, & Boone, 2004). Specifically, I predicted that higher resting HRV, fasting blood glucose levels, self-reported trait self-control, and intrinsic motivation for self-regulatory tasks would predict persistence on a self-regulatory task following high self-regulatory demand.

Chapter Two: Method

Participants

Participants were 12 males ages 21-25 recruited from the University of Kentucky's Introductory Psychology participant pool. Of the 12 participants, 9 participants completed both conditions, 2 participants completed the high self-regulation condition only, and 1 participant completed the low self-regulation condition only. The University of Kentucky Medical Institutional Review Board approved the protocol before recruitment began. Volunteers received course credit and $10 for their participation in the entire two-session study.

Physiological Measures

Drug Screens. Drug screens were performed in the laboratory using single-use OnTrak TesTstick dip-and-read urine drug tests (Varian, California, United States). Participants were tested for recent use of amphetamine, barbiturates, benzodiazepines, morphine, cocaine, and tetrahydrocannabinol before each session.

Blood Glucose. Blood samples were attained using single-use blood sampling lancets, and an Accu-check compact glucose testing meter was utilized to measure blood glucose levels (mg/dL). The Accu-check compact meter has demonstrated acceptable accuracy in plasma glucose level measurements (Dillon, 1997; Vallera, Bissell, & Barron, 1991). Readings indicate the amount of glucose in peripheral blood.

Blood Alcohol Content (BAC). Blood alcohol content was measured using an Intoxilyzer 400 handheld breath alcohol screener (CMI, Inc, Kentucky, United States). At each measurement point, two samples were collected and later averaged together to

increase the reliability of BAC measurement. Participants rinsed their mouths with water three times prior to completing each test.

Heart Rate Variability (HRV). Heart rate variability is a measure of parasympathetic control over the heart (primarily via the vagus nerve), and has been associated with self-regulatory strength, effort, and fatigue (Segerstrom & Solberg Nes, 2007). Cardiovascular activity was recorded using the MP150 Biopac data acquisition system and Acqknowledge software was used for acquisition and storage (Biopac Systems, Inc, Santa Barbara, CA). Three Ag/AgCl electrodes with shielded leads were attached to the chest in a Lead II configuration. Electrocardiogram (EKG) readings were amplified using an ECG150C Electrocardiogram Amplifier, and were sampled at 1,000 samples/s. Spectral analysis of the EKG data was conducted using Mindware HRV software (Mindware, Inc; Gahanna, OH). HRV was estimated using log high-frequency (.12-.40) spectral power, an indicator of vagally-mediated changes in HRV. Resting HRV was measured at both sessions; because the correlation between the two measurements was high (r=.93), the two measurements were averaged for analysis.

Psychological Measures

Demographic Variables. For descriptive purposes, participants were asked to provide their age and race.

Short Michigan Alcoholism Screening Test (S-MAST; Selzer, Vinokur, and Van Rooijen, 1975). The S-MAST is a structured interview for the detection of alcoholism. The S-MAST is composed of 25 yes/no items such as “Are you able to stop drinking when you want to?” and “Have you ever gotten into trouble at work because of drinking?” The S-MAST has good internal consistency (.95), and has been shown to

differentiate alcoholic from normal populations (Selzer, Vinokur, & Van Rooijen, 1975; Shields, Howell, Potter, & Weiss, 2007; Storgaard, Nielsen, & Gluud, 1994). Because the scale was used as a screening measure in the current study, the range of scores was restricted such that all participants had low scores on this measure; however, the scale was reliable (α= .87).

Positive and Negative Affect Schedule – Expanded Form (PANAS-X). Positive, negative, fatigued, and attentive affect were measured using 26 items from the PANAS-X (Watson and Clark, 1994). Completion of the PANAS-X requires participants to rate, on a scale of 1 to 5 (where 1 is very slightly or not at all, and 5 is extremely), the extent to which they are experiencing a given affective state at the present moment (e.g., afraid, distressed, determined, proud, concentrating, sluggish). The PANAS-X has convergent validity with other mood measures (Watson, Clark, & Tellegen, 1988). In the present study, the positive, negative, fatigued, and attentive affect scales were administered so as to measure the effects of the experimental conditions on affect and rule out any possibility that changes in affect are responsible for results. Internal consistency was acceptable throughout, with α's ranging from .72 to .92.

Perceived Self-Regulatory Demand. After each self-regulation task and the persistence task, participants were asked to appraise the current task with regard to its self-regulatory demand; this scale served as a manipulation check. This scale uses six items with Likert-type response scales ("It was difficult," "It was stressful," It made me tired," "It required a lot of effort," "I had to concentrate on the task," "I had to force myself to keep going," "I wanted to stop before it was over"). The scales demonstrated acceptable internal consistency in the current study; α's ranged from .79 to .95.

Intrinsic Motivation Inventory (IMI). The intrinsic motivation inventory is a questionnaire used to determine an individual's mood, arousal, and motivation orientation (Ryan, 1982). There are four subscales of this inventory; the interest/enjoyment subscale, which consists of 7 items considered to measure intrinsic motivation, was used to measure motivation orientation toward each self-regulatory task in this study. Separate instructions for each inventory instructed the participant to rate each self-regulatory task separately. The inventories demonstrated adequate internal consistency in the current study; α's ranged from .75 to .87. Because the inventories were highly correlated across tasks (r=.94), they were combined for analyses.

Self-Control Scale (SCS). The self-control scale is a 36-item questionnaire designed to measure one's trait capacity for self-control (Tangney, Baumeister, and Boone, 2004). The measure contains 24 negatively-worded items ("I often act without thinking through all the alternatives") and 12 positively-worded items ("I am able to work effectively toward long-term goals."). In previous studies, the scale has shown good internal consistency (.89) and test-retest reliability over three weeks (.89). In the current study, internal consistency was adequate (α= .80). Higher scores on the self-control scale are associated with higher grade point average, lower scores on the S-MAST (Selzer, Vinokur, & Van Rooijen, 1975), and positive psychological adjustment as measured by the Symptom Checklist 90 (SCL-90; Derogatis, Lipman, & Covi, 1973). In our sample, the SCS and the S-MAST were uncorrelated (r=.27, p=.45).

Procedure

Participant Recruitment and Screening

Males in the subject pool who were between the ages of 21-35 were made aware of their potential eligibility in a mass email message. Interested parties responded to the email and the researcher conducted a phone screen, which included the S-MAST, a brief drinking habits questionnaire, and a standard health screening questionnaire. Individuals were excluded if they had a score of 5 or higher on the S-MAST or reported an average of 5 or more drinks per drinking episode. Individuals reporting psychiatric or substance abuse disorders, cigarette use, head trauma, or other central nervous system injuries were excluded. Volunteers reported their weight; those under 100 lbs or over 210 lbs were excluded.

Pre-Experiment Instructions

Participants completed two conditions in counterbalanced order. In the high self-regulation condition, the participant was dosed with alcohol, presented with self-regulatory tasks, and his blood alcohol content was measured at regular intervals so as to calculate the rate of alcohol metabolism. In the low self-regulation condition, the same participant was dosed with alcohol, presented with similar tasks not requiring self-regulation, and his blood alcohol content was measured in an identical fashion. This study was designed so as to compare rates of alcohol metabolism within a given participant, varying the type of tasks (self-regulatory or not). Because the amount of food in the gastrointestinal tract can have an effect on rate of alcohol metabolism, participants were instructed to fast overnight starting at midnight the night prior to the study, and asked not to drink anything but water between midnight and their scheduled experiment

time. In addition, participants were asked not to drink alcohol or take any medications for 24 hours prior to their appointment.

Initial Measures

See Figure 1 for a visual timeline of the experiment. Sessions were held in the University of Kentucky Psychoneuroimmunology Laboratory between 8 a.m. and 12 p.m. Testing was conducted in a small room with a table, chair, and laptop computer. First, participants completed a demographics questionnaire and the PANAS-X scales (after giving informed consent in the first session). Breath alcohol and field sobriety tests were then administered to confirm a blood alcohol content (BAC) of 0, and a urine sample was screened for evidence of recent use of amphetamine, barbiturates, benzodiazepines, morphine, cocaine, and tetrahydrocannabinol. No participant tested positive for any drugs, had a BAC greater than 0, or failed the sobriety test. Then, a fingerstick blood sample was analyzed for fasting levels of blood glucose; participants whose blood glucose levels indicated noncompliance with overnight fasting instructions or insulin resistance (i.e., blood glucose levels above 100 mg/dl) were rescheduled. Two participants were unable to participate due to two consecutive fasting blood glucose readings over 100. Heart rate leads were then attached to participants in a Lead II configuration, and the EKG was collected for 10 minutes.

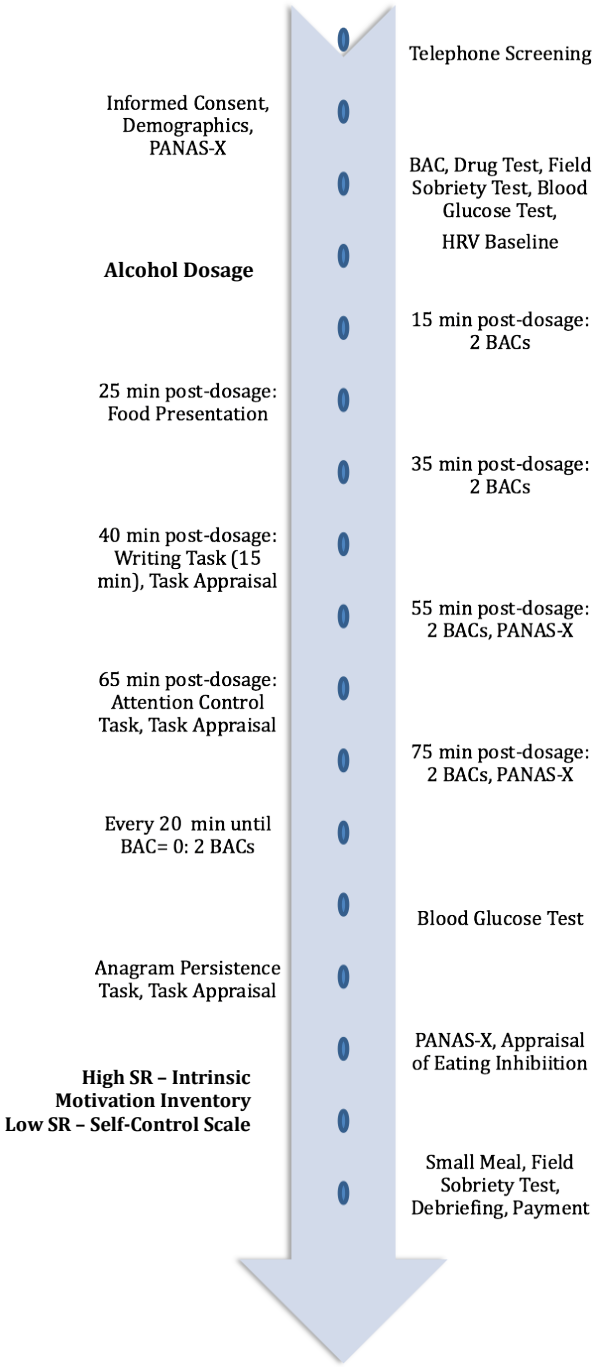

Figure 1. Visual Timeline of the Experiment.

Alcohol Dosing

Participants were then dosed with pure ethanol in diet lemon soda, calculated based on their body weight, to achieve a peak BAC of 0.03 g%. This dosage was selected because it would raise BAC enough to plot the curve of decline, but would not raise BAC enough to cause significant behavioral impairment, which has been demonstrated at BACs of 0.05 g% and greater (Fillmore, 2007), and would not create significant challenge for the liver. At 15 minutes post-dosage, participants rinsed their mouths with water three times and were given two breath alcohol tests one minute apart (two measurements were averaged for reliability).

Self-Regulatory Manipulation

Resisting the urge to eat attractive food has been shown to fatigue self-regulatory strength (Baumeister, Bratslavsky, Muraven, & Tice, 1998). At 25 minutes post-dosage, participants were presented with a plate of food and told that they could eat some of the food at the end of the experiment. The food was attractive in the high self-regulation condition (cookies, chips, and candy) and unattractive in the low self-regulation condition (radishes, celery, and carrots). At 35 minutes post-dosage, participants rinsed and underwent breath alcohol tests as before.

At 40 minutes post-dosage, participants completed a writing task. In the high self-regulation condition, they wrote for 15 minutes about a recent trip without using the letters A or N. The experimenter asked the participant to "be slow and careful, and don't make any mistakes" in writing their stories; these instructions were intended to minimize the participants' perception of the task as stressful while increasing their motivation to self-regulate. This task required participants to inhibit the use of two frequently used

letters, and has been shown to fatigue self-regulatory strength (Schmeichel, 2007). In the low self-regulation condition, participants wrote for 15 minutes about a recent trip with no restrictions. After completion, participants filled out an appraisal of the self-regulatory demand of the task. At 55 minutes post-dosage, participants rinsed, underwent 2 breath alcohol tests, and completed the PANAS-X. Participants then underwent another blood glucose test.

At 65 minutes post-dosage, participants watched a video clip with no sound lasting 3 minutes and 54 seconds, in which an off-camera interviewer interviews a female while random words flash below the image. In the high self-regulation condition, participants were told not to read or look at any of the words that appear at the bottom of the screen, and must return their gaze to the woman being interviewed if they find that their attention has shifted to the words. In the low self-regulation condition, participants merely watched the video. Participants then completed an appraisal of the self-regulatory demand of the task. At both 75 and 95 minutes post-dosage, participants rinsed and underwent 2 breath alcohol tests and completed the PANAS-X. At 95 minutes post-dosage, participants underwent a final blood glucose test.

Final Measures

Next, to measure level of self-regulatory depletion, the participants were presented with an unsolvable anagram and asked to solve it. They were told that they could quit whenever they like by saying "stop". Participants were timed starting at the end of instructions and ending when they said "stop". Persistence (in seconds) on this task served as a marker of self-regulatory fatigue; longer persistence was assumed to represent less fatigue. After this, participants completed an appraisal of the self-

regulatory demand of the anagram task, the PANAS-X, and an appraisal of the self-regulatory demand of not eating the food on the table. Next, participants completed either the interest/enjoyment subscale items from the Intrinsic Motivation Inventory (high self-regulation condition) or the Self-Control Scale (low self-regulation condition). Then, participants were allowed to eat some of the food that they were previously promised and another small meal, and were free to go once they had successfully completed a field sobriety test. At the end of the second session, participants were debriefed and paid $10.

Chapter Three: Results

Descriptive Analyses

Means and standard deviations for between-person variables are presented in Table 1. The average correlation between the two BAC measurements at any given time point was moderate; the two values were averaged at each measurement point to increase reliability of the BAC measure ($r(105)=.41$, $p<.001$).

Analyses

Both BAC and blood glucose data were analyzed using multi-level growth models with time nested within conditions nested within people. Between person predictors were grand mean centered for analysis. The total effect of each predictor was evaluated by calculating the change in -2 log likelihood (LL) between a null model and a model including predictors. The effects of each predictor were evaluated by the gamma weight for that component.

The three-level unconditional growth model predicting BAC included a random effect of time at the person level, and both a random intercept (peak BAC) and a random effect of time at the condition level. This structure indicates that people differed from each other in their change in BAC over time, and that conditions differed within people in both peak BAC and change in BAC over time. An unconditional model including a random effect for the intercept at the person level did not converge, suggesting that there was not a random intercept; that is, peak BAC did not significantly differ between participants. Prediction models were fit for each hypothesized effect and compared to the unconditional model.

Table 1

Means and Standard Deviations for Between-Person Variables

Variable	Mean (SD)
Weight (in pounds)	177.83 (20.41)
Frequency of Drinking Alcohol (in sessions per week)	2.16 (1.09)
Typical Number of Beverages in a Drinking Session	4.37 (.98)
Dosage (in grams)	25.78 (3.30)
Resting HRV (log high frequency power)	6.38 (.83)
Self-Control Scale	3.26 (.36)
Intrinsic Motivation Inventory (Average)	3.70 (.57)
Perceived Self-Regulatory Demand in High SR Condition(Average)	3.89 (1.71)
Perceived Self-Regulatory Demand in Low SR Condition (Average)	2.65 (1.40)
Fasting Blood Glucose	92.24 (5.41)
Peak BAC	.039 (.007)
Rate of Alcohol Elimination (BAC reduction per hour)	.0013

Self-Regulatory Fatigue, Individual Differences, and Alcohol Metabolism

It was hypothesized that liver function is downregulated in response to a self-regulatory challenge. Therefore, I predicted that participants would metabolize alcohol more slowly in the high self-regulation condition than in the low self-regulation condition. Contrary to prediction, the effect of condition on rate was not statistically significant ($\gamma_{CONDITION*TIME}$ = -.02, *SE*=.03, *t*(90)=-.59, *p*=.56).

It was also hypothesized that several individual differences relevant to self-regulation interact with self-regulatory fatigue to predict alcohol metabolism. First, it was predicted that heart rate variability (HRV), which is thought to index trait self-regulatory capacity, would interact with self-regulatory demand to predict rate of alcohol metabolism such that lower HRV would be associated with slower alcohol metabolism in the high self-regulation condition than in the low self-regulation condition. However, this effect was not statistically significant ($\gamma_{HRV*CONDITION*TIME}$ = -.01, *SE*=.04, t(87)= -.27, *p*=.79; model converged only after removing the random effect of time at the condition level).

Second, it was predicted that self-reported trait self-control (as indexed by the Self-Control Scale) would interact with condition such that lower trait self-control would be associated with slower alcohol metabolism in the high self-regulation condition than in the low self-regulation condition. The interaction of condition and trait self-control was significant in the expected direction ($\gamma_{TRAITSELFCONTROL*CONDITION*TIME}$ = -.30, *SE*=.09, *t*(79)= -3.55, *p*=.0006; see Table 2 and Figure 2). Because the random effect of time at the condition level was not significant, it was removed; this indicates that, after inclusion

Table 2

Interaction of Trait Self-Control (Self-Control Scale), Condition, and Time Predicting BAC

Fixed Effects	Estimate	S.E.	df	t value	Pr >
Intercept (peak BAC)	38.08	1.15	8	33.02	<.0001
Time	-.34	.02	79	-15.99	<.0001
High SR Condition	-.31	1.67	8	-.18	.86
Self-Control Scale (SCS)	-6.09	3.10	8	-1.97	.08
Time*High SR Condition	-.01	.03	79	-.37	.71
Time*SCS	.01	.06	79	.11	.91
SCS*High SR Condition	21.15	4.81	79	4.61	<.0001
Time*SCS*High SR Condition	-.30	.08	79	-3.55	<.0001

Random Effects	Variance Component	S.E.	Z value	Pr Z
Time (person-level)	.001	.001	1.01	.16
Intercept (condition-level)	4.28	2.65	1.62	.05
Residual	14.56	2.47	5.88	<.0001

-2LL	547.3
Δ -2LL	87.4
χ^2 (7)	10.62*

*p<.15

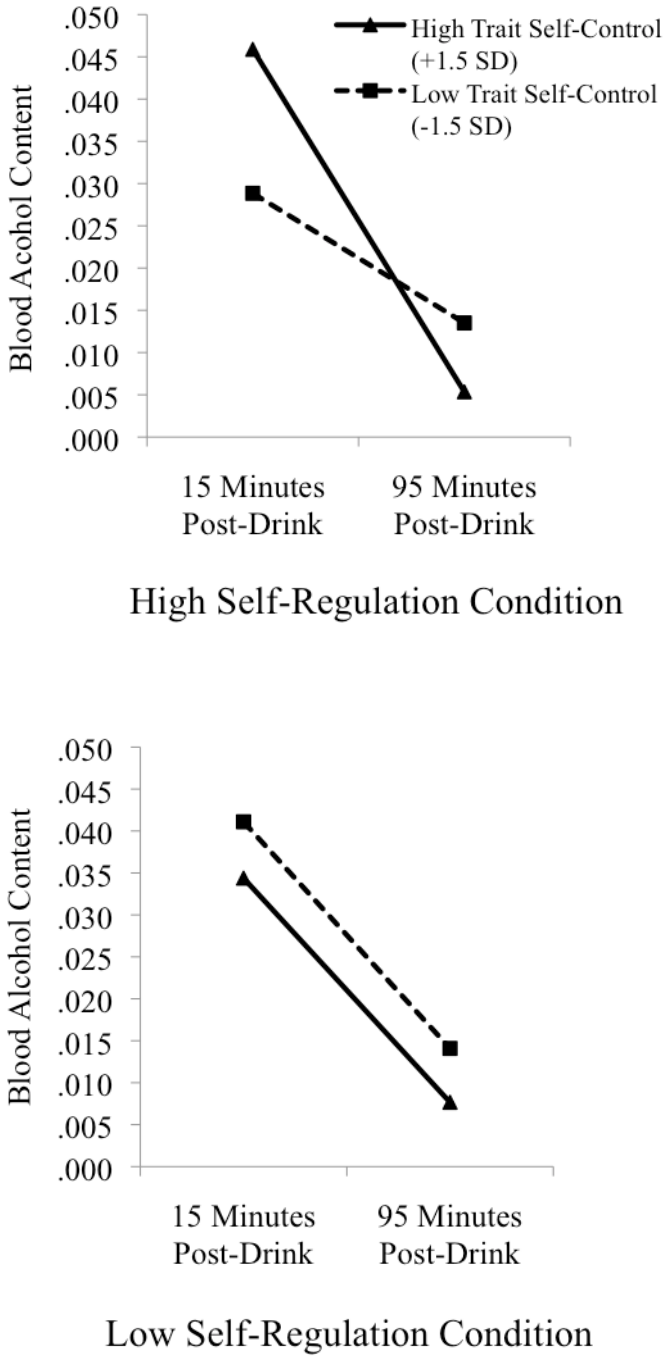

Figure 2. Trait self-control (Self-Control Scale) and self-regulatory demand predicting BAC over time.

of predictors in the model, there was no longer a significant amount of variance in rate of metabolism between conditions within a given participant.

In order to decompose this interaction, the data set was split by condition and the simple effects of time, trait self-control, and their interaction were tested in multilevel models with time nested within person. In the low self-regulation condition, there was a significant effect of time only (γ_{TIME}=-.34, *SE*=.02, *t*(38)=-18.44, *p*<.0001). However, in the high self-regulation condition, there were significant effects of time, trait self-control, and their interaction on BAC, suggesting that those with higher trait self-control had both higher peak BACs in the high self-regulation condition and metabolized alcohol more quickly in the high self-regulation condition (γ_{TIME}=-.35, *SE*=.02), *t*(34)=-15.25, *p*<.0001; $\gamma_{TRAITSELFCONTROL}$=17.91, *SE*=4.42, *t*(7)=4.05, *p*=.005; $\gamma_{TRAITSELFCONTROL*TIME}$=-.29, *SE*=.07, *t*(34)=-4.08, *p*=.0003). The finding that men with higher trait self-control had higher peak BACs in the high self-regulation was unanticipated. This effect appears to represent a failure of randomization to eliminate within-subject variability in factors associated with peak BAC, such as recent diet. Condition order did not account for this effect. Although this effect remains unexplained, peak BAC does not account for the effect of the interaction of trait self-control and condition predicting rate of alcohol metabolism.

Third, it was predicted that higher intrinsic motivation for self-regulatory tasks would interact with condition such that individuals with lower intrinsic motivation for the *self*-regulatory tasks would metabolize alcohol more slowly in the high self-regulation condition, but that individuals with higher intrinsic motivation for the self-regulatory tasks would metabolize alcohol at a constant rate regardless of condition. This effect was

not statistically significant ($\gamma_{INTRINSICMOTIVATION*CONDITION*TIME}$ = .03, *SE*=.03, *t*(87)=1.04, *p*=.30).

Finally, it was predicted that if fasting blood glucose levels were in normal range, higher fasting blood glucose levels would predict a faster rate of alcohol metabolism, and would interact with condition to predict a faster rate of alcohol metabolism between subjects in the high self-regulation condition. Although fasting blood glucose was within normal ranges, neither effect was statistically significant ($\gamma_{FASTINGGLUCOSE*TIME}$ = -.01, *SE*= .003, *t*(90)= -1.47, *p*= .14; $\gamma_{FASTINGGLUCOSE*CONDITION*TIME}$ = -.01, SE=.007, t(87)=-1.37, *p*=.17).

Self-Regulatory Fatigue, Individual Differences, and Changes in Blood Glucose

The three-level unconditional growth model predicting blood glucose levels included a random effect of time at the person level and a random intercept at the condition level. This structure suggests that rate of blood glucose change varied between people, and that fasting blood glucose varied between conditions within people.

It was predicted that blood glucose would decrease more rapidly in the high self-regulation condition than in the low self-regulation condition. However, this effect was not statistically significant ($\gamma_{CONDITION*TIME}$ = -.03, SE=.03, t(48)=-1.03, *p*=.30). It was also predicted that individual differences in trait self-control, resting HRV, and intrinsic motivation would moderate the effect of condition on rate of glucose change. However, none of these interactions were statistically significant ($\gamma_{HRV*CONDITION*TIME}$= .08, SE=.09, *t*(41)=.92, *p*=.36; $\gamma_{TRAITSELFCONTROL*CONDITION*TIME}$= .13, SE=.04, t(45)=-.1, *p*=.91; $\gamma_{INTRINSICMOTIVATION*CONDITION*TIME}$= -.01, SE=.05, t(43)=.30, *p*=.76).

Self-Regulatory Fatigue, Individual Differences, and Persistence

Anagram persistence data were analyzed with two-level models with conditions nested within people. The two-level null model predicting anagram persistence included a random effect for the intercept, which in this case reflects differences between people across conditions.

In keeping with previous findings that self-regulatory fatigue is associated with reduced persistence, it was predicted that individuals would persist longer on an anagram task at the end of the session in the low self-regulation condition than in the high self-regulation condition. However, the effect of condition on anagram persistence was not statistically significant ($\gamma_{CONDITION}$= -7.88, *SE*=9.00, *t*(29)=-.88, *p*=.38). With regard to individual differences, trait self-control moderated the effect of condition such that lower trait self-control predicted less persistence in the high self-regulation condition than in the low self-regulation condition ($\gamma_{TRAITSELFCONTROL*CONDITION}$=82.05, *SE*=23.51, *t*(26)=3.49, *p*=.002; see Table 3 and Figure 3). Additionally, HRV moderated the effect of condition on persistence such that higher HRV was associated with less persistence in the high self-regulation condition than in the low self-regulation condition ($\gamma_{HRV*CONDITION}$= -24.82, *SE*=9.70, *t*(28)=-2.56, *p*=.01; see Table 4 and Figure 4). Finally, intrinsic motivation moderated the effect of condition on persistence such that higher intrinsic motivation to engage in self-regulatory tasks was associated with less persistence in the high self-regulation condition than in the low self-regulation condition ($\gamma_{INTRINSICMOT*CONDITION}$=-28.81, *SE*=11.70, *t*(27)=-2.46, *p*=.02; see Table 5 and Figure 5).

Table 3

Interaction of Trait Self-Control (Self-Control Scale) and Condition Predicting Persistence

Fixed Effects	Estimate	S.E.	df	t value	Pr >
Intercept	187.62	22.42	8	8.37	<.0001
High SR Condition	-7.27	7.72	26	-.94	.36
Self-Control Scale (SCS)	-46.54	61.17	8	-.76	.47
High SR Condition*SCS	82.06	23.51	26	3.49	.002

Random Effects	Variance Component	S.E.	Z value	Pr Z
Intercept	4620.19	2152.45	2.15	.02
Residual	536.63	143.89	3.73	<.0001

-2LL	381.7
Δ -2LL	51.6
χ^2 (3)	44.79*

*p<.001

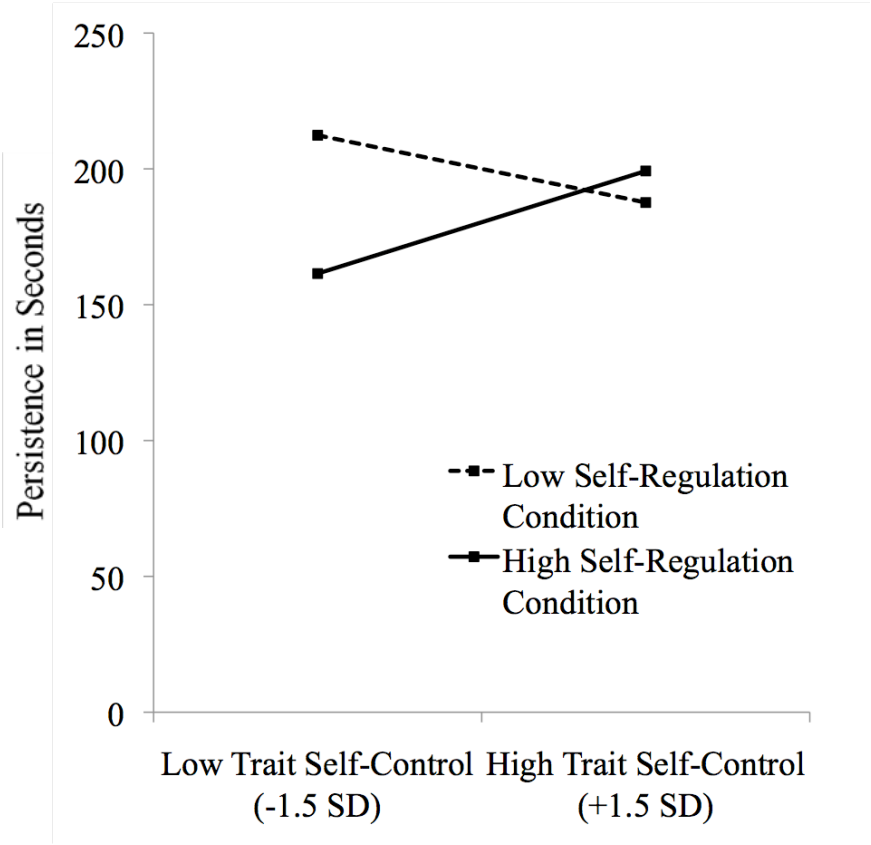

Figure 3. Trait self-control (Self-Control Scale) and self-regulatory demand (condition) interact to predict persistence (in seconds) on an anagram task at the end of the session.

Table 4

Interaction of Heart Rate Variability (HRV) and Condition Predicting Persistence

Fixed Effects	Estimate	S.E.	df	t value	Pr > __
Intercept	185.13	15.32	10	12.09	<.0001
High SR Condition	-9.03	8.26	28	-1.09	.28
Heart Rate Variability	-37.08	18.48	10	-2.01	.07
High SR Condition*HRV	-24.82	9.70	28	-2.56	.02

Random Effects	Variance Component	S.E.	Z value	Pr Z
Intercept	2420.24	1086.72	2.23	.01
Residual	624.21	162.24	3.85	<.0001

-2LL	421.3
Δ -2LL	12
χ^2 (3)	29.40*

*p<.001

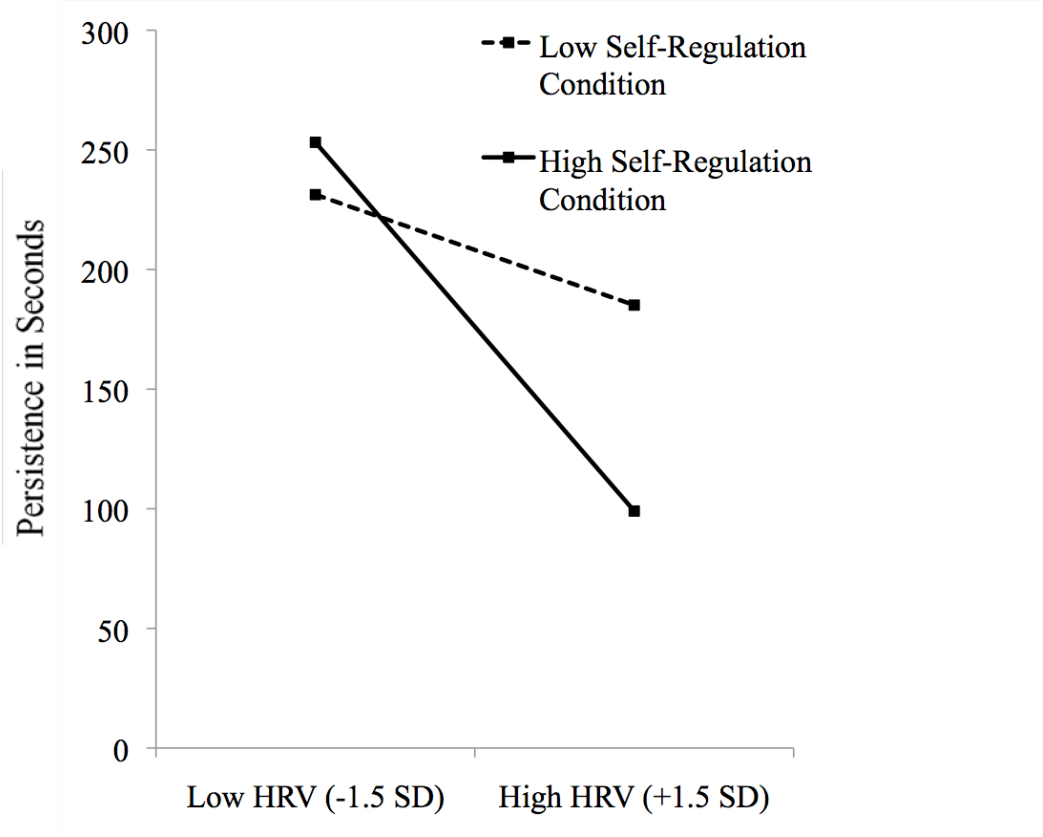

Figure 4. Heart rate variability (HRV) and self-regulatory demand (condition) interact to predict persistence (in seconds) on an anagram task at the end of the session.

Table 5

Interaction of Intrinsic Motivation and Condition Predicting Persistence

Fixed Effects	Estimate	S.E.	df	t value	Pr > __
Intercept	188.09	18.97	9	9.91	<.0001
High SR Condition	-7.24	8.31	27	-.87	.39
Intrinsic Motivation (IM)	-14.26	26.35	9	-.54	.60
High SR Condition*IM	-28.81	11.70	27	-2.46	.02

Random Effects	Variance Component	S.E.	Z value	Pr Z
Intercept	3646.32	1638.57	2.23	.01
Residual	625.89	164.54	3.80	<.0001

-2LL	404.9
Δ -2LL	28.4
χ^2 (3)	41.72*

*p<.001

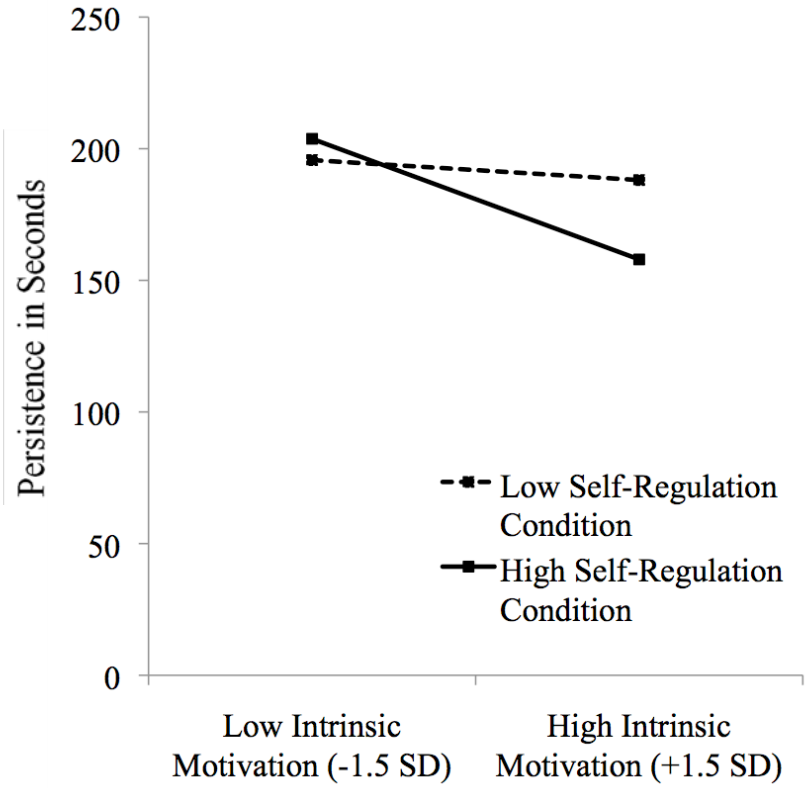

Figure 5. Intrinsic motivation and self-regulatory demand (condition) interact to predict persistence (in seconds) on an anagram task at the end of the session.

Can Affect or Perceived Self-Regulatory Demand explain these Results?

One possibility is that the effects on BAC and persistence described above were affected by changes in affect or perceived self-regulatory demand. Therefore, all significant predictors described above were tested as predictors of each type of affect and of perceived self-regulatory demand. Many significant effects emerged; they are described below (means and standard deviations are presented in Table 6).

Across conditions, participants reported less positive, negative, and attentive affect as well as less perceived self-regulatory demand during the attention task phase; less negative and attentive affect along with greater perceived self-regulatory demand in the anagram task phase; and less negative affect and less perceived self-regulatory demand in the eating task phase. Between conditions across task phases, participants rated tasks in the high self-regulation condition as more demanding ($\gamma_{CONDITION}$= 1.19, *SE*=.32, *t*(8)=3.73, *p*=.006). However, there were no significant effects of condition or the interaction of condition and task on any type of affect.

Trait self-control and condition interacted to predict perceived self-regulatory demand; in the high self-regulation condition, participants with higher self-control rated the tasks as much less demanding (γ= -1.94, *SE*=.93, *t*(64)= -2.08, *p*=.04). There were no significant effects of this two-way interaction on any type of affect. However, the three-way interaction of trait self-control, condition, and task phase predicted affect and perceived self-regulatory demand: positive affect was lower during the anagram task in the high self-regulation condition for those with higher trait self-control (γ= -1.12, *SE*=.53, *t*(44)=-2.12, *p*=.04), negative affect was higher during the anagram task in the

Table 6

Means and Standard Deviations for Affect and Perceived Self-Regulatory Demand Across Tasks and Conditions

	Eating Task		Writing Task		Attention Task		Anagram Task	
Participant Ratings	High SR	Low SR	High SR	Low SR	High SR	Low SR	High SR	Low SR
Positive Affect	2.70 (.63)	2.40 (.54)$_a$	2.59 (.55)	2.24 (.79)$_a$	2.35 (.54)	1.83 (.54)$_b$	2.49 (.67)	2.03 (.91)$_a$
Negative Affect	1.16 (.25)	.99 (.53)$_a$	1.36 (.34)	2.20 (.86)$_b$	1.19 (.28)	1.00 (.38)$_a$	1.16 (.29)	1.09 (.53)$_a$
Fatigued Affect	2.43 (.73)	2.50 (.77)	2.45 (.89)	2.20 (.86)	2.59 (.99)	2.51 (1.14)	2.50 (.92)	2.23 (1.26)
Attentive Affect	2.93 (.63)	2.92 (.71)$_a$	3.11 (.79)	2.70 (.76)$_a$	2.98 (.70)	2.15 (.77)$_b$	2.86 (.80)	2.25 (1.08)$_a$
Perceived SR Demand	2.18 (1.30)	1.73 (.76)$_a$*	4.68 (1.48)	2.14 (.90)$_b$*	3.62 (1.42)	2.11 (.75)$_a$*	5.09 (1.09)	4.60 (.89)$_a$*

Note: Standard deviations are in parentheses. SR = Self-regulation. * $p < .05$ for difference between high and low SR conditions. Tasks significantly different from each other are indicated by different subscripts.

high self-regulation condition for those with higher trait self-control (γ= .59, *SE*=.28, *t*(52)=2.10, *p*=.04), and attentive affect was lower during the eating task in the high self-regulation condition for those with higher trait self-control (γ= 2.10, *SE*=.79, *t*(45)=-2.65, *p*=.01).

To explore the possibility that affect or perceived self-regulatory demand mediated or confounded the previously described effect of the interaction of trait self-control, condition, and time on BAC, positive, negative, and attentive affect and perceived self-regulatory demand were added to the predictive model for BAC. The significance of the trait self-control by condition by time interaction term was not reduced by the inclusion of any of these three types of affect, eliminating the possibility that the interaction effect on BAC was influenced by affect. However, when perceived self-regulatory demand was included in the model, the interaction effect of trait self-control, condition, and time on BAC was no longer significant ($\gamma_{\text{TRAITSELFCONTROL*CONDITION*TIME}}$ = -.09, *SE*=.07, *t*(59)= -1.29, *p*=.20).

There were no significant effects of the intrinsic motivation by condition interaction on any type of affect or perceived self-regulatory demand. There were significant effects of the HRV by condition interaction on negative and fatigued affect but not perceived self-regulatory demand; participants with higher HRV reported less negative and fatigued affect in the high self-regulation condition. However, neither variable changed the nature or significance of the interaction of HRV and condition predicting persistence when added to the model.

Chapter Four: Discussion

This study investigated the possibility that self-regulatory demand affects the functioning of the liver, slowing the metabolism of alcohol. The results suggest that individual differences in trait self-control may moderate the occurrence of such effects; in the current study, men who reported low trait self-control metabolized alcohol more slowly during a condition with high self-regulatory demand than during a condition with low self-regulatory demand, whereas men who reported higher trait self-control metabolized alcohol at an equivalent rate regardless of the self-regulatory demands placed on them. Men reporting high trait self-control also reported that they found the tasks in the high self-regulation condition to be less demanding, and this perceived demand mediated the interaction effect of trait self-control, condition and time on BAC. Other individual differences thought to be associated with self-regulation such as HRV, fasting blood glucose, and intrinsic motivation failed to moderate the relation between self-regulatory fatigue and alcohol metabolism.

A similar pattern of results emerged for persistence at the end of the sessions. Men who reported high trait self-control persisted equally at the end of the high and low self-regulatory demand conditions, whereas men reporting low trait self-control persisted less in the high self-regulation condition, again suggesting that high trait self-control buffers one against the negative effects of self-regulatory fatigue. These results extend previous findings by demonstrating that self-regulatory demand can fatigue self-regulatory capacity even if initial self-regulatory tasks are performed while one is under the influence of alcohol.

Surprisingly, men with lower resting HRV persisted equally in the two conditions, whereas men with higher resting HRV persisted less in the high self-regulation condition. This effect was surprising given previous findings that HRV protects against the effects of self-regulatory fatigue (Segerstrom & Solberg Nes, 2007). There are several possible explanations for this unanticipated finding. First, resting HRV was taken before participants were dosed with alcohol, raising the possibility that alcohol negates the protective effects of high tonic HRV. Second, it may be that higher resting HRV predisposes one to spontaneous self-regulation but also subsequent depletion; one study found that individuals with higher resting HRV engaged in more spontaneous (uninstructed) self-regulation of emotion while watching emotional film clips, and that their greater levels of regulation lead to worse performance on a subsequent self-regulatory task (Pu, Schmeichel, and Demaree, 2009). The second possibility seems more likely, especially given that individuals with higher HRV had lower levels of both fatigued and negative affect during the high self-regulation condition, suggesting that they may have allocated their remaining self-regulatory resources at the end of the high self-regulation session to emotion regulation rather than anagram persistence.

In contrast with studies suggesting that self-regulatory demand depletes blood glucose, the effects of level of self-regulatory demand on blood glucose in the present study were not statistically significant. Additionally, the effect of self-regulatory demand was not moderated by trait self-control, resting HRV, or intrinsic motivation for self-regulatory tasks, and no main effects of these individual difference variables on glucose levels emerged. These results suggest that self-regulatory demand may not have a meaningful effect on blood glucose levels in the presence of a low dose of alcohol. This

is especially surprising given the fact that acute alcohol administration results in hypoglycemia (Shelmet, Reichard, Skutches, Hoeldtke, Owen, and Boden, 1988).

Individual Differences in Self-Regulation: Proclivity, Strength, and Effectiveness

In the present study, several variables thought to be associated in some way with trait self-regulation were key in predicting both alcohol metabolism and resistance to self-regulatory fatigue. Theoretically, these variables should be positively associated with both each other and self-regulatory outcomes; however, this did not appear to be the case in the present sample (see Table 7 for intercorrelations among the Self-Control Scale, resting HRV, fasting blood glucose, average ratings of the self-regulatory tasks using the Intrinsic Motivation Inventory, and average ratings of the perceived self-regulatory demand of the self-regulatory tasks using the Current Activity Appraisal scale). Because the size of this sample is quite small (n=10 for most correlations), correlations should probably be interpreted as characteristics of this sample only; generalizations to the general population of men should be made with extreme caution. Nevertheless, the pattern of associations is helpful for understanding the results of the current study.

First and perhaps most notably, HRV, which has been previously tied to innate self-regulatory capacity or strength, was not correlated with the Self-Control Scale in our sample ($r(10)= -.28$, $p=.44$). However, recent studies have provided evidence that HRV may index *proclivity* toward the exertion of self-control, particularly in the context of regulating negative emotion (Pu, Schmeichel, & Demaree, 2009; Ode, Hilmert, Zielke, & Robinson, 2010). This alternative explanation is helpful for interpreting HRV's failure to correlate with the Self-Control Scale, and is also consistent with the divergent associations of these variables with affect in the high self-regulation condition. Whereas

resting HRV was associated with less negative and fatigued affect in the high self-regulation condition, higher scores on the Self-Control Scale were associated with decreased positive affect and increased negative affect during the anagram phase in the high self-regulation condition. These divergent patterns of association with affect provide further evidence that resting HRV predicts proclivity for spontaneous emotion regulation in ways that other indices of self-control may not. Further, HRV and the Self-Control Scale related in opposite ways to perceived self-regulatory demand; while higher Self-Control Scale scores were associated with lower perceived self-regulatory demand of the self-control tasks, higher resting HRV was associated with higher perceived self-regulatory demand of the same tasks. Those with higher HRV may have rated the self-regulatory tasks as more demanding due to the extra self-regulatory demand associated with their spontaneous emotion regulation.

The Self-Control Scale was negatively associated with perceived self-regulatory demand of the self-control tasks, and this perceived self-regulatory demand mediated the interaction of the Self-Control Scale and high self-regulation condition predicting BAC over time. This finding is consistent with the idea that people who typically achieve high self-regulatory success actually experience self-regulatory tasks as less demanding. However, contrary to hypotheses, the Self-Control Scale was also negatively associated with average ratings of intrinsic motivation for self-regulatory tasks using the Intrinsic Motivation Inventory interest/enjoyment subscale. This intrinsic motivation for the self-regulatory tasks presented in the high self-regulation condition was unrelated to average perceived self-regulatory demand of the same tasks, suggesting that people who were

Table 7

Intercorrelations Between Variables Hypothesized to be related to Self-Regulation

Variable	1	2	3	4	5
1. Self-Control Scale		-.28	.41	-.70**	-.76***
2. Resting HRV			-.15	.12	.65**
3. Fasting Blood Glucose				.30*	-.21
4. Average Intrinsic Motivation for SR Tasks					.23
5. Average Perceived SR Demand of SR Tasks					

*p< .10, **p< .05, ***p< .01

more interested in or more likely to enjoy the self-regulatory tasks did not necessarily find the tasks to be easier. Previous studies using this intrinsic motivation measure have used it as a manipulation check following experimental manipulations designed to encourage intrinsic motivation for subsequent self-regulatory tasks. It may be that intrinsic motivation measurements such as this one function more as state-like, environmentally determined variables (rather than trait-like variables) in laboratory settings. Further, it is possible that intrinsic motivation served as a proxy for increased effort during the self-regulatory tasks, which was greater in men with low trait self-control.

Finally, although the Self-Control Scale has been validated as a measure of "trait self-control," it appears to measure *outcomes* typically associated with an ability to sustain self-regulatory efforts rather than the variables that actually enter into the predictive equation for these positive outcomes. It is important to note that these outcomes are certainly multiply determined; physiological traits and states (e.g., HRV), levels of impulsivity (see Strack and Deutsch, 2004), motivational states, knowledge of efficient and effective self-regulation skills, practice, and other developmental factors are all likely to play a role in predicting the outcomes measured by this scale. Therefore, I propose that this scale measures one's typical *self regulatory effectiveness*, which results from the dynamic interplay of many variables—many of which may have nothing to do with trait self-regulation. As an illustration, imagine a man with a relatively low level of heart rate variability, high levels of impulsivity, and a developmental history that includes learning effective self-regulatory strategies from his parents and encouragement to practice these skills. This man may obtain a high score on the Self-Control Scale even

though his heart rate variability is not particularly high and he often has to work hard to overcome unwanted impulses. In contrast, imagine a man with a relatively high level of heart rate variability, high trait impulsivity, and a developmental history in which his parents did not model effective self-regulatory strategies or encourage him to practice these skills. This man may obtain a very low score on the Self-Control Scale even though his heart rate variability is quite high, as he may struggle to overcome unwanted impulses due to ineffective self-regulatory strategies and insufficient self-regulatory practice.

Ecological Effects on the Liver

The present study provides further evidence that exerting self-control can have an impact on the functioning of other parts of the body. However, ecological effects are often dependent on the level of challenge presented to the various organs involved. For example, self-regulatory demand reduces the response of the immune system to small, local challenge (e.g., a delayed-type hypersensitivity skin test), but these effects may not be present under conditions of higher immune challenge. When one has an infection, optimal functioning of the immune system generally takes priority over motivated behavior. This effect of the immune system on motivated behavior is called "sickness behavior," and typically involves disruption of the drives to eat, engage in sexual activity, seek social interaction, and pursue long-term goals. In the same way, effects of self-regulatory demand on the liver may be dependent on the level of challenge presented to the liver. In the current study, a low dose of alcohol was used so as not to create a high enough level of toxins that optimal liver functioning would take priority over self-

regulation. However, under a very high dose of alcohol, one would certainly expect the liver to take priority.

In the context of a social gathering, the results of the current study suggest that if an otherwise average male of below average self-regulatory effectiveness engages in self-regulation during his first 2 alcoholic drinks, his alcohol metabolism will be slowed—perhaps to accommodate the energetic needs of the brain. However, after a certain number of drinks, self-regulation is no longer the priority as the body recognizes the need to clear toxins. It is important to note that these processes are complicated by the negative effect of alcohol on the functioning of the frontal lobes at BACs around .05.

As an illustration of the effect, imagine that two work colleagues attend the same office party, and imagine that these otherwise similar men have low and high trait self-regulatory effectiveness, respectively. Because many of their coworkers disapprove of excessive drinking, these two men arrive at the party intending to drink no more than two drinks despite the fact that both men typically like to drink four to five drinks at social gatherings. Both men drink two alcoholic beverages in a short period of time, and then sit in the living room to socialize. Just as they sit down, their supervisor from work arrives unexpectedly, and they spend the next 30 minutes regulating their speech, postures, and behaviors so as to appear perfectly sober. After this period of time, the boss leaves, and both men are faced with the temptation to drink more alcohol. All else being equal, the results of the current study suggest that these men will have different BACs and different levels of self-regulatory strength (or, levels of self-regulatory fatigue) after this string of events. The man with high self-regulatory effectiveness will likely have a BAC of roughly .023, and he will likely be able to resist the urge to drink more

alcohol after his supervisor leaves. On the other hand, the man with low self-regulatory effectiveness will likely have a BAC of roughly .031, and he will probably have greater difficulty resisting the urge to drink more alcohol after the supervisor leaves. Therefore, exerting self-control after drinking has only positive consequences for the man with high trait self-regulatory effectiveness, but may have mixed consequences—especially long-term—for the man with low trait self-regulatory effectiveness.

Future Directions

Although the results indicate that trait self-regulatory effectiveness as measured by the Self-Control Scale moderates the effect of self-regulatory demand on both self-regulatory fatigue and alcohol metabolism, it is unclear which determinant—or determinants—of this multiply-determined variable is driving its moderating effect. Future studies examining the ecological effects of self-regulatory demand should carefully consider and measure the dynamic interplay between temperament/personality, self-regulatory skills, specific motivational factors, and physiology. Both state and trait variables are likely to play roles in the prediction of ecological effects, and these variables may not relate to one another in expected ways. Additionally, a larger sample should be used to replicate these preliminary findings, particularly those involving person-level individual differences, as these analyses may have been underpowered.

Of potential concern is the fact that men in the high self-regulation condition with higher trait self-regulatory effectiveness had significantly higher peak BACs. This effect was not accounted for by condition order, weight, or body mass index (BMI). Rather, the difference appears to reflect a failure of randomization to neutralize the impact of other factors influencing peak BAC such as trace amounts of food in the gastrointestinal tract,

stomach motility, or percentage of body fat. However, although the difference between the peak BACs is significant, these BACs are not high enough to activate secondary metabolic processes that increase rate of alcohol metabolism in a dose-dependent manner, and rate of alcohol metabolism is otherwise unaffected by peak BAC (Lieber, 1999).

This study has interesting clinical implications. Individuals with alcohol use problems typically score lower on the Self-Control Scale; this is an unfortunate fact given the finding that these are the individuals who are likely to experience downregulated liver functioning under self-regulatory demand—attempting to resist further alcohol ingestion, for example. Indeed, the current finding may help to explain why those with alcohol use problems struggle to moderate their drinking; trying to stop drinking after the second or third drink may actually *prolong* the effects of alcohol in these individuals and fatigue vulnerable self-regulatory processes in the process, perhaps significantly decreasing the individual's probability of effective regulation. The implementation of more efficient, less fatiguing self-regulatory strategies (e.g., stimulus control) may prove most helpful for individuals with low trait self-regulatory effectiveness. Clinicians should incorporate such paradoxical effects in their conceptualization and treatment of these patients.

The current study addressed ecological processes in males only so as to avoid the variance in alcohol metabolism associated with the menstrual cycle. It is important to determine whether these effects are present in women, and if changing energetic demands across the menstrual cycle interact with psychological processes such as self-regulation and stress to predict ecological effects. The results of such a study would be particularly relevant given the greater negative health consequences of excessive drinking in women.

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TORY EISENLOHR-MOUL
VITA
Department of Psychology
University of Kentucky

Place of Birth: Shelby, Michigan
Date of Birth: January 21, 1986

EDUCATION

Hillsdale College, Hillsdale, Michigan
B.A. in Psychology, Magna cum Laude
Date of Completion: May 2008
Honors Thesis: Perceived control over future performance eliminates the effect of goal-related failure on disinhibition of dietary restraint in chronic dieters.

PUBLICATIONS

Segerstrom, S.C., Evans, D.R., & **Eisenlohr-Moul, T.A.** (2010). Optimism and pessimism dimensions in the Life Orientation Test-Revised: Method and meaning. *Journal of Research in Personality*.

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MANUSCRIPTS UNDER REVIEW

Evans, D.R., **Eisenlohr-Moul, T.A.**, Button, D., Baer, R., & Segerstrom, S.C. (under review). Novel mindfulness strategies decrease pain tolerance associated with high heart rate variability.

Segerstrom, S.C., **Eisenlohr-Moul, T.A.,** & Evans, D.E. (under review). Stress-related growth.

Baer, R., Peters, J., **Eisenlohr-Moul, T.A.,** Geiger, P., Sauer, S., & (under review). Cognitive bias in borderline personality disorder: A review of the empirical literature.

MANUSCRIPTS IN PREPARATION

Eisenlohr-Moul, T.A., & Segerstrom, S.C. (in preparation). Autonomy, relationships, and IL-6 in older men and women.

Eisenlohr-Moul, T.A., Segerstrom, S.C., & Fillmore, M. (in preparation). Self-regulation and liver function: Expanding an ecological model.

Walsh, E., **Eisenlohr-Moul, T.A.**, Milich, R., & Lynam, D. (in preparation).

Understanding the mindfulness-substance use connection: The importance of distinguishing between observation and nonreactive observation.

Eisenlohr-Moul, T.A., DeWall, C.N., Pond, R. (in preparation). Perceptions of exclusion at ovulation lead to increased mateguarding in anxiously attached women.

Eisenlohr-Moul, T.A., Burris, J., & Evans, D. (in preparation). Chronic pain acceptance, mental fatigue, and psychological symptoms: Are fatigued regulatory processes responsible for psychological symptoms in chronic pain?

PAPERS PRESENTED AT SCIENTIFIC MEETINGS

Eisenlohr-Moul, T.A., Evans, D.R., Button, D., Baer, R., & Segerstrom, S.C. (2010, January). *Novel mindfulness strategies decrease pain tolerance associated with high heart rate variability*. Poster presented at the Society for Personality and Social Psychology Annual Meeting, Las Vegas, NV.

Eisenlohr-Moul, T.A. (2011, March). *Self-Regulatory Demand Slows the Metabolism of Alcohol in Healthy Males.* Poster presented at the American Psychosomatic Society Annual Meeting, San Antonio, TX.

Eisenlohr-Moul, T.A., Walsh, E., & Milich, R. (2011, March). *Mindfulness and Substance Use: Relating the Five Facet Mindfulness Questionnaire (FFMQ) to the Use and Abuse of Alcohol, Tobacco, Marijuana, & Stimulants in College Students.*

PROFESSIONAL POSITIONS HELD

2011-Present	**Department of Psychology, University of Kentucky** *Research Assistant, Center for Drug Abuse Research Translation*
2010-Present	**Orofacial Pain Center, University of Kentucky** *Behavioral Medicine Resident*
2009-2011	**Department of Psychology, University of Kentucky** *Project Manager/Interviewer, "Thoughts, Stress, and Immunity in Older Adults"*
2009-Present	**Jesse G. Harris Psychological Services Center, University of Kentucky** *Therapist to Individual Clients*
2009-2011	**Jesse G. Harris Psychological Services Center, University of Kentucky** *Group Therapist: Dialectical Behavior Therapy Skills Group*
2008-2009	**Department of Psychology, University of Kentucky** *Teaching Assistant*