DISSOCIATING FACETS OF IMPULSIVITY: EXECUTIVE CONTROL VS. INTERTEMPORAL CHOICE

By

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To my grandfather, Dragić Bastaja, and to the loving memory of my grandmother, Stefania Bastaja, whose endless love and continuous encouragement made all of this possible
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This research investigated whether two distinct facets of impulsivity could be dissociated: (a) impulsivity due to deficits in attention and executive control, and (b) impulsivity due to deficits in decision making. The first type, *attentional impulsivity*, represents a type of cognitive dysfunction linked to deficits in attention and failure to inhibit preponent thoughts and actions not relevant to one's current goal. The second type, *choice impulsivity*, represents an emotional-motivational deficit, linked to a phenomenon called delay discounting. As a means of testing the dissociation between the two facets of impulsivity, two types of arousal manipulation were employed: (a) global, nonspecific arousal induced by caffeine, which was hypothesized to influence attentional impulsivity, and (b) emotional-motivational arousal, induced by the prospect of receiving a reward, hypothesized to influence choice impulsivity. This research also provided an important extension of past work by directly comparing several popular behavioral measures of impulsivity in the two types of arousal conditions.

Results supported the idea that the two facets of impulsivity are dissociable, as the different types of arousal manipulation influenced the various impulsivity tasks differentially. The results of the current research were consistent with the notion that impulsivity is a complex,
multifaceted construct. This research contributes to the knowledge on impulsivity by proposing an integrated model of impulsivity that consists of at least two independent components.
CHAPTER 1
INTRODUCTION

Research on impulsivity has a long and extensive history, yet there is little agreement about the nature of this concept or its theoretical classification. The topic of impulsivity has been of interest in nearly all areas of psychology. Not surprisingly, definitions and conceptualizations have varied widely, and distinct research questions and goals have been developed by those different areas. For instance, in personality psychology, impulsivity is commonly seen as a stable personality trait, while in clinical psychology it is seen as a symptom of psychopathology. In cognitive psychology, impulsivity has been most closely related to various basic cognitive processes, including executive control, inhibition, working memory, and particularly deficits in those processes - although the term *impulsivity* hasn’t been very frequently used by cognitive theorists. Despite differences in approach to theory and research, a growing number of researchers across domains agree that impulsivity is not a unitary term, but rather it likely describes two or more different constructs (Dougherty, Mathias, Marsh, & Jagar, 2005; Evenden, 1999; Moeller, Barratt, Dougherty, Schmitz, & Swann, 2001; Reynolds, Ortengren, Richards, & de Wit, 2006; Swann, Bjork, Moeller, & Dougherty, 2002).

There are multiple reasons for studying impulsivity. Impulsive behavior can affect the daily functioning and wellbeing of any healthy individual and it has been associated with behavior that leads to certain negative consequences, such as debt (e.g., impulsive purchases, shopping sprees) and health problems (e.g., unhealthy food choices and overeating, risky behaviors), among others. Impulsivity is also plays a role in psychopathology and it has been linked to various psychiatric disorders, suicide attempts, aggression, self-injurious behaviors, etc. Another reason for studying impulsivity is improving cognitive theories of executive control. Although this may not be an intuitive approach to studying such processes, it could be argued
that findings from different disciplines on related topics, such as impulsivity, can shed more light on processes of executive functioning and control that are of vital interest for cognitive psychologists.

**Theoretical Background**

In laboratory settings, the approach to studying impulsivity commonly involves the use of various cognitive and neuropsychological tests, which were originally developed to study various higher-level cognitive processes. The diversity of measures can be reduced to two distinct theoretical approaches: a) the executive-function approach and b) the decision-making approach. The executive-function approach to studying impulsivity has emerged from the premise that impulsivity represents a type of self-regulatory dysfunction, and various neurocognitive measures of executive functioning are used in assessment of impulsivity. The decision-making approach, on the other hand, originated from phenomenon called delay discounting, which refers to the observation that subjective value of the reward decreases when delayed. Impulsivity, in this model, represents a choice of a small immediate reward over a larger reward in the future. The two models have traditionally been orthogonal to each other in that they’ve been studied largely independently by different areas of psychology, and almost no integration between the two approaches has occurred.

**The Executive-Function Approach to Impulsivity**

Executive functions (EF) are commonly seen as an umbrella term describing higher-level cognitive processes of planning, thinking, problem solving, and attention. The role of EF is associated with control of other, lower-level functions and resolution of conflict. These are considered to be processes, through which people adapt to ongoing changes in the environment, maintain the current context, adjust perceptual selection, and retrieve relevant information from long-term memory. There are several terms synonymous with or closely related to executive
functions (Baddeley, 1996; Shallice, 1994; 2002), such as executive control, executive attention, working memory, effortful/cognitive control, and frontal functions, among others. Importantly, executive functions represent related, yet separable, processes. Miyake et al. (2000) showed evidence for three distinct processes underlying EF: (a) mental set shifting, (b) information updating and monitoring, and (c) inhibition of prepotent responses. Shifting or attentional switching refers to controlling multiple tasks, or more precisely being able to shift back and forth between two tasks. Updating and monitoring are closely related to the executive control of working memory. Finally, inhibition of prepotent responses represents a strategic inhibition of dominant, automatic responses.

Schachar, Tannock, & Logan (1997) were probably the first to explicitly operationalize impulsivity in terms of one of the deficits of executive functioning. Logan et al. link impulsivity to response inhibition (deficits thereof, to be precise), which is commonly seen as the ability to inhibit thoughts and action when they are not goal-relevant (Logan & Cowan, 1984). Furthermore, response inhibition is seen as “horse race” between two competing mental processes, one of which is typically automatic and well learned and the other, a non-automatic process, requiring control and effort to be executed. Successful control requires the ability to inhibit ongoing courses of action that are dominant (typically automatic and well practiced) if the situation or the task requires execution of a non-dominant (non-automatic) response.

The Stop-Signal Task (Logan & Cowan, 1984) was introduced to study processes of control and response inhibition. The task involves making a speeded response to a dominant go signal, and restraining from making the response if a non-dominant, stop signal occurs. The go signal is considered dominant because of its frequent occurrence during the task (typically 75% of the time). The stop signals are rare, and occur after the response to the go signal has already
been initiated, and therefore require control and effort. As described above, participants are expected to inhibit the dominant response on trials on which a stop signal occurs. Successful control or inhibition has occurred if no overt response is made. In addition to the percentage of inhibited responses, many authors stress the importance of latencies to those processes. Latencies to the primary go signal are directly measured; while latencies to unobservable stop-signal reaction times (SSRT) can be calculated by various methods (see Logan & Cowan, for a review). Although poor inhibitory control can be attributed to either responding too quickly to the go signal or responding too slowly to the stop signal, studies suggest evidence for latter. Schachar, Tannock, & Logan (1993) observed longer SSRTs for children with ADHD, when compared with normal controls. In addition to ADHD sample, Logan et al. (1997) observed longer SSRTs in healthy adults, who had high impulsivity scores, as estimated by a version Eysenck Personality Inventory (Eysenck, Eysenck, and Barrett 1985).

With the exception of inhibition of prepotent responses, the theoretical association between executive functions and impulsivity has not yet been explicitly developed, and a growing number of researchers recognize that selection of measures of impulsivity has often been based on the researchers’ preferences, rather than on theoretically established grounds (Keilp, Sackeim, & Mann, 2005). Typically, researchers use various neuropsychological and cognitive tests for assessing impulsivity, such as the Continuous Performance Test (CPT), the Stop-Signal Task (SST), the Go/No-Go task (all of which will be described in detail later), and the Wisconsin Card Sorting Test (WCST), to name a few.

**Decision-Making Approach to Impulsivity: Intertemporal Choice**

Impulsivity, in this model, is related to the phenomenon of delay discounting, a finding that the subjective value of reward declines as a function of time (between the offer and the actual reward). Impulsivity, in this model, is a chronic preference for a smaller, but immediate
reward over a larger reward that is delayed; while self-control represents its opposite (Ainslie, 1975). Most people are able to delay gratification for months or even years. Impulsive individuals, however, have severe difficulty resisting the temptation of a smaller immediate reward, even when the benefits of a later reward are obvious. Monterosso & Ainslie (1999) link the concept of impulsivity with irrationality, considering impulsive behavior to be a choice of lesser value, despite one’s recognition that this choice wasn’t in her/his best interest. Interestingly, the authors stress the difference between such impulsive people and others who would make identical choices, yet believe that they made a choice in their best interest. In other words, in impulsive behavior, its actor recognizes that a decision is not optimal, yet, he/she is not able to withhold it. Researchers studying impulsivity using delay discounting approach, link it with violence, gambling, and substance abuse, among other maladaptive activities (Dougherty et al., 2004; Evenden, 1999; Kirby, Petry, & Bickel, 1999).

The main mechanism indicated in the delay-discounting is oversensitivity to reward. In other words, people behave impulsively because certain stimuli (or patterns of behavior) are particularly rewarding for them. Recent studies indicate activation of the limbic system as a cause of preference of a more immediate reward over the later one. McClure, Laibson, Loewenstein, & Cohen (2004) used functional magnetic resonance imaging (fMRI) to explore neuroanatomical correlates of choices made in the delay discounting paradigm. McClure et al. hypothesized that the immediate choices are driven by the limbic system, while the delayed choices by the lateral prefrontal cortex, predicting dissociation between mechanisms responsible for immediate vs. delayed choice. The results of the study indeed showed a support for the two separate systems: the limbic system was activated only when decisions involved rewards that are immediately available, while the lateral prefrontal cortex and posterior parietal cortex were
engaged regardless of the timing of a reward. This led McClure et al. to conclude that the activity in the limbic system decreases if opportunities for reward are delayed, while the frontal/parietal cortex system is much less sensitive to the timing of available rewards. The authors also suggest a dominance of automatic processes over more deliberate in cases when immediate reward is chosen, which is somewhat discrepant with the previously discussed Monterosso and Ainslie (1999).

**Impulsivity as a Personality Construct**

Besides the above presented two models of impulsivity, related to executive functions and delay discounting, the issue of impulsivity has been of interest in theoretical work on personality. Personality psychologists view impulsivity as a stable trait and various major personality theories (and inventories) include impulsivity as part of their theory. For instance, a version of Eysenck’s scale is frequently used in studies on impulsivity (Eysenck, Eysenck, & Barrett, 1985). Another, very popular approach has been to study performance on behavioral measures of impulsivity (e.g., neuropsychological tests) as function of self-reported impulsivity. Problems associated with the use of self-report measures of impulsivity are similar to those of self-report measures in general, including susceptibility to altered self-presentations, and/or unawareness of one’s own traits and behaviors. Besides this, there is mixed evidence that there is a correspondence between self-reported impulsivity and behavioral impulsivity tasks. Although a growing number of researchers report only weak-to-moderate correlations between the two types of measures (e.g., Keilp, Sackeim, & Mann, 2005; Reynolds, 2006), others were able to observe strong correlations (e.g., Logan, Schachar, & Tannock, 1997). Currently, no major theoretical framework addresses the conceptual relationship between self-report measures and the two models of impulsivity discussed above.
Clinical Aspects of Impulsivity

Another approach to impulsivity has come from clinical research. Impulsivity plays a role in diagnosis of a variety of disorders classified in DSM-IV; and it is typically understood as follows:

Impulsive behavior is a fairly nonspecific complication of a number of the psychiatric disorders that often requires the most urgent diagnostic and treatment attention because it may lead to considerable morbidity and mortality. However, it must be recognized that some degree of "impulsivity" is normal (and even desirable). Indeed, a total lack of spontaneity is itself considered a symptom of several disorders (e.g., Schizophrenia, Obsessive-Compulsive Personality Disorder). To be considered part of a mental disorder, the impulsivity must be persistent and severe and lead to clinically significant impairment or distress (Diagnostic and statistical manual of mental disorders (4th ed.)1994).

According to DSM-IV classification, impulsivity could be a cause or a result of a substance abuse; present in delirium or dementia; associated with a manic episode of bipolar disorder; a chronic characteristic of attention-deficit/hyperactivity disorder (ADHD), conduct disorder, antisocial personality disorder, and borderline personality disorder. Also, an entire section of DSM-IV is devoted to impairments of impulse control, such as paraphilias, eating disorders, substance dependence, pathological gambling, and intermittent explosive disorder, among other. It hasn’t been empirically established whether impulsivity associated with disorders listed above share underlying mechanisms; however, there is some evidence suggesting at least some overlap (Evenden, 1999; Swann, Bjork, Moeller, & Dougherty, 2002)

Attention-Deficit/Hyperactivity Disorder (ADHD). Linking the literatures on ADHD and impulsivity may be a particularly fruitful approach to exploring this construct. One reason is that there are many similarities in assessment methods used in research on ADHD and research on impulsivity. For instance, various tests of executive functions, such as Go/No-Go, Continuous Performance Task (CPT), Stroop tasks, and the Wisconsin Card Sorting Task (WCST), are commonly used in both literatures. Also, compared to other disorders, people with ADHD are
typically well adapted and highly functioning, and therefore a parallel with healthy population is easier to draw. A diagnosis of ADHD is based on chronic symptoms of inattention, hyperactivity, and impulsivity that have an onset in childhood and may or may not persist through adulthood (e.g., Barkley, 1997, 1999, 2001; Biederman, 2005). In DSM-IV, the disorder is divided into three subtypes: predominantly inattentive, predominantly hyperactive-impulsive, and combined. Impulsivity is associated with the predominantly hyperactive-impulsive type, and with the combined types\(^1\) of ADHD. Symptom of impulsivity is inferred if a child (or adult) “often blurts out answers before questions have been completed, often has difficulty waiting turn, often interrupts or intrudes on others”(Diagnostic and statistical manual of mental disorders (4th ed.)1994).

Several explanatory models of ADHD have been proposed. The first and predominant model associates ADHD with deficits in executive functioning\(^2\) (e.g., Barkley, 1997). In this model, response inhibition is the primary deficit, while other deficits come secondary to this. In other words, various deficits in cognition and behavior, which characterize ADHD, are viewed as consequences of the inability to inhibit prepotent responses. Accordingly, Barkley predicts that improvement in response inhibition will cause improvement in all other other issues related to ADHD.

A second approach, proposed by Sonuga-Barke (2003), is a dual-pathway model of ADHD comprising (a) executive dysfunction and (b) delay aversion factors (Sonuga-Barke & Taylor, 1992; Sonuga-Barke, 2003; Sonuga-Barke, Dalen, & Remington, 2003; Sonuga-Barke, 2005; Sonuga-Barke, Taylor, & Heptinstall, 1992; Sonuga-Barke, Taylor, Sembi, & Smith, 1992)

\(^1\) Combined type of ADHD includes both, symptom of inattention and symptom of hyperactivity/impulsivity.

\(^2\) An important characteristic of this model is that the inattentive type of ADHD was not included, which is particularly relevant to our discussion as only other two subtypes have been associated with impulsivity.
argues for distorted reward process in children with ADHD, in addition to deficits in executive functioning. A process of delay aversion was proposed to explain the observed hypersensitivity to delay, difficulties in delaying a response, and difficulties in working for prolonged periods of time, among children with ADHD. Sonuga-Barke argues that ADHD children are hyper-vigilant for environmental cues, because they represent an opportunity to escape a delay. In other words, as a delay causes significant discomfort, a person with ADHD presumably partakes in goal-irrelevant activities, that make the delay less “painful.” This in turn creates a perception that a person is inattentive and “off-task.” The main claim of this model, then, is that there might be multiple mechanisms responsible for the symptoms of ADHD. Dissociation between performance on executive function and delay discounting tasks has been offered as support for this view (Solanto et al., 2001).

The third model of ADHD is the cognitive-energetic model (CEM; Sergeant, 2000, 2005). In this model, ADHD is linked with deficits of energy (capacity) pools required for information processing. The efficiency of information processing can be seen as interplay of low and high-level cognitive processes, with energy (capacity) pools required for information processing. The first, low-level of cognitive processes involves sensori-motor systems (e.g., visual search; motor organization). The second level involves energetic pools, defined as follows: effort as energy needed to do the task; arousal as a response to certain stimulus features (e.g., intensity or novelty); and activation as the readiness to respond, which is often influenced by alertness, time of the day, etc. The third level of the CEM model represents executive functions. The energetic resources in this model are based on theory of attention by Pribram and McGuinness (1975), which also distinguished between arousal, activation, and effort.
Sergeant (2005) applied this theory to ADHD, focusing on possible deficits in the energetic pools in allocation of resources to low and/or high-level cognitive processes. The model asserts the deficits in energetic resources or inability to properly use energetic resources for optimal functioning as primarily related to the abnormalities in ADHD. A part of the energy pool labeled *arousal* is associated with *phasic* responses that are time-locked to processing of the current stimuli, and are typically influenced by the salience or novelty features of the stimuli. A part of the energy pool labeled *activation* is associated with *tonic* states of alertness, and global readiness to respond. Sergeant sees effort and activation pools as being deficient in ADHD. In support of this claim, Sergeant cites studies manipulating the rate of presentation, which have shown disadvantages for ADHD children when stimuli are presented in a slow rate, and advantages if a stimuli are presented in a faster rate, which he links to an inability to adjust the energetic state. Presumably, a constant and fast rate of presentation of stimuli increases tonic arousal, which brings those with ADHD to a more optimal level of functioning; during the slow presentation of stimuli, however, ADHD children are under-aroused, and have consequent difficulties in functioning.

**The Current Study**

**Cognitive Energetics and Impulsivity**

The research questions and the predictions in the current investigation emerge from the integration of the theoretical perspectives and research findings reviewed above. The two models outlined in this paper – the executive-functions and the delay-discounting model of impulsivity – appear to capture two distinct aspects of impulsivity. Given the nature of the two constructs and the findings reviewed above, there is reason to believe that the two types of impulsivity are dissociable. Furthermore, a recently suggested link between arousal and ADHD in the cognitive-energetic model, also seem important in research on impulsivity in healthy adults.
The idea of two distinctive types of arousal is an old one in psychology (e.g., Sokolov, 1963; Pribram and McGuiness, 1975). Although concepts of energy pools, arousal, and cognitive resources have remained useful in work relating cognitive, motivational and emotive systems, this approach hasn’t been explicitly used in research on impulsivity. Critical for the present research was the hypothesis that the two types of impulsivity (ED and DD) are sensitive to two different types of arousal. Specifically, the two types of arousal presumed to underlie EF and DD impulsivity, are respectively: (a) tonic, global arousal arising as a consequence of nonspecific events, such as use of stimulants, exercise and alike; and (b) phasic, specific arousal, arising as a consequence of gratification and reward specific stimuli provide.

The executive-function type of impulsivity should be particularly impacted by tonic arousal manipulation. Evidence to support this prediction comes from research and clinical practice suggesting substantial decreases in a variety of symptoms of ADHD following the treatment with stimulant medications. More importantly, there is evidence that impulsivity symptoms, including impulsivity measured by Go-Stop task, diminish after stimulant medication intake.

The delay-discounting type of impulsivity should be particularly impacted by phasic arousal manipulation. The phenomenon of delay discounting has been observed in everyday life of healthy, normal individuals. For example, if given an option to choose between 10 dollars now and 15 dollars in a year, people in general choose the immediate option. But, if the choice involves 10 dollars now or 150 dollars in a year, more people are willing to wait. This idea will be incorporated to the current research, predicting less impulsive responding if there is a substantial reward for non-impulsive performance. It has been shown that ADHD children, people with gambling addiction, etc. are particularly prone to chose immediate rewards;
however, they are also able to postpone their choice. Thus, the prospect of getting a large reward may have a sizeable impact on DD impulsivity.

**Specific Goals and Predictions**

The primary goal of the study was to search for evidence of a dissociation between the two hypothesized types of impulsivity: executive-function (EF) impulsivity and delayed-discounting (DD) impulsivity. In contrast to previous work, this research takes an experimental approach by overtly manipulating factors hypothesized to differentially affect the two types of impulsivity. Specifically, the two types of arousal were manipulated by (a) caffeine intake in case of tonic arousal; and (b) monetary reward, based on performance in case of phasic arousal. It was further predicted that the effects of arousal might differ depending on a level of impulsivity at baseline, as explained below.

**H1:** Performance on the executive-function measures will be influenced by the increase of tonic arousal, by administration of caffeine at a dose of 4 mg/kg of body weight; at the same time, the performance on these measures will not be affected by the increased phasic arousal, by reward.

Assuming that impulsivity is a continuum, the more impulsive end of the healthy sample should resemble a clinical population, and therefore improvement in performance after caffeine should be observed, while the non-impulsive end should be hindered by over-arousal.

**H1a:** The effects of caffeine will depend on the participants’ baseline impulsivity levels: increasing tonic arousal will decrease the level of EF impulsivity for participants who are high-impulsive at baseline; but increase impulsivity of low-impulsive individuals.

**H2:** Performance on the delay-discounting measures will be influenced by the offer of reward for performance; at the same time, the performance on these measures will *not* be affected by caffeine.
The effects on the delay-discounting tasks may also depend on the level of impulsivity at baseline, because reward is expected to change choices of high-impulsive individual, but the reward should not have any influence on choice, if a person is already able to delay response at baseline.

**H2a:** The effects of reward will depend on the participants’ baseline impulsivity levels: Increasing phasic arousal will decrease the level of DD impulsivity for participants who score high on DD impulsivity at baseline, but will not change the level of impulsivity of already low-impulsive individuals.

Further, several different behavioral tasks were used, some of which are considered to measure EF impulsivity and others, DD impulsivity, so that patterns of performance on theoretically similar tasks could be compared to those across dissimilar tasks. Thus, a second goal involved exploring the relationship (a) within the behavioral measures of impulsivity representing a certain type of impulsivity, (b) across measures hypothesized to represent the two types of impulsivity.

**H3:** A strong positive relationship among measures of EF impulsivity, as well as among measures of DD impulsivity, however, no correlation between tasks measuring the opposing impulsivity type.

The relationship between self-reported impulsivity and behavioral impulsivity tasks will also be explored, however, specific predictions were not made, as prior research did not provide sufficient support for this relationship.
CHAPTER 2
METHOD

Participants

One hundred forty-two healthy young adults (99 female) participated in the study in partial fulfillment of a course requirement at the University of Florida. The average age was $M_{age} = 19.49; SD = 1.64$. Exclusionary criteria included a medical history of diabetes, heart disease, high blood pressure, gastrointestinal problems (e.g., peptic ulcers), epilepsy, other seizures disorders, anxiety or panic disorders, hypoglycemia, pregnancy, and allergy to caffeine. The Institutional Review Board of University of Florida reviewed and approved the experimental protocol, and written informed consent was obtained prior to study participation from all participants.

Design

The design was 3 (condition: baseline, reward, caffeine) x 6 (task: Go-Stop, IMT, DMT, Two Choice, SKIP, Time) repeated measures design, with both factors manipulated within subjects. Participants completed the same set of computerized impulsivity tasks in each of the three different sessions that took place on three nonconsecutive days within one week. Sessions corresponded to the three experimental conditions in the study: baseline, caffeine, and reward. The order of the conditions was counterbalanced across days, and order of the task was counterbalanced across participants. In the caffeine condition, participants completed a set of self-report measures in addition to behavioral impulsivity measures. The total time for completing the study was approximately 6 h (approximately 2 h/session).

Caffeine condition. In this condition, participants consumed a caffeine solution at the dose of 4 mg/kg body weight at least 30 minutes prior to beginning of the first computerized task. The caffeine solution was created from 100% anhydrous caffeine powder (Carolina Biological
Supply) and distilled water. The solution was mixed with orange juice prior to consumption to diminish bitter taste of caffeine.

**Reward condition.** In this condition, participants were informed they will be rewarded for performance. In addition to this, participants received feedback about rewards for their performance in a form of number of points presented on the computer screen (see Procedure below for details).

**Baseline condition.** Performance in this condition was used as a baseline for comparison with the two other experimental conditions. All parameters were identical to that in the caffeine and reward conditions, except that caffeine and reward were not manipulated.

**Materials**

Five computerized measures of impulsivity were used: (a) the Immediate and Delayed Memory Task (Dougherty et al., 2005), (b) the Go-Stop Paradigm, (c) the Single Key Impulsivity Paradigm (SKIP), (d) the Two-Choice Impulsivity Paradigm, and (e) the Time Paradigm (Dougherty et al., 2005). The IMT/DMT and the Go-Stop task were used as measures of executive functions, while the Two-Choice and the SKIP were used as measures of delay discounting. The Time Paradigm was an additional behavioral measure of impulsivity, included to establish the possible role of time perception in impulsivity.

**Behavioral Measures of Impulsivity**

**The Immediate and Delayed Memory Tasks (IMT/DMT).** This task involved rapid presentation of 5-digit numbers on a computer screen. The participants were instructed to click a mouse button whenever the 5-digit number they see is identical to the one that was designated as a target. In the *immediate* version of the task, a target appeared on the screen immediately after

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3 Dosage and distribution of caffeine followed previously used procedures (e.g., Schicatano & Blumenthal, 1995)
the initial presentation of the target, while in the delayed version of the task there are three distracter items between the two critical items. The targets were continuously updated in both versions of the task. There are two main measures in this task: (a) correct detections, which are correct responses to a particular target stimulus; and (b) commission errors which are responses to catch stimuli, which are stimuli similar to the target (e.g., 45647 for a target 45674). Commission errors and correct detection are calculated from two different pools of trials. The main measure of impulsivity is the percent of commission errors. Participants received a standard set of instructions and a training session before the experimental trials began. The training included 2 blocks of trials for approximately 3 minutes. The actual task was 12 minutes long; with 8 blocks of trials (4 blocks for IMT and 4 blocks for DMT). Numbers were presented for 500 ms, with an inter-stimulus interval of 1500 ms. Target and catch stimulus presentations were presented 33% of the time each; a filler was presented 34% of the time. In the caffeine and baseline conditions, participants did not get any performance/reward feedback. In the reward condition, participants received information about their earnings after each block (8 times during the 12-minute session).

The Go-Stop Task. This task is a variant of the previously discussed stop-signal paradigm (Logan and Cowan, 1984). In this task, a series of 5-digit numbers were presented on a computer screen, and the task was to respond when a go signal appears, and withhold responding when a stop signal or non-target stimulus appears. The go signal is a 5-digit number, presented in black font. The stop signal is a change in the color of that 5-digit number from black to red during the presentation. That means that a certain number of go signals changes to a stop signal while still on the screen. The main dependent measure was the percent inhibited responses on “stop” trials.

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4 Although correct detections indicate sustained attention or vigilance, they are typically not used to indicate impulsivity.
Several other measures, including the Stop Signal Reaction Time\(^5\) (SSRT), explained were also recorded. Participants received a standard set of instructions and a training session before the experimental trials began. The training session included 2 blocks of trials for approximately 3 minutes. The task was 20 minutes long, with 6 blocks of trials in each session. Each stimulus was displayed for 500 ms with a 1500 ms inter-stimulus interval. The timing of the “stop” signal varied (50, 150, 250, or 350 ms). This represents a possible duration of a black number prior to turning to red. A go and stop signals were presented 15% of the time each a novel stimulus 70% of the time. In the reward condition, participants received feedback about the points/earnings after each block. In baseline and caffeine conditions, feedback was not presented.

**The Two-Choice Task.** This task measured participants’ tendency to choose a small immediate reward over a larger, delayed reward. In a baseline and caffeine conditions, subjects were presented with an option to choose to wait 5 seconds for 5 points, or 15 seconds for 15 points. In the reward condition, contingencies were 5s for 5points or 15s for 45 points. Across experimental conditions, the goal of the task was to earn as many points as possible and the information about the accumulated points was presented on the computer screen after each choice. Participants received a standard set of instructions and a training session before the experimental trials began. The training session included 2 blocks of trials for approximately 2.5 minutes. There were 60 trials in each condition, and the main dependent measure was the percentage of immediate responses.

**The Single Key Impulsivity Paradigm (SKIP).** The goal of the task was to earn as many points as possible. Participants were told that they need to click the mouse to earn points. The

\(^5\) For a method of calculating SSRT, relevant for this paper, see Appendix A (Figure A-1).
only other instruction participants received was that frequent responding earned a smaller amount, while scarce responding, a larger amount. Every mouse click earned a certain amount of points, and it was displayed immediately on the computer screen, regardless of the condition. In the baseline and caffeine conditions, the contingency between clicks and earned points was set as a linear function, while in the reward condition as an exponential function. Linear meant that there was a constant (1:1) ratio between the length of delay and earnings. The exponential function allowed for exponential increase in reward, and thus not clicking frequently was particularly beneficial. Participants received a standard set of instructions. There was only a single block that lasted 10 minutes. In the caffeine and baseline conditions, the ratio was linear, and in reward condition, there was a positive exponential relationship between waiting and reward. The main measure was the total number of responses during task.

**The Time Task.** This is a computerized method of estimating participants’ subjective perception of time. Participants estimated the duration of 90 seconds in 5 blocks. No feedback about the accuracy of estimation or any other feedback was given in baseline and caffeine conditions. In the reward condition, after each trial, participants received a feedback about the accuracy and the amount of points earned. Time estimation may be linked to both types of impulsivity. It has been suggested that impulsive individuals have a perception that time passes more slowly than it actually does, which results in an assessment of interval longer than objective (e.g., assessing 10 minutes elapsed, when in reality only 7 minutes went by).

**Self-Report Measures of Impulsivity**

In addition to the computerized measures of impulsivity, three popular self-report measures of impulsivity were used: *the Barratt Impulsiveness Scale* (BIS11; Patton, Stanford, M.,
& Barratt, 1995), the Impulsiveness Questionnaire (I7; Eysenck et al., 1985), and the Monetary Choice Questionnaire (MCQ; Kirby, Petry, & Bickel, 1999).

The Barratt Impulsiveness Scale (BIS11). This scale consists of 30 items, measured on a 4-point scale, ranging from rarely/never, to almost always, with no available neutral response. Three components of impulsivity are assumed: motor (e.g., I do things without thinking), cognitive (e.g., I don’t pay attention) and non-planning (e.g., I plan /don’t plan tasks carefully).

The Impulsiveness Questionnaire (I7). The scale consists of 54 items, measured on a 2-point scale (Yes and No). Three components are measured: impulsiveness (e.g., Do you often buy things on impulse?), venturesomeness (e.g., Do you quite enjoy taking risks?), and empathy (e.g., Would you feel sorry for a lonely stranger?). Impulsiveness is here defined as action without prior thinking, while venturesomeness is conceptualized as sensation seeking, or being aware of the risk of the behavior but acting anyway.

Monetary Choice Questionnaire (MCQ). The scale consists of 27 items, measured on a 2-point scale (Today or Certain Number of Days). This is a questionnaire version of a delay-discounting task. Participants have a choice between two hypothetical monetary rewards: either a smaller, immediate or a larger, delayed reward (e.g., Would you prefer $31 today or $85 in 7 days?). For full versions of the above measures see Appendices C, D, and E, respectively.

Other Measures

The Caffeine Consumption Questionnaire (Schicatano & Blumenthal, 1995). This scale was used to assess participants’ everyday caffeine intake. Participants reported about their typical consumption of various products containing caffeine. Because habitual drinking of caffeine causes tolerance, the score on this scale was used as a covariate in the caffeine condition to test if typical consumption of caffeine moderated the effects of caffeine.
**Caffeine Daily Diary (Landrum, 1992).** This is a self-report measure assessing caffeine intake (different products) on hour-to-hour basis. The Caffeine Daily Diary scale was distributed at the start of each session to monitor caffeine intake and also to reinforce the instructions regarding caffeine abstinence 12 h prior to each session.

**PANAS (brief version; Watson, D., Clark, A.L., & Tellegen, A, 1988).** Participants indicated the extent to which they feel this way right now (Irritable, Nervous, Jittery, Distressed, Scared, Upset) on a five-point scale (1 - Very slightly or not at all; 5 – Extremely). The six items from the brief version of PANAS were used to control for potential physiological/emotional side effects of caffeine that could account for change in performance. The responses on the six items were collected in the caffeine condition: (a) immediately after caffeine consumption, and (b) at the end of the session.

**Follow-Up Questionnaire.** Three questions were developed to assess participants’ subjective perception of difficulty, effort, and importance of each of the behavioral impulsivity tasks. Answers regarding task difficulty (How difficult was it for you to do the ... task?); exerted effort (Did you put effort into doing the ... task?); and importance of doing well on the task (To what extent was doing well on ... task important to you?) were coded on a 5-point scale (1 - not at all; 5 - very much). These three items were presented in each of the three conditions, for each of the five behavioral impulsivity tasks.

**Procedures**

All testing sessions took place in a small laboratory room, and all participants were tested individually. Upon arrival to the first session, participants filled out the prescreening questionnaire (see Appendix B) to assess their eligibility for the study; participants who passed a screening procedure were given a consent form to read and sign. Participants were not allowed to
have a watch, cellular phone or any other electronic devise that would allow them to check the time. Participant was randomly assigned to one of the 6 possible testing sequences.6

In all conditions: participants first filled out a caffeine daily diary (Landrum, 1992) to check for their consumption of caffeine 12 hours prior to the study. Then, participants completed the five computerized measures of impulsivity (order counterbalanced across participants), and a follow-up questionnaire for each measure.

In the caffeine condition: following the daily diary, participants completed the MCQ and then they consumed a caffeine beverage. Immediately following caffeine consumption, participants filled out questionnaires for the next 10 minutes (a) PANAS, (b) I7, (c) BIS11, and (d) Caffeine Consumption Questionnaire (assessment of typical usage). Next, participants took a short break, so that at least 30 minutes elapsed between caffeine consumption and the start of the first computerized task of impulsivity.

In the reward condition: upon arrival to the reward condition, participants were informed they will be competing for the reward in that session. It was explained that the reward would be based on their overall performance on the five computer tasks, and that the participant who performs the best would receive the $100 reward, followed by the second best who would receive $50, and the third best who would receive $25.

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6 Latin square design was used to counterbalance the order of conditions, resulting in a six possible testing sequences.
CHAPTER 3
RESULTS

The main aim of the study was to explore the multifaceted nature of impulsivity and to test the hypothesis about the dissociation between executive-function and delay-discounting types of impulsivity. Another aim was to explore the relationship between the behavioral measures at baseline, as well as to explore the relationship between measures at baseline and self-report measures. Therefore, the results are presented under the two main subsections: (a) the effects of arousal manipulation on impulsivity and (b) the relationship between measures.

The Effects of the Manipulations on Behavioral Measures of Impulsivity

This subset of analyses had three major goals, which included describing the extent of the effects that the two arousal manipulations had on the behavioral measures of impulsivity; testing whether the effects depended on the level of impulsivity in the baseline condition; and the extent of the effects on perception of effort exerted on tasks, importance of doing well and tasks difficulty.

The Effects of the Manipulations on Behavioral Measures Combined

The first goal of this subset of analyses was to determine the extent of the effects of the reward and caffeine manipulations on performance on the six dependent measures, and to establish whether the effects differed depending on the type of arousal manipulation and the type of task. The prediction was that the executive functions measures (Go-Stop and IMT/DMT) will be influenced more strongly by caffeine\(^7\) (vs. reward) manipulation, while the measures of delay discounting (Two-Choice and SKIP) will be affected by the reward (vs. caffeine) manipulation. The demonstration that two different manipulations each have different effects on two

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\(^7\) Typical usage of caffeine, as measured by the Caffeine Consumption Questionnaire, indicated that the participants were low-to-moderate caffeine users. The consumption of caffeine did not change any of the scores in the caffeine condition. Also, scores on PANAS subset did not differ significantly when distributed pre- vs. post- caffeine consumption.
hypothesized types of impulsivity will be interpreted as evidence for dissociation. For summary of score distributions on the behavioral impulsivity tasks see Table 3-1.

A doubly multivariate analysis of variance\(^8\) was employed to test for differences in the effect of arousal condition on performance on six impulsivity tasks (see Figure 3-1). The design was a 3 (arousal condition: baseline, caffeine, and reward) x 6 (impulsivity tasks: Go-Stop, IMT, DMT, Two Choice, SKIP, Time) Doubly Multivariate ANOVA. Evaluation of the data suggested that the distribution of scores on the SKIP, IMT, and DMT tasks were positively skewed, and therefore log\(_{10}\) linear transformations were performed to normalize distributions on these variables. All other measures were normally distributed; estimated skewness and kurtosis were below 1. No data were missing. Wilk’s lambda criterion was used for multivariate significance testing. To allow comparison on a common scale and at the same time allow for the effects of change, all dependent variables were converted to standardized scores using the following equations (Eq. 3-1, 3-2, and 3-3):

\[
Z_{\text{base}} = \frac{(X_{\text{base}} - M_{\text{base}})}{SD_{\text{base}}} \\
Z_{\text{reward}} = \frac{(X_{\text{reward}} - M_{\text{base}})}{SD_{\text{base}}} \\
Z_{\text{caff}} = \frac{(X_{\text{caff}} - M_{\text{base}})}{SD_{\text{base}}}
\]

A doubly multivariate test of parallelism (type of task x arousal condition interaction; Wilk’s \(\lambda\): \(F(10,132) = 7.45, p < .02, \eta^2_p = .40\)) was significant. Also, a multivariate analysis of flatness yielded significant results: type of task test of flatness, Wilk’s \(\lambda\): \(F(5,137) = 4.99, p < .001, \eta^2_p = .154\), as well as arousal condition test of flatness, Wilk’s \(\lambda\): \(F(2,140) = 4.01, p < .02, \eta^2_p = .054\). Because both test of flatness and parallelism yielded significant results, interactions at the level of each task were explored next (see Tabachnick & Fidell, 2001).

\(^8\) Doubly multivariate analysis is a type of profile analysis (repeated measures MANOVA) where several different DVs are measured at several different occasions. Because the DVs are not measured on the same scale, scores are often standardized prior to analysis so that the effects can be compared.
The Effects of the Manipulations on Measures Separately

**Reward and caffeine interaction.** A series of multiple regression analyses with an interaction term (caffeine x reward) were conducted as a follow-up a doubly MANOVA and to explicitly test the hypothesis that the two different types of arousal will have differential effects on performance. Separate regression analyses were performed for each of the behavioral impulsivity tasks. The dependent measure was baseline level of impulsivity for the task of interest. Both independent variables (performance at caffeine and performance at reward) were centered to prevent potential problems with multicollinearity (e.g., Tabachnick & Fidell, 2001). For each regression, reward and caffeine were entered at stage one and the interaction between reward and caffeine were entered at stage two (see Table 3-2, for summary of results). There was a significant caffeine x reward interaction for a Go Stop (β = -.006; \( p < .03 \)) and the IMT task (β = .160; \( p < .03 \)) indicating differential effects of the two types of manipulations on those tasks. This interaction was not significant for the DMT, Two Choice, SKIP or Time tasks.

**Follow-up ANOVAs.** To determine the differences in performance on each of the measures in the three arousal conditions, a series of follow-up ANOVAs were conducted. The analyses were conducted separately for each of the behavioral impulsivity tasks measure in order to order to determine the origin of the effect (Tabachnick & Fidell, 2001). Simple-effects tests were followed by the pairwise comparisons.

**Go-Stop**. As can be seen in Figure 3-1A, a significant effect of arousal condition on percentage of inhibited responses was observed, \( F (2, 140) = 8.42, p < .001, \eta^2_p = .107. \) Consistent with the prediction that caffeine (vs. reward) will have stronger influence on this

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9 On the Go-Stop task, the data from the 350 ms stop delay were used because the performance discriminated participants’ performance and it is the most difficult variant of the task.
measure, the pairwise comparisons were significant for Go-Stop base vs. Go-Stop caffeine ($p < .001$) and Go-Stop reward vs. Go-Stop caffeine ($p < .001$), but not for Go-Stop base vs. Go-Stop reward ($n.s.$).

In addition to the analysis of inhibited responses, the effects of the two types of manipulation on the Go-Stop SSRT were also conducted, yielding significantly reduced stop-signal reaction time in the caffeine, compared to baseline condition ($p < .05$).

**IMT/DMT.** As can be seen in Figure 3-1B-C, the effect of arousal condition was not significant on either IMT or DMT measures. Further analyses were not conducted.

**Two Choice.** As can be seen in Figure 3-1D, there was a significant effect of arousal condition, $F (2, 140) = 24.97, p < .001, \eta^2_p = .263$. Consistent with predictions, pairwise comparisons indicated significantly less impulsive choices in the reward condition (Two-Choice base vs. Two-Choice reward, $p < .001$), while no significant changes occurred after caffeine (Two-Choice base vs. Two-Choice caffeine, $n.s.$). Moreover, comparison of reward and baseline conditions also indicated significantly less impulsive responses in reward condition (Two-Choice reward vs. Two-Choice caffeine, $p < .001$).

**SKIP.** As can be seen in Figure 3-1E, there was a significant effect of arousal condition, $F (2, 140) = 14.91, p < .001, \eta^2_p = .176$. Consistent with predictions, and similar to the Two Choice task, pairwise comparisons indicated significantly fewer impulsive responses in the reward condition (SKIP base vs. SKIP reward, $p < .001$), while no significant changes occurred in the caffeine condition (SKIP base vs. SKIP caffeine, $n.s.$). Furthermore, comparison of reward and baseline conditions also indicated significantly less impulsive responses in reward condition (SKIP reward vs. SKIP caffeine, $p < .002$).

**Time.** As can be seen in Figure 3-1F, a significant effect of arousal condition was found, $F (2, 140) = 8.28, p < .001, \eta^2_p = .106$. Pairwise comparisons were significant only for Time base vs.
Time reward conditions \((p < .001)\), indicating that the reward improved accuracy of time estimation.

**Level of Impulsivity at Baseline as a Moderator of the Effects**

The second goal of this subset was to test whether the effects depended on the participant’s baseline level of impulsivity. The prediction was that the effect of *caffeine* will be moderated by the baseline level of performance on executive function measures: decreasing impulsivity for participants who score high on EF impulsivity at baseline (low percent of inhibited responses; high percent commission errors), while it will increase impulsivity for people who score low on EF impulsivity at baseline. At the same time, the prediction was that the effect of *reward* will be moderated by the baseline level of performance on delay discounting measures: decreasing impulsivity for participants who score high on DD impulsivity at baseline (high number of immediate responses; high number of clicks), while it will increase impulsivity for people who score low on DD impulsivity at baseline.

To determine whether the observed effects depended on the baseline level of impulsivity, a series of repeated measure ANCOVAs were conducted for each task individually. Performance measures in the reward and caffeine conditions were entered as repeated measure variables and performance at baseline as a covariate. Somewhat surprisingly, the interaction between type of arousal (reward and caffeine) x covariate (baseline) was not significant for the following dependent measures of impulsivity: Go-Stop inhibition, IMT error, DMT error (all \(F < 1\)); suggesting that the baseline level of impulsivity did not moderate the effects of caffeine and reward on these measures.

A significant interaction between type of arousal (reward and caffeine) x covariate (baseline) was obtained for the Two-Choice Task, \(F(1,140) = 21.12, p < .001\); SKIP task, \(F(1,140) = 8.02, p < .005\), and Time, \(F(1,140) = 10.14, p < .002\); suggesting that the effects of
manipulation on these tasks depended on a level of performance at baseline. To examine the nature of the interaction, regression lines were plotted at ±1SD of the mean at baseline measure. In the Two Choice (Figure 3-2), SKIP (Figure 3-3), and Time (Figure 3-3) tasks, the significant interaction was driven by individuals who were high impulsive at baseline. In these three tasks, the reduction in impulsivity occurred in the reward condition, while there was no difference in the level of impulsivity after caffeine (both compared to baseline). Individuals who were low impulsive at baseline, not surprisingly, had similar pattern of response (ceiling effect) in all three conditions, baseline, reward and caffeine.

The Effects of Manipulation on Perception of Difficulty, Effort, and Importance

The third goal of this subset of analyses was to determine the extent of the effects of the reward and caffeine manipulations on participants’ subjective ratings of (a) exerted effort, (b) importance of doing well on tasks, and (c) task difficulty of the behavioral impulsivity tasks. The prediction was that the participants will put more effort, rate tasks as more important, and possibly as more difficult in the reward, compared to other conditions. The results of the evaluation of subjective effort, importance and difficulty for each task at three experimental conditions (baseline, reward, and caffeine) indicated that all behavioral impulsivity tasks followed similar pattern (see Tables 3-3; 3-4; and 3-5). Therefore, ratings of effort, importance, and difficulty were collapsed across tasks.

**Effort.** As can be seen in Figure 3-3, participants’ self-reported effort was different across conditions, $F(2,281) = 9.50, p < .001, \eta^2_p = .063$. Consistent with the prediction that the participants will exert more effort in the reward condition (compared to both baseline and caffeine), the planned contrast showed significantly greater effort at reward (vs. baseline); $F(1,141) = 16.64, p < .001$, and also significantly greater self-reported effort at reward (vs.
caffeine); $F(1,141) = 11.09, p < .001$. As expected, the self-reported effort of the task did not change between baseline and caffeine conditions \( (n.s.) \).

**Importance.** As can be seen in Figure 3-4, participants’ self-reported importance of the task was different across conditions. Similar to effort, there was a significant effect of importance $F(2,282) = 28.91, p < .001, \eta^2_p = .171$. Consistent with the prediction that the self-reported importance of the tasks will be rated as the most important when the reward is present, the planned contrast showed significantly greater importance in the reward condition (vs. baseline); $F(1,141) = 51.61, p < .001$, and also significantly greater importance of tasks at reward (vs. caffeine); $F(1,141) = 35.36, p < .001$. As expected, the self-reported importance of the task did not change between baseline and caffeine conditions ($F < 2$).

**Difficulty.** As can be seen in Figure 3-5, participants reported difficulty of the task to vary depending on a condition. There was a significant effect of difficulty $F(2,282) = 24.29, p < .001, \eta^2_p = .147$. The results indicated an interesting effect of caffeine on self-reported difficulty of tasks. Planned contrast yielded significant decrease in self-reported difficulty in the caffeine condition (vs. baseline); $F(1,141) = 21.36, p < .001$, while the perception of difficulty in the reward condition (vs. baseline).

**The Relationship between Measures**

This subset of analyses also had three major goals, which included describing the relationship between the set of behavioral measures of impulsivity; relationship between the self-report measures used in the study, and the relationship between the behavioral tasks and self-reported impulsivity.

**The Relationship between the Impulsivity Tasks at Baseline**

Another goal of analyses was to determine the relationship between the various behavioral measures of impulsivity at baseline. A weak relationship between EF and DD measures, but a
A strong relationship between the measures of EF (Go-Stop and IMT/DMT) and similarly between DD measures (Two-Choice and SKIP) was predicted.

In general, the analyses yielded low-to-moderate correlations among the behavioral impulsivity tasks (see Table 3-6 for full correlation matrix). There was a significant negative relationship between Time estimation and Go-Stop inhibition \((r = -.282, p < .001)\), as well as Time and GoStop SSRT \((r = -.325, p < .001)\) indicating that the longer the estimated time, less inhibited responses/ shorter stop latencies at baseline. Also, there was a correlation and between Time estimation and IMT error \((r = -.169, p < .05)\), indicating more commission errors and longer time estimates at baseline. These correlations were somewhat surprising given that, the pattern of the effects in Time estimation resembled the pattern observed for the delay discounting tasks. Contrary to predictions, measures within the impulsivity types did not correlate significantly (Two Choice and SKIP, n.s.; Go-Stop and IMT/DMT, n.s.\(^{10}\)).

To further explore the relationship between the tasks, exploratory factor analysis was conducted on five impulsivity variables in the baseline condition: Go Stop, IMT, Two Choice, SKIP and Time. Three factors were extracted (see Table 3-7), using an oblique solution with promax rotation. The results suggest that the two measures might be measuring different aspects of executive functions.

**The Relationship between Self-Reported Impulsivity**

Mean scores on the trait impulsivity measures (Table 3-8) were comparable to the normative mean for healthy young adults (Patton, Stanford, M., & Barratt, 1995; Eysenck, Eysenck, & Barrett, 1985). Although not the primary focus of this investigation, it was also worth noting the relationship between self-reported impulsivity (see Table 3-8). Within the same

\(^{10}\) There was a significant correlation between IMT and DMT \((r = .256)\), however, this is a variant of the same task.
scale, there was a strong positive correlation between the subscales of BIS\textsubscript{11} (all $r > .37$, all $p < .001$). The relationship between the subscales of I\textsubscript{7} was less pronounced. There was a significant correlation between I\textsubscript{7impulsivity} and I\textsubscript{7venturesomeness}, $r = .32$, $p < .001$. Interestingly, there was a negative correlation between I\textsubscript{7empathy} and I\textsubscript{7venturesomeness}, $r = -.18$, $p < .05$). Subscales of I\textsubscript{7}, I\textsubscript{7} impulsivity and I\textsubscript{7} empathy, were not correlated. Across different scales, there was a significant positive correlation between all subscales of BIS\textsubscript{11} and I\textsubscript{7impulsivity} (all $r > .36$, all $p < .001$), and also between BIS\textsubscript{11motor} and I\textsubscript{7venturesomeness} ($r = .34$, $p < .05$). Percent of immediate choices on the MCQ was not correlated to any of the other scales/subscales.

**The Relationship between Behavioral and Self-Report Measures of Impulsivity**

Consistent with the literature, only weak-to-moderate correlations were observed between self-report measures of impulsivity and behavioral impulsivity tasks (Table 3-9). Percent of commission errors on DMT was positively correlated with BIS\textsubscript{11attention} ($r = .197$, $p < .05$); percent of inhibition on the Go-Stop was negatively correlated with BIS\textsubscript{11motor} ($r = -.171$, $p < .05$), and SKIP was negatively correlated with I\textsubscript{7impulsivity} ($r = -.214$, $p < .05$). Percent of immediate choices on the MCQ was not correlated to any of the other scales/subscales.
Table 3-1. Distribution of responses for all behavioral measures of impulsivity in the baseline, reward, and caffeine conditions on the original scale of measurement.

<table>
<thead>
<tr>
<th>Behavioral Impulsivity Task</th>
<th>Baseline</th>
<th>Reward</th>
<th>Caffeine</th>
<th>Scale$^a$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Go-Stop Inhibition350</td>
<td>53.57 (23.69)</td>
<td>56.43 (23.29)</td>
<td>49.41 (24.03)</td>
<td>0-100</td>
</tr>
<tr>
<td>Go-Stop SSRT350$^b$</td>
<td>99.51 (102.70)</td>
<td>99.55 (108.91)</td>
<td>87.65 (77.61)</td>
<td>0-300</td>
</tr>
<tr>
<td>Go-Stop Inhibition250</td>
<td>80.26 (22.82)</td>
<td>77.41 (22.04)</td>
<td>77.14 (25.17)</td>
<td>0-100</td>
</tr>
<tr>
<td>Go-Stop Inhibition150</td>
<td>89.93 (17.38)</td>
<td>87.91 (18.95)</td>
<td>89.06 (17.15)</td>
<td>0-100</td>
</tr>
<tr>
<td>IMT %error</td>
<td>17.47 (13.81)</td>
<td>17.24 (13.79)</td>
<td>18.86 (13.54)</td>
<td>0-100</td>
</tr>
<tr>
<td>IMT %correct$^c$</td>
<td>92.89 (14.44)</td>
<td>92.96 (10.72)</td>
<td>94.12 (7.05)</td>
<td>0-100</td>
</tr>
<tr>
<td>DMT %error</td>
<td>24.11 (28.17)</td>
<td>23.55 (27.55)</td>
<td>22.56 (25.08)</td>
<td>0-100</td>
</tr>
<tr>
<td>DMT %correct</td>
<td>88.96 (26.07)</td>
<td>89.52 (20.77)</td>
<td>90.43 (21.13)</td>
<td>0-100</td>
</tr>
<tr>
<td>Two-Choice Immediate</td>
<td>18.94 (19.62)</td>
<td>7.54 (12.01)</td>
<td>15.98 (17.90)</td>
<td>0-60</td>
</tr>
<tr>
<td>SKIP total</td>
<td>176.37 (435.60)</td>
<td>33.49 (76.75)</td>
<td>145.17 (397.70)</td>
<td>0-∞</td>
</tr>
<tr>
<td>Time</td>
<td>80.39 (26.26)</td>
<td>88.24 (11.10)</td>
<td>82.99 (26.26)</td>
<td>/90s</td>
</tr>
</tbody>
</table>

$^a$ The range of possible scores/scale of measurement.

$^b$ SSRTs for 250 and 150 ms delay were not presented because large number of participants inhibited all stop signals, and therefore SSRTs were impossible to calculate.

$^c$ Percent of correct detections in IMT/DMT are correct responses to a target stimulus. These are calculated separately from commission errors as they represent two different pools of trials.
Table 3-2. Beta coefficients and indices of R square change when interaction term is introduced.

<table>
<thead>
<tr>
<th>Predictors</th>
<th>Behavioral Impulsivity Task</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Go-Stop inhibition</td>
</tr>
<tr>
<td>Stage 1</td>
<td></td>
</tr>
<tr>
<td>Reward</td>
<td>.354**</td>
</tr>
<tr>
<td>Caffeine</td>
<td>.344**</td>
</tr>
<tr>
<td>Stage 2</td>
<td></td>
</tr>
<tr>
<td>Reward</td>
<td>.301**</td>
</tr>
<tr>
<td>Caffeine</td>
<td>.371**</td>
</tr>
<tr>
<td>Reward x Caffeine</td>
<td>-.006*</td>
</tr>
</tbody>
</table>

**. $p < .001$, *. $p < .05$

Note: significant interactions represent significant $\Delta R^2$, after the interaction term had been added.
Table 3-3. Summary table of self-reported effort put on tasks.

<table>
<thead>
<tr>
<th></th>
<th>Effort base</th>
<th>Effort reward</th>
<th>Effort caffeine</th>
<th>Effort base vs. reward</th>
<th>Effort base vs. caffeine</th>
<th>Effort reward vs. caffeine</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M (SD)</td>
<td>M (SD)</td>
<td>M (SD)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IMT/DMT</td>
<td>3.71 (1.02)</td>
<td>3.94 (1.00)</td>
<td>3.80 (1.03)</td>
<td>2.81**</td>
<td>-1.15</td>
<td>1.59</td>
</tr>
<tr>
<td>Go-Stop</td>
<td>3.86 (0.99)</td>
<td>4.04 (0.97)</td>
<td>3.83 (1.01)</td>
<td>2.03**</td>
<td>0.24</td>
<td>2.26**</td>
</tr>
<tr>
<td>Two-Choice</td>
<td>2.85 (1.25)</td>
<td>3.01 (1.31)</td>
<td>2.88 (1.23)</td>
<td>-1.50*</td>
<td>-0.37</td>
<td>1.32</td>
</tr>
<tr>
<td>SKIP</td>
<td>3.28 (1.17)</td>
<td>3.55 (1.16)</td>
<td>3.35 (1.19)</td>
<td>-2.85**</td>
<td>0.73</td>
<td>1.98*</td>
</tr>
<tr>
<td>TIME</td>
<td>3.62 (1.06)</td>
<td>4.01 (0.91)</td>
<td>3.73 (1.03)</td>
<td>4.95**</td>
<td>-1.17</td>
<td>3.10**</td>
</tr>
<tr>
<td>All Tasks</td>
<td>17.32 (4.26)</td>
<td>18.55 (4.08)</td>
<td>17.60 (4.19)</td>
<td>-4.10**</td>
<td>-0.92</td>
<td>3.19**</td>
</tr>
</tbody>
</table>

** p < .001, * p < .05
<table>
<thead>
<tr>
<th>Importance</th>
<th>Importance</th>
<th>Importance</th>
<th>Importance</th>
<th>Importance</th>
<th>Importance</th>
</tr>
</thead>
<tbody>
<tr>
<td>base</td>
<td>reward</td>
<td>caffeine</td>
<td>base vs. reward</td>
<td>base vs. caffeine</td>
<td>reward vs. caffeine</td>
</tr>
<tr>
<td>M (SD)</td>
<td>M (SD)</td>
<td>M (SD)</td>
<td>t</td>
<td>t</td>
<td>t</td>
</tr>
<tr>
<td>IMT/DMT</td>
<td>3.20 (1.08)</td>
<td>3.67 (1.07)</td>
<td>3.43 (1.16)</td>
<td>5.44**</td>
<td>-2.66*</td>
</tr>
<tr>
<td>Go-Stop</td>
<td>3.33 (1.09)</td>
<td>3.81 (1.11)</td>
<td>3.45 (1.09)</td>
<td>5.76**</td>
<td>-1.29</td>
</tr>
<tr>
<td>Two-Choice</td>
<td>2.95 (1.23)</td>
<td>3.57 (1.19)</td>
<td>3.03 (1.27)</td>
<td>-6.19**</td>
<td>-0.83</td>
</tr>
<tr>
<td>SKIP</td>
<td>3.20 (1.15)</td>
<td>3.47 (1.17)</td>
<td>3.14 (1.18)</td>
<td>-2.76*</td>
<td>-0.53</td>
</tr>
<tr>
<td>TIME</td>
<td>3.23 (1.11)</td>
<td>3.84 (1.05)</td>
<td>3.32 (1.18)</td>
<td>-7.34**</td>
<td>0.86</td>
</tr>
<tr>
<td>All Tasks</td>
<td>15.91 (5.01)</td>
<td>18.36 (4.91)</td>
<td>16.37 (5.09)</td>
<td>-7.13**</td>
<td>-1.31</td>
</tr>
</tbody>
</table>

** p < .001, * p < .05
Table 3-5. Summary table of self-reported difficulty of tasks.

<table>
<thead>
<tr>
<th>Difficulty</th>
<th>M (SD)</th>
<th>Difficult</th>
<th>M (SD)</th>
<th>Difficult</th>
<th>M (SD)</th>
<th>M (SD)</th>
<th>t</th>
<th>t</th>
<th>t</th>
</tr>
</thead>
<tbody>
<tr>
<td>baseline</td>
<td>reward</td>
<td>caffeine</td>
<td>reward vs. base</td>
<td>base vs. caffeine</td>
<td>reward vs. caffeine</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IMT/DMT</td>
<td>2.67 (0.96)</td>
<td>2.64 (1.03)</td>
<td>2.17 (0.94)</td>
<td>-0.37</td>
<td>5.22**</td>
<td>5.28**</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Go-Stop</td>
<td>3.62 (1.23)</td>
<td>3.71 (1.14)</td>
<td>3.39 (1.32)</td>
<td>0.79</td>
<td>1.74</td>
<td>2.65**</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Two-Choice</td>
<td>1.62 (0.89)</td>
<td>1.68 (0.98)</td>
<td>1.48 (0.84)</td>
<td>0.58</td>
<td>1.71</td>
<td>2.33*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SKIP</td>
<td>2.28 (1.17)</td>
<td>2.75 (1.17)</td>
<td>2.06 (1.12)</td>
<td>4.07**</td>
<td>1.77</td>
<td>5.43**</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TIME</td>
<td>2.72 (1.15)</td>
<td>2.60 (1.11)</td>
<td>2.45 (1.12)</td>
<td>-1.03</td>
<td>2.93**</td>
<td>1.42</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All Tasks</td>
<td>12.91 (3.56)</td>
<td>13.37 (3.20)</td>
<td>11.55 (3.41)</td>
<td>-1.70</td>
<td>4.44**</td>
<td>6.54**</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: ** p < .001, * p < .05
Table 3-6. Correlation coefficients of behavioral impulsivity tasks at baseline.

<table>
<thead>
<tr>
<th></th>
<th>GS_{inh350}</th>
<th>Go-St_{SSRT350}</th>
<th>Go-St_{inh250}</th>
<th>IMT %err</th>
<th>IMT %corr</th>
<th>DMT %err</th>
<th>DMT %corr</th>
<th>Two-Ch</th>
<th>SKIP_{total}</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Go-Stop_{inh350}</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G-SSRT_{inh350}</td>
<td>.492**</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Go-Stop_{inh250}</td>
<td>.771**</td>
<td>.533**</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IMT %err</td>
<td>-.059</td>
<td>-.089</td>
<td>-.143</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IMT %corr</td>
<td>-.190*</td>
<td>-.107</td>
<td>-.100</td>
<td>-.125</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DMT %err</td>
<td>-.004</td>
<td>.115</td>
<td>-.038</td>
<td>.256**</td>
<td>-.109</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DMT %corr</td>
<td>-.113</td>
<td>-.079</td>
<td>-.073</td>
<td>-.046</td>
<td>.487**</td>
<td>.051</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Two-Ch</td>
<td>.074</td>
<td>-.004</td>
<td>.098</td>
<td>-.085</td>
<td>-.021</td>
<td>.012</td>
<td>-.144</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SKIP_{total}</td>
<td>-.103</td>
<td>-.111</td>
<td>-.195*</td>
<td>.173*</td>
<td>.004</td>
<td>.101</td>
<td>.010</td>
<td>.158</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Time</td>
<td>-.282**</td>
<td>-.325**</td>
<td>-.196*</td>
<td>-.169*</td>
<td>.217**</td>
<td>-.078</td>
<td>.222**</td>
<td>-.076</td>
<td>-.127</td>
<td>1</td>
</tr>
</tbody>
</table>

** p < .001, * p < .05
Table 3-7. Factor scores of the behavioral impulsivity tasks at baseline.

<table>
<thead>
<tr>
<th>Task</th>
<th>F1</th>
<th>F 2</th>
<th>F3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Go-Stop inhibition 350</td>
<td>-.604</td>
<td>-.167</td>
<td>-.030</td>
</tr>
<tr>
<td>TIME</td>
<td>.529</td>
<td>-.180</td>
<td>-.129</td>
</tr>
<tr>
<td>IMT correct</td>
<td>.365</td>
<td>-.162</td>
<td>.062</td>
</tr>
<tr>
<td>IMT error</td>
<td>-.091</td>
<td>.646</td>
<td>-.094</td>
</tr>
<tr>
<td>Two-Choice</td>
<td>.079</td>
<td>.142</td>
<td>.564</td>
</tr>
<tr>
<td>SKIP</td>
<td>-.083</td>
<td>-.256</td>
<td>.411</td>
</tr>
</tbody>
</table>

*a factor labels: F1: EF inhibition
F2: EF working memory
F3: Delay discounting
Table 3-8. Means and standard deviations of self-report measures of impulsivity.

<table>
<thead>
<tr>
<th>Measure</th>
<th>M (SD)</th>
<th>Measure</th>
<th>M (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I\textsubscript{7} impulsivity</td>
<td>6.00 (3.81)</td>
<td>BIS\textsubscript{11} attention</td>
<td>15.21 (3.50)</td>
</tr>
<tr>
<td>I\textsubscript{7} venture</td>
<td>9.51 (3.24)</td>
<td>BIS\textsubscript{11} motor</td>
<td>20.50 (3.84)</td>
</tr>
<tr>
<td>I\textsubscript{7} empathy</td>
<td>14.11 (3.00)</td>
<td>BIS\textsubscript{11} planning</td>
<td>23.11 (4.81)</td>
</tr>
<tr>
<td>I\textsubscript{7} total</td>
<td>29.62 (6.29)</td>
<td>BIS\textsubscript{11} total</td>
<td>58.82 (9.49)</td>
</tr>
<tr>
<td>MPQ</td>
<td>54.88 (18.75)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GSinh350</td>
<td>IMT.err</td>
<td>DMT.err</td>
<td>T-Ch</td>
</tr>
<tr>
<td>----------</td>
<td>---------</td>
<td>---------</td>
<td>------</td>
</tr>
<tr>
<td>GSinh350</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IMT.err</td>
<td>-0.059</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>DMT.err</td>
<td>-0.004</td>
<td>0.256**</td>
<td>1</td>
</tr>
<tr>
<td>T-Ch</td>
<td>0.074</td>
<td>-0.085</td>
<td>0.012</td>
</tr>
<tr>
<td>SKIP</td>
<td>-0.103</td>
<td>0.173*</td>
<td>0.101</td>
</tr>
<tr>
<td>Time</td>
<td>-0.282**</td>
<td>-0.169*</td>
<td>-0.078</td>
</tr>
<tr>
<td>BIS_mot</td>
<td>-0.171*</td>
<td>-0.066</td>
<td>0.055</td>
</tr>
<tr>
<td>BIS_plan</td>
<td>0.010</td>
<td>-0.016</td>
<td>0.056</td>
</tr>
<tr>
<td>BIS_att</td>
<td>-0.128</td>
<td>0.114</td>
<td>0.197*</td>
</tr>
<tr>
<td>BIS_tot</td>
<td>-0.112</td>
<td>0.007</td>
<td>0.123</td>
</tr>
<tr>
<td>I7imp</td>
<td>0.003</td>
<td>0.013</td>
<td>0.033</td>
</tr>
<tr>
<td>I7ven</td>
<td>-0.050</td>
<td>0.055</td>
<td>0.077</td>
</tr>
<tr>
<td>I7emp</td>
<td>-0.012</td>
<td>0.112</td>
<td>-0.063</td>
</tr>
<tr>
<td>I7tot</td>
<td>-0.030</td>
<td>0.090</td>
<td>0.030</td>
</tr>
<tr>
<td>MPQ</td>
<td>0.014</td>
<td>0.147</td>
<td>0.076</td>
</tr>
</tbody>
</table>

** p < .001, * p < .05
Figure 3-1. The effects of the two types of manipulations on performance on the standard scale. A) Go-Stop; B) IMT; C) DMT; D) Two Choice; E) SKIP, and F) Time. Note: The bars represent a mean of standard scores (+SE) in the reward and caffeine conditions (see Eq. 3-1, and 3-3, for calculations), while baseline is at zero. To match the directionality in impulsive responding across all measures, the standardized scores for the Go-Stop and Time were inverted to match other measures. Thus, positive scores indicate increased impulsivity compared to baseline and vice versa.
Figure 3-2. Moderation of effects by baseline level of impulsivity in the Two-Choice task.

Figure 3-3. Moderation of effects by baseline level of impulsivity in the SKIP task.
Figure 3-4. Moderation of effects by baseline level of impulsivity in the Time Estimation task.
Figure 3-5. Self-reported exerted effort in the behavioral impulsivity tasks. The bars represent a mean difference (+SE) calculated by subtracting sum of scores on all tasks at baseline from the sum in the reward or caffeine conditions, respectively.

Figure 3-6. Self-reported importance of the behavioral impulsivity tasks. The bars represent a mean difference (+SE) calculated by subtracting sum of scores on all tasks at baseline from the sum in the reward or caffeine conditions, respectively.
Figure 3-7. Self-reported difficulty of the behavioral impulsivity tasks. The bars represent a mean difference (+SE) calculated by subtracting sum of scores on all tasks at baseline from the sum in the reward or caffeine conditions, respectively.
Overall, the results were consistent with the main predictions, demonstrating that (a) different types of arousal differentially affected performance; and (b) the effects depended not only on the type of arousal manipulation, but also on the type of impulsivity the task was assessing. Moreover, the results were consistent with the more specific predictions regarding the effects of the two types of arousal. On the one hand, caffeine (vs. reward) seemed to influence measures of executive functions more strongly, which was largely evident in more impulsive performance on the Go-Stop and IMT tasks. On the other hand, manipulation of reward (vs. caffeine) had a generally stronger effect on delay-discounting tasks, as revealed by the substantial decrease in impulsive choices on a Two-Choice and SKIP tasks. Because differential effects of manipulations on performance have been observed, the components of impulsivity, represented by the tasks used in the study, may be attributed to different underlying processes. When performance on individual measures was considered, several interesting patterns of results emerged.

Executive-Function Impulsivity. Performance on the executive function measures was influenced by caffeine, while at the same time, the performance on these measures was largely unaffected by reward, providing support for the main hypothesis regarding executive-function impulsivity (H1)\(^1\).

In the Go-Stop task, caffeine increased impulsivity by reducing both the percentage of inhibited responses and stop-signal latency. Moreover, the results indicated that the effects did not depend on the level of impulsivity at baseline. Whereas the hypothesis regarding the moderating role of the baseline level of EF impulsivity (H1a) was not supported, this result was

\(^1\) This statement is based primarily on results obtained in the Go-Stop tasks, but see discussion below.
not surprising. It is well established that stimulants, when taken in excess, may hinder performance of healthy adults. To recap based on the assumption that healthy and clinical population lie on the continuum on impulsivity dimension, the prediction was that the more impulsive end of the healthy sample would resemble clinical population. Because this wasn’t the case, it is important to discuss whether healthy and clinical populations differ in terms of mechanisms that drive the effects of caffeine. As mentioned in the introduction, prior research suggests that the reduction in impulsivity in children with ADHD is due to decrease in stop-signal reaction time (e.g., Logan et al., 1997). In this study, the stop-signal latencies also decreased greatly after caffeine consumption, suggesting that the same mechanism may be responsible for the increase in impulsivity in healthy and the decrease in impulsivity in clinical population. This finding is, however, inconsistent with previous reports, where d-amphetamine was found to decreases SSRT only in subjects who have exhibited relatively long SSRTs (de Wit et al. 2000, 2002). Interestingly, this finding also suggests that impulsivity can arise due to either (a) too fast a response to a go signal; or (b) too slow a response to a stop signal. This is further consistent with the classic Yerkes-Dodson’s (1908) U-shaped relationship between arousal and optimal performance, suggesting suboptimal levels of arousal on either ends as roots of impulsive behavior.

In the immediate version of the IMT/DMT task, the effect of the two manipulations was similar to that in the Go-Stop task. However, although the caffeine manipulation somewhat increased the percentage of commission errors, the effect was much smaller than that observed in the Go-Stop task. Therefore, it is important to discuss what caused this divergence, in order to understand if the two tasks tap into the same EF processes. First of all, it might be that the

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2 The response occurred at the beginning of the trial, prior to a signal change from go to stop.
difference in difficulty between the IMT and Go-Stop tasks caused this discrepancy. In other words, it seems that the IMT task was less challenging and therefore there was little room to observe the effect. First, the Go-Stop trials with a 350 ms delay of stop signals may be objectively considered more difficult, than the catch trials in the IMT task, which are presented on the screen for the same duration as the other stimuli. Second, the proportion of catch stimuli in the IMT task was greater than the proportion of stop signals in the Go-Stop, which made the responses to targets in IMT less dominant and therefore easier. Lastly, the objective difficulty (or more precisely easiness) of the task may also be inferred from the outstanding performance on the IMT task, where many participants obtained a perfect score. This suggests that the difficulty of the task caused the differences in effects of caffeine between the Go-Stop and IMT tasks. In support of this explanation, also speaks the comparison of the results on the IMT with easier trials of the Go-Stop task (e.g., 250 ms), where the effect of caffeine was substantially smaller, while the overall performance outstanding. This would, furthermore, suggest that both tasks, Go-Stop and the IMT, tap into same or closely related executive function.

What makes this inference problematic, however, is the absence of correlation between the IMT commission errors and the Go-Stop inhibition in any of its variants used in the study (H3). Furthermore, the results of the factor analysis showed that the Go-Stop and the IMT tasks loaded on separate factors, which is suggestive of the role of different executive functions in the Go-Stop and the IMT tasks. Indeed if we consider the nature of the two tasks, it seems possible that the two tap into different executive functions (see Miyake et al., 2000, for a review). The Go-Stop task is a prototypical response inhibition measure. While the IMT is a related task, it probably targets updating and working-memory type of processes in greater extent than it does inhibitory processes. That said, future research should aim to specifically establish the role of
executive functions different from response inhibition, because it seems very likely that other forms of EF play a noteworthy role in impulsivity.

In the delayed version of the IMT/DMT task, performance was not affected by either of the manipulations. Similar to the immediate version, discussed above, this could be in part due to (a) the difficulty level of the task, which again did not represent much challenge for the participants in the study or (b) this task may tap into separate executive functions. A more challenging variant of the task should be used in future studies to establish this. An alternative possibility should, however, be explored; namely, that the DMT task shares more characteristic mechanisms with the delay discounting tasks than other EF measures. Although the current investigation did not provide evidence for such claim, a slight change in means in the direction predicted for the delay discounting tasks suggests it may be important to establish whether this claim is valid. Although speculative at this point, such a finding would provide an important link between the two types of impulsivity by establish a measure that taps into both executive-function and delay-discounting types of impulsivity.

**Delay-Discounting Impulsivity.** Performance on both delay discounting measures was influenced by reward, while at the same time, the performance on these measures was largely unaffected by caffeine, providing support for the main hypothesis regarding DD impulsivity (H2). The hypothesis about the moderation of the effect by the level of impulsivity at baseline (H2a) was also supported. The low-impulsive at baseline, as indicated by the small percentage of immediate choices on the Two-Choice and a low number of clicks in the SKIP task in the baseline condition, did not change this pattern of behavior in neither of the experimental conditions. The high-impulsive participants, on the other hand, radically changed their pattern of
choices in the reward condition, decreasing the proportion of the immediate choices in the Two-Choice, and decreasing clicking in the SKIP task.

Although both of the tasks were similarly influenced by the two types of arousal, performance on the Two-Choice task seemed to be particularly prone to reductions in impulsivity. Similar to the finding for the executive-functions measures, no correlation among the two delay-discounting measures was found (H3). Similar to the earlier discussion of the effects observed on the executive-function tasks, it might be that the SKIP task was more difficult than the Two-Choice. There is, however, a difference between task difficulty here and that discussed in the executive-function impulsivity above. The SKIP task was possibly more “difficult” because response-reward contingencies were not apparent and only vague instructions were given to participants. In the Two-Choice task, on the other hand, participants learned contingences explicitly prior to the start of the task. Therefore any differences in the size of the effects may be attributed to the lack of awareness of how “clicking” translates into reward. It is however, important for future research to establish a link between rates of learning (and unlearning) of the reward-behavior contingences, as well as provide clearer picture of the role of awareness in response to reward, as these may play an important role in this type of impulsivity.

**Time Estimation.** Time estimation was perhaps the most intriguing measure used in current study. Processes responsible for biases in time perception, however, are seldom discussed. On the one hand, the perception of time has been indicated in ADHD literature (Barkley et al., 2001; Barkley, Murphy, & Bush, 2001), although it hasn’t been substantially explored. On the other hand, time is an important part of the delay-discounting tasks. Therefore, specific predictions regarding the classification of the Time tasks into one of the types of impulsivity were not made. In this investigation, estimation of time was correlated with both
measures of executive functioning, the Go-Stop and the IMT/DMT, while simultaneously the pattern of effects of the two types of manipulation was similar to that of observed for the measures of delay discounting. Particularly, estimation of time improved greatly in the reward condition (vs. baseline), while it wasn’t affected in the caffeine condition (vs. baseline). These results are consistent with the previous literature, linking both types of impulsivity with time. However, the role of time in the two types of impulsivity was not established due to the current study design.

Impulsivity and Automaticity. The results of the study also suggest a link between different types impulsivity and automatic (vs. controlled) processes. First of all, participants reported that they exerted more effort on the task and that doing well was more important to them in the reward condition (compared to both other conditions). This finding confirmed that a $100 incentive considerably increased participants’ motivation for doing well. Yet, only delay discounting tasks were impacted by this effort and motivation, while performance on the executive function tasks did not change. This finding suggests that conscious effort and motivation does not play much of a role in regulation of processes involved in executive-function impulsivity. It does, however, suggest a rather automatic nature of the processes involved in this type of impulsivity.

In contrast, processes involved in the delayed discounting were greatly impacted by effort and motivation and therefore seem to be under control of conscious processes. Yet, the lack of correlations between the self-reported impulsivity and performance on these tasks, make this claim problematic. It is therefore important to explore the extent to which delay-discounting impulsivity is under conscious control. Another interesting issue, of particular interest for future research, is the role of awareness in reward-behavior contingency learning. Particularly, it is
important to establish whether learning occurs outside of awareness and how does that play out in impulsivity. Also, it is possible that there are differences in learning (mechanisms, rate, etc) between high vs. low impulsive individuals.

Biases in time estimation may also have both automatic and controllable nature. For instance, long intervals, such as those seen in delay discounting, may be particularly easy to control consciously. Very short intervals, such as those required in the Go-Stop task, are probably not controllable on the conscious level. It is worth exploring whether this dimension in time estimation plays a critical role in distinguishing the two types of impulsivity.

**Perception of Task Difficulty.** The change of the perception of task difficulty in the caffeine condition (vs. baseline and reward) was an unexpected outcome that may shed more light into processes underlying global arousal and performance. Two possibilities come to mind when explaining the observed effect. First, it may be that caffeine changed subjective perception of difficulty of task difficulty, which in turn contributed to the reduction in reaction time. Second, it may be that caffeine changed the speed of performance, which in turn changed the perception of difficulty. In fact, it is important to establish this because both possibilities seem plausible.

On the other hand, it is reasonably well established that caffeine and other stimulants affect the speed of responses. However, to my knowledge, no previous studies established the role of stimulants in perception of task difficulty, though it is possible that this alteration happens via increased positive mood, self-esteem and sense of power, which have been linked to effects of stimulants. Establishing the mediators of the effects may possibly contribute to the greater understanding of the phenomenon in general.
One limitation of the study, similar to that of many other studies on impulsivity, is a lack of established relationship between the performance on the task used in measuring impulsivity and a “real-life” impulsive behavior of these participants. However, what justifies this approach is a previously established link between measures used in this study and reports of self-injurious behavior, suicide attempts, alcoholism, among other disorders associated with impulsivity. It is, nonetheless, important to link the performance on behavioral measures with certain day-to-day impulsive behavior.

There are many possible directions for future research, many of which have been already discussed. What seems particularly interesting is the role of time perception in impulsivity. Although some hypothetical explanations were discussed, research is needed to address the relationship between time perception and impulsivity, and especially the role of time in the two different types of impulsivity. Second, the distinction between automatic and controlled processes may be an important one in understanding impulsive behavior. In this research, executive function impulsivity seemed linked to automatic processes, while delay discounting seemed linked to effortful and motivational aspects of performance. It is of interest to establish this relationship more clearly and also explore boundary conditions.

**Contributions and Conclusions.** The results of the current research were consistent with the notion that impulsivity is a complex, multifaceted construct. The current study provided an important extension of past work by directly comparing several popular behavioral measures of impulsivity in three types of conditions. This is, to my knowledge, the first paper to experimentally test and provide evidence for the dissociation in mechanisms responsible for the regulation of the two types of impulsivity. These findings are important for both theoretical and practical domains of psychology. For instance, the findings are applicable to theories of self-
regulation and control of behavior in cognitive and social psychology. At the same time, this research also suggests that it is useful to link literatures on ADHD with the literature on impulsivity in healthy adults. The results of the present research suggest that the dual-pathway model of ADHD (Sonuga-Barke, 2003) may be particularly applicable in understanding of impulsivity in healthy adults.
APPENDIX A
CALCULATION OF SSRT IN THE GO-STOP TASK

The calculation of SSRT is represented in Figure A-1. The top line represents mean reaction time to the go signal. The bottom line represents stop-signal delay plus stop-signal reaction time. Stop-signal delay is adjusted so that subjects inhibit 50% of the time, which means the race is tied. Therefore the two lines end at the same point in time (Logan et al. 1997).

Go Signal Reaction Time (Mean RT)

Stop Signal Delay | Stop Signal Reaction Time (SSRT)

Time

Figure A-1. Estimation of Stop Signal Reaction Time.
APPENDIX B.
PRESCREENING QUESTIONNAIRE

In this study, you will be asked to consume a caffeinated drink. Thus, if you have a medical condition that can be worsened by caffeine or if you are taking any medications that may interact with caffeine; you should not participate in this study.

You should not be participating in this study if you have a history of current health conditions:
- Diabetes
- heart disease or heart problems
- high blood pressure
- gastrointestinal problems (e.g., peptic ulcers)
- epilepsy or any other seizure disorder
- anxiety or panic attack
- hypoglycemia
- fibrocystic disease
- hypoglycemia
- asthma or respiratory problems
- allergy to caffeine
- you are currently pregnant

Do you have any of the health conditions listed above?  ____ YES  ____ NO
If your answer is YES, you are not eligible to participate in this study.

You should not participate in this study if you are taking the following medications:
- adenosine
- certain asthma medications (theophylline, beta-agonists such as albuterol)
- ciprofloxacin
- disulfiram
- drugs affecting liver enzymes that remove caffeine from your body (such as cimetidine, fluvoxamine, macrolide antibiotics including erythromycin)
- lithium
- any other medications that may interact with caffeine (please consult your pharmacist or your medical doctor if you are unsure).

Are you currently on any of the medications listed above?  ____ YES  ____ NO
If your answer is YES, you are not eligible to participate in this study.

If you are unsure if the amount of caffeine equivalent to 2-3 cups of coffee could be harmful to you, you should not participate until you have consulted with your medical doctor.

Do you actively try to avoid consuming caffeine?  ____ YES  ____ NO
Do you still want to participate in the study?  ____ YES  ____ NO
APPENDIX C
QUESTIONNAIRE BIS$_{11}$

Instructions:

People differ in the ways they act and think in different situations. This is a test to measure some of the ways in which you act and think. Do not spend too much time on any statement. Answer quickly and honestly.

Answer options:

Rarely/Never

Occasionally

Often

Almost Always/Always

1. I plan tasks carefully.
2. I do things without thinking.
3. I make-up my mind quickly.
4. I am happy-go-lucky.
5. I don’t “pay attention.”
6. I have “racing” thoughts.
7. I plan trips well ahead of time.
8. I am self controlled.
9. I concentrate easily.
10. I save regularly.
11. I “squirm” at plays or lectures.
12. I am a careful thinker.
13. I plan for job security.
15. I like to think about complex problems.
16. I change jobs.
17. I act “on impulse.”
18. I get easily bored when solving thought problems.
19. I act on the spur of the moment.
20. I am a steady thinker.
21. I change residences.
22. I buy things on impulse.
23. I can only think about one thing at a time.
24. I change hobbies.
25. I spend or charge more than I earn.
26. I often have extraneous thoughts when thinking.
27. I am more interested in the present than the future.
28. I am restless at the theater or lectures.
29. I like puzzles.
30. I am future oriented
APPENDIX D
QUESTIONNAIRE 17

Instructions:

Please answer each question by choosing the ‘YES’ or the ‘NO’ following the question. There are no right or wrong answers, and no trick questions. Work quickly and do not think too long about the exact meaning of the question.

Answer options:

    Yes

    No

1. Would you enjoy water skiing?
2. Usually do you prefer to stick to brands you know are reliable, to trying new ones on the chance of finding something better?
3. Would you feel sorry for a lonely stranger?
4. Do you quite enjoy taking risks?
5. Do you often get emotionally involved with your friends problems?
6. Would you enjoy parachute jumping?
7. Do you often buy things on impulse?
8. Do unhappy people who are sorry for themselves irritate you?
9. Do you generally do and say things without stopping to think?
10. Are you inclined to get nervous when others around you seem to be nervous?
11. Do you often get into a jam because you do things without thinking?
12. Do you think hitch-hiking is too dangerous a way to travel?
13. Do you find it silly for people to cry out of happiness?
14. Do you like diving off the highboard?
15. Do people you are with have a strong influence on your mood?
16. Are you an impulsive person?
17. Do you welcome new and exciting experiences and sensations, even if they are a little frightening and unconventional?
18. Does it affect you very much when one of your friends seems upset?
19. Do you usually think carefully before doing anything?
20. Would you like to learn to fly an airplane?
21. Do you ever get deeply involved with the feelings of a character in a film, play, or novel?
22. Do you often do things on the spur of the moment?
23. Do you get very upset when you see someone cry?
24. Do you sometimes find someone else’s laughter catching?
25. Do you mostly speak without thinking things out?
26. Do you often get involved in things you later wish you could get out of?
27. Do you get so “carried away” by new and exciting ideas that you never think of possible snags?
28. Do you find it hard to understand people who risk their necks climbing mountains?
29. Can you make decisions without worrying about other people’s feelings?
30. Do you sometimes like doing things that are a bit frightening?
31. Do you need to use a lot of self control to keep out of trouble?
32. Do you become more irritated than sympathetic when you see someone cry?
33. Would you agree that almost everything enjoyable is illegal or immoral?
34. Generally, do you prefer to enter cold sea water gradually, to diving or jumping straight in?
35. Are you often surprised at people’s reactions to what you do or say?
36. Would you enjoy the sensation of skiing very fast down a high mountain slope?
37. Do you like watching people open presents?
38. Do you think an evening out is more successful if it is unplanned or arranged at the last moment?
39. Would you like to go scuba diving?
40. Would you find it very hard to break bad news to someone?
41. Would you enjoy fast driving?
42. Do you usually work quickly, without bothering to check?
43. Do you often change your interests?
44. Before making up your mind, do you consider all the advantages and disadvantages?
45. Can you get very interested in your friend’s problems?
46. Would you like to go pot-holing?
47. Would you be put off a job involving quite a bit of danger?
48. Do you prefer to “sleep on it” before making decisions?
49. When people shout at you, do you shout back?
50. Do you feel sorry for very shy people?
51. Are you happy when you are with a cheerful group and sad when the others are glum?
52. Do you usually make up your mind quickly?
53. Can you imagine what it must be like to be very lonely?
54. Does it worry you when others are worrying and panicky?
APPENDIX E
QUESTIONNAIRE MCQ

Instructions:

For each of the next 27 choices, please indicate which reward you would prefer: the smaller reward today or the larger reward in the specified number of days.

Answer options:

The smaller reward today

The larger reward in the specified number of days

1. Would you prefer $54 today or $55 in 117 days?
2. Would you prefer $55 today or $75 in 61 days?
3. Would you prefer $19 today or $25 in 53 days?
4. Would you prefer $31 today or $85 in 7 days?
5. Would you prefer $14 today or $25 in 19 days?
6. Would you prefer $47 today or $50 in 160 days?
7. Would you prefer $15 today or $35 in 13 days?
8. Would you prefer $25 today or $60 in 14 days?
9. Would you prefer $78 today or $80 in 162 days?
10. Would you prefer $40 today or $55 in 62 days?
11. Would you prefer $11 today or $30 in 7 days?
12. Would you prefer $67 today or $75 in 119 days?
13. Would you prefer $34 today or $35 in 186 days?
14. Would you prefer $27 today or $50 in 21 days?
15. Would you prefer $69 today or $85 in 91 days?
16. Would you prefer $49 today or $60 in 89 days?
17. Would you prefer $80 today or $85 in 157 days?
18. Would you prefer $24 today or $35 in 29 days?
19. Would you prefer $33 today or $80 in 14 days?
20. Would you prefer $28 today or $30 in 179 days?
21. Would you prefer $34 today or $50 in 30 days?
22. Would you prefer $25 today or $30 in 80 days?
23. Would you prefer $41 today or $75 in 20 days?
24. Would you prefer $54 today or $60 in 111 days?
25. Would you prefer $54 today or $80 in 30 days?
26. Would you prefer $22 today or $25 in 136 days?
27. Would you prefer $20 today or $55 in 7 days?
LIST OF REFERENCES


BIOGRAPHICAL SKETCH

Sonja Damnjanović was born and raised in Serbia. She completed her high school education in Belgrade, Serbia in 1997. Immediately after, Sonja moved to Poland to pursue her further education. Sonja graduated from the University of Warsaw in Warsaw, Poland in 2002 with a Master of Arts degree (Tytuł Magistra) in psychology. Upon graduating with her master’s degree, Sonja worked as a research assistant at New York University for one year in a laboratory devoted to social cognition research. Shortly after, Sonja entered the doctoral program in cognitive psychology at the University of Florida. Her dissertation research was supported by the Sigma Xi research grant. Sonja received her Doctor of Philosophy degree in 2009.