Impulsivity and the "All-Nighter:" Combined Effects of Acute Sleep Deprivation and Circadian Low-Point on Discounting

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As it is used in everyday speech the term "impulsivity" forms rather a wide conceptual umbrella, spanning an enormous breadth of topographically disparate behaviors. For example, individuals who overeat, take risks in dangerous situations, make unnecessary purchases, use illicit drugs, engage in crimes, or fail to take preventive safety measures all might be described as "impulsive." This manifold quality presents an interesting challenge to researchers who wish to study the wide range of behavioral phenomena that fall into the category of impulsivity. However, researchers have devised a method to unify the study of the many diverse examples of real-world impulsivity. This method is simply to think of impulsive behaviors as choices between different types of consequences: between immediate or certain consequences and delayed or probabilistic ones. For example, a person on a diet may be faced with a mutually-exclusive choice between the delayed reinforcement of weight loss and the immediate reinforcement of an order of french fries. Despite the *objectively* higher value of losing weight, the person might still choose the french fries because of their more immediate and certain reinforcing consequences. Within this framework, the term *discounting* refers to the behavioral process by which an otherwise salient consequence, like weight loss, has a diminished power to affect behavior because its delivery is either delayed or probabilistic. In cases where discounting results in choices that are judged to be problematic or undesirable, as in the examples of overeating, risk-taking, and the others listed above, the discounting behavior is generally described as "impulsive." In this way, discounting represents a single behavioral process that may underlie many seemingly unrelated forms of behavior that are thought of as impulsive.

Much research has been conducted to operationalize and study the notion of impulsivity using discounting models. Such studies with humans tend to examine the relation between performance on discounting tasks and group-membership variables expected to relate to impulsivity (e.g., a study might compare overeaters to controls in the tendency to discount). However, little research has been done to examine the degree to which an individual's tendency to discount might be influenced by situational variables.

Discounting research, which grew largely out of the behavior-analytic framework, has recently been singled out as an important area in which applied behavior analysis might direct itself towards a wider range of socially relevant problems than it is currently addressing (Critchfield & Kollins, 2001). Indeed, the increased publication of articles dealing with discounting in the past decade, both within and outside of behavior-analytic journals, suggests a growing interest in the various ways of applying discounting to human problem behaviors. Yet, discounting research is unlikely to yield behavioral technologies useful to human problems, such as interventions to reduce the tendency to behave impulsively, unless it can be demonstrated that within-subject changes in impulsive behavior are possible. Naturally, if an individual's tendency to behave impulsively is an unchangeable trait, then the potential for useful interventions arising from research using tasks to study that tendency is quite limited.

As an attempt to demonstrate that impulsive responding (as measured by discounting tasks) is indeed a malleable behavior pattern in humans, the current study introduced the manipulation of acute sleep deprivation, a largely unexplored variable in the impulsivity literature, to observe its effects on two measures of the tendency to discount along with other convergent measures and manipulation checks. These measures were taken at the approximate circadian nadir, most generally occurring between 0200 hrs and 0700 hrs, a time at which sleep-deprived individuals have been found to be most impaired (see below). This specific type of sleep deprivation is of particular interest because of the sorts of situations that can elicit it. Many individuals, for example, are familiar with the experience of an "all-nighter," in which a person forgoes sleep for a night, often to accomplish some task before a deadline. Many people regard "pulling an all-nighter" as a generally benign, if somewhat fatiguing, strategy for dealing with a time pressure. However, these "all-nighters" may be especially problematic when the individuals working without sleep need to make important and sensitive decisions in the early morning hours. Workers who deal with crisis response, for example, sometimes have to unexpectedly forego sleep in order to deal with an emerging situation. At nearly every occupational level, from first responders to high-level government decision makers, an increased tendency to make impulsive choices in such situations could have dire consequences. A greater understanding of the effects of acute sleep deprivation on impulsive decision-making is therefore of considerable potential import.

To delineate the conceptual foundation for the current study, the discounting model of impulsivity is introduced below, followed by a specific explanation of how it is measured in the laboratory and an examination of the problematic issues surrounding such research, particularly the paucity of studies showing clear within-subject variability in discounting. The prior evidence suggesting a potential relation between sleep deprivation and discounting is then explored. Finally, the current study is introduced, which was conducted to help elucidate problems with the measurement of discounting and questions about its nature.

The Problems and Promise of Discounting as a Model for Impulsive Behavior

William James notes that, “Inner happiness and serviceability do not always agree. What immediately feels most ‘good’ is not always most ‘true,’ when measured by the verdict of the rest of experience” (1982, pp.15-16). The temporal quandary that James articulates here is precisely the concern of discounting research, which aims to study how (and understand why) we sometimes choose rewards that we know stand in opposition to “the verdict of the rest of experience.”

The phenomenon of discounting is well illustrated by examples outside of the laboratory: for example, seat belt use. When measured against the ultimate reward of a safe and injury-free life, the immediate rewards of comfort/convenience afforded by not wearing a seat belt are comparatively miniscule. Yet, in 1984, for example, before laws mandating seat belt use came into widespread effect, the national usage rate among drivers was only 14%, which has increased in subsequent years only with the introduction of legal penalties for non-use (National Highway Traffic Safety Administration, 1998). Why were governments forced to rearrange contingencies in such a way as to tip the behavioral decision-making scale, as it were, towards compliance? If anyone were given the specific choice between a lifetime of safety and a bit of slightly increased comfort/convenience, he or she would surely choose the lifetime of safety. So why isn’t the lifetime of safety, by itself, reinforcing enough to result in 100% seat belt usage rates?

One viable answer to these questions seems to lie in a process called *discounting*. Discounting is the behavior pattern in which a consequence, be it a reinforcer or punisher, is discounted in subjective value (i.e., in its power to influence behavior) as a function of various parameters such as the *delay to delivery* or *probability of occurrence* for that consequence. So, in the seat belt example, we would say that the negatively reinforcing value of avoiding injury in a potential accident is *discounted* as a function of its temporal distance and its low probability of occurrence, thus making it less likely to influence behavior.

As suggested above, a diverse array of behaviors commonly called "impulsive" can fit within this conceptual framework. Behaviors such as overeating, impulsive buying, drug use, risk-taking, and many more like them, all put immediate reinforcement above the long-term best interests of the individual. To choose to engage in these behaviors is thus to discount the distal consequences of events in favor of their more immediate, objectively smaller-valued, counterparts.

The discounting conception of impulsive choice is useful because it yields an objective vocabulary for understanding and studying occasions when organisms counterintuitively show a behavioral preference for smaller rewards that come at a long-term cost. Moreover, discounting provides researchers with laboratory procedures for operationalizing, quantifying, and modeling the many behaviors that fall under the otherwise imprecise descriptor of "impulsive," in hopes of leading to their prediction and control.

Such laboratory procedures are generally aimed at assessing relative degrees of discounting for a particular individual or group. In both humans and non-human animals this approach usually involves procedures with multiple choices between larger delayed or probabilistic rewards and smaller immediate or certain rewards, respectively. For example, an organism's subjective value for a larger delayed (and initially preferred) reward might be determined by making an alternative smaller option available immediately and gradually increasing its size over successive trials. One then observes what amount of the immediate reward is sufficient to cause the organism to shift its preference and choose that smaller reward.

The adjusting-amount procedure of Richards, Mitchell, de Wit, & Seiden (1997) is an example of such a task. Using water as a reinforcer for water-deprived rats, the procedure presents repeated choices between a) a *standard option*, which is an invariable amount of reinforcer that is delayed by a particular interval within a given session, and b) an *adjusting option*, which is an amount of reinforcer that is variable across trials within a session and always delivered immediately. Changes in the adjusting amount are made systematically, based on the organism's choice on the preceding trial. If, for example, an organism makes a standard-side response, then the amount available on the adjusting side would be greater on the next trial. Conversely, if the organism made an adjusting-side response, then the amount available immediately on that side would be less in the next trial. The subject changes the adjusting reinforcer amount with its response pattern until it chooses that option with roughly equal frequency as the standard amount, thus keeping the adjusting-amount value approximately constant across several trials. This point in the session is called the *indifference point*, at which the adjusted amount on the immediate reinforcer side is taken to indicate the organism's subjective value for the delayed reinforcer. That is, for a session with a delay of 60 s and a standard reinforcer amount of 100 µl of water, if a subject reached an indifference point with 16 µl of water on the adjusting-side, one could say that the 60-s delay reduces the value of 100 µl of water to that of only 16 µl for that subject. If, for the same 60-s delay, another rat were to reach an indifference point at 26 µl on the adjusting side, that rat would have discounted to a lesser degree and might, within the discounting definition of impulsivity, properly be called less impulsive.

In the adjusting-amount procedure, such indifference points are obtained for multiple delays. The indifference points for the delays can then be plotted to show a *discount function*, which illustrates the rate at which the value of a reward decreases with delay for a particular organism (see Myerson, Green, & Warusawitharana, 2001, for a review of different approaches to characterizing this function). From discounting studies with both humans and non-human animals, some characteristic features of these functions have been observed. There is generally considerable inter-individual variability in degrees of discounting, and for all individuals there is usually a hyperbolic pattern of decrease in the power of contingencies over behavior with increases in the delay or decreases in the probability of a particular consequence (e.g., Green, Fry, & Myserson, 1994; Rachlin, Raineri, & Cross, 1991; Reynolds, de Wit, & Richards, in press; Richards et al., 1997).

The procedures for measuring discounting rates in humans are based on the same principles described above—and, indeed, have been derived directly from them. Most employ hypothetical questions about preferences between an amount of money that is either delayed or probabilistic and an amount that is immediate and certain. In these procedures, participants are asked to indicate their hypothetical preference between two reward options, usually without actually contacting the consequences of their choices. For example, participants might be asked to choose between “5 dollars now” and “10 dollars 365 days from now,” or between “5 dollars for sure” and “10 dollars with a 25% chance.” Reward options are then adjusted over successive trials to arrive at indifference points for different delays or probabilities, much like the procedure with non-human animals described above.

Group comparisons can then be made from these data, looking for relations between the tendency to discount as measured by the task and other variables generally considered “impulsive.” For example, discounting procedures with hypothetical choices between monetary rewards have found significant differences between controls and chronic users of ethanol (Vuchinich & Simpson, 1998), opioids (Madden, Petry, Badger, & Bickel, 1997; Petry & Casarella, 1999), and nicotine (Bickel, Odum, & Madden, 1999; Mitchell, 1999). These findings suggest that impulsive behavior in one circumstance (delay discounting) may correlate with impulsive behavior in other (real-world) situations.

While discounting tasks with hypothetical choices have been shown to relate to group-membership variables, some evidence suggests that such tasks are less sensitive to more transitory “state-like” variability resulting from environmental variables. That is, the sensitivity of question-based tasks to *within-subjects* situational manipulations is unclear. For example, Richards, Zhang, Mitchell, and de Witt (1999) used a hypothetical question-based task with humans and did not find expected intra-individual increases in discounting after an administration of ethanol, which has been shown to increase discounting in rats (Evenden & Ryan, 1999; Tomie, Aguado, Pohorecky, & Benjamin, 1998). However, Beck & Watts (2001) found differences in the discounting of hypothetical rewards on a question-based task resulting from different states of “current mood,” operationalized by exposure to different types of music and the experimenter’s request to reflect on emotional memories corresponding with the appropriate mood state.

This latter finding is concordant with behavior modification work showing that it is possible to specifically train individuals to decrease their discounting rates (Dixon et al., 1998; Schweitzer & Sulzer-Azaroff, 1988), at least as that individual's discounting is manifested by one particular task. Based on these findings, it seems reasonable to conclude that discounting might indeed be a variable behavior pattern (rather than a fixed personality trait), but that question-based tasks are sometimes unable to detect such transitory changes in an individual's tendency to discount.

Given that the data on the sensitivity of hypothetical question-based tasks to situational manipulations are quite tentative, a more experiential task (Reynolds & Schiffbauer, 2002; Reynolds, Schiffbauer, Swenson, & Karraker, 2001) has been developed in hopes of finding an alternative discounting measure that might be more sensitive to situational manipulations (like sleep deprivation.) This task more closely approximates non-human discounting procedures by delivering reinforcers according to the contingencies of *each* choice. Rather than presenting hypothetical questions verbally, two response buttons are presented and the participant learns the contingencies of the task by making choices and experiencing their consequences. That is, if a participant chooses an option corresponding to a probabilistic $0.30 with a 60-s delay, he or she must actually wait the 60 s, after which the reinforcer may be delivered. By having participants contact the delay and probability consequences of each choice, the task is intended to make the discounting situation more immediately "real." It is hoped that this closer approximation of the non-human procedures will address the discrepancies between, for example, human and non-human findings on the effects of ethanol on discounting (cited above).

In an attempt to clarify questions surrounding the measurement of intra-individual variability in discounting and, at once, to address an important threat to public safety that has heretofore been mostly ignored in the impulsivity literature, the present study investigated sleep deprivation as a manipulation potentially affecting discounting behavior.

Sleep Deprivation and Discounting

Sleep deprivation has been found to impair performance on numerous behavioral tasks and affective measures (e.g., Williamson & Feyer, 2000; see Pilcher & Huffcutt, 1996, for a meta-analysis). The data are such that a number of prominent sleep researchers joined together to publish a consensus report stressing that the effects of sleep deprivation pose a considerable risk to public safety (Mitler et al., 1988). It is argued that these effects can be especially problematic when they emerge in the workplace or on the road, where individuals deprived of sleep by shift work or other occupational demands are often in an environment where performance impairments, aberrant behavior, and decision-making irregularities can do the most harm.

Some evidence suggests that a portion of the public threat posed by sleep deprivation may lie in its ability to increase impulsive behavior. Specifically, sleep deprivation and fatigue have been found to increase risk-taking and behavioral disinhibition (Harrison & Horne, 2000), both of which may be convergent constructs to impulsivity. For example, Brown, Tickner, and Simmons (1970) found that drivers became increasingly willing to take risks with increasing fatigue by engaging in specific hazardous "overtaking maneuvers" (e.g., passing in low visibility, forcing other drivers to adjust speed to permit them to pass). The same participants, however, did not adopt other overly cautious (non-risky) bad driving behaviors that would indicate a more general deterioration in driving skills (Harrison et al., 2000). Harrison and Horne (1998) also found that sleep deprived participants were more likely to take risks, to their own detriment, in a complex strategic task that required them to draw cards from different stacks, which each had different payoff-to-penalty ratios.

Additionally, some known effects of sleep deprivation might affect mechanisms underlying discounting behavior. For example, temporal memory is disrupted in sleep deprivation. Sleep-deprived participants are able to recall that events have occurred ("recognition") but are often unable to report accurately the timing ("recency") of those events (Harrison et al., 2000; Morris, Williams, & Lubin, 1960). There is also some evidence that impulsive individuals (as defined by a questionnaire) tend to have an impaired ability to make accurate judgments about the passage of time (van den Broek, Bradshaw, & Szabadi, 1992). The ability to make accurate discriminations about the passage of time is important to impulsive behavior because, in the delay discounting paradigm, the power of contingencies to affect behavior can change as a function of delay length. Therefore, a disruption in the perception of delay lengths might result in disrupted delay discounting behavior.

Although the above indirect evidence was suggestive of an effect that sleep deprivation might have on impulsive behavior, no studies before the current inquiry had investigated the direct effects of sleep deprivation on discounting. Given that sleep deprivation remained to be explored in this literature, and that it might produce important intra-individual variability in discounting, there was clear potential utility in an investigation into the effects of sleep deprivation on impulsive responding. The investigation was intended, therefore, to help in the search for ways of predicting and controlling socially problematic impulsive behavior patterns, while at the same time uncovering a new component of the threat to public safety posed by sleep deprivation.

Overview of the Proposed Study

In service of the above goals, the present study examined the effects of acute sleep deprivation at the approximate circadian nadir on impulsive responding in humans. Participants were observed on three occasions in order to permit within-subjects comparisons of performance on two measures of discounting (one question-based and one experiential), along with convergent measures (risk-taking, behavioral inhibition) and manipulation checks (reaction time, vigilance). Participants were acutely deprived of sleep in *Condition B* of a repeated-measures cross-over design, half receiving a BA sequence and half receiving an AB sequence, where *Condition A* served as a baseline. A pre-test practice session was administered to both groups in circumstances that mirrored the "A" condition.

Hypotheses

The following hypotheses express the effects that were expected to result from the sleep deprivation manipulation.

1. Acute sleep deprivation at the circadian nadir increases an individual's tendency to discount.
2. Acute sleep deprivation at the circadian nadir affects constructs convergent to discounting.
    a. Acute sleep deprivation at the circadian nadir increases risk-taking.
    b. Acute sleep deprivation at the circadian nadir decreases inhibitory control.

3. Acute sleep deprivation at the circadian nadir increases simple reaction times in response to a stimulus.
4. Acute sleep deprivation at the circadian nadir increases reaction times in response to a particular stimulus when sustained attention to other monotonous stimuli is required.
5. Acute sleep deprivation at the circadian nadir affects the subjective perception of the passage of time, causing intervals to be perceived as longer than they actually are.

Methods

Participants

A total of 12 participants (6 males and 6 females), aged 18 to 23 years, were recruited from West Virginia University undergraduate classes. Potential participants were interviewed about their sleeping patterns. To be included, potential participants must have not taken regular daily naps, must have had a normal waking time between 0600 hrs and 0800 hrs, and must have reported sleeping no more than 8 and no less than 6 hours per night on average. Additionally, any potential participants who had been diagnosed with psychiatric or neurological conditions were excluded. To prevent any unknown reactions due to a first encounter with sleep deprivation, participants must also have had at least once previously undergone 24 hours of acute sleep deprivation (time since waking). However, to insure that participants were not uniquely accustomed to sleep deprivation and had not thereby developed any well-practiced coping skills to compensate for its effects, they must not have undergone 24 or more hours of acute sleep deprivation more than twice during any past semester (or 4-month period). Selected participants were randomly assigned to two groups of 6 (3 males and 3 females), each being exposed to one of two different sequences of experimental conditions.

Discounting Measures

Discounting question task. A choice procedure was administered by computer to observe and record the discounting of delayed and uncertain reinforcers. This choice task replicated the procedure used by Richards et al. (1999), using the same computer software. This task, along with many similar to it, has been shown to discriminate between "impulsive" groups and controls. For example, psychiatric outpatients at high risk for impulsive behavior (as determined by DSM-IV diagnostic status) discounted by delay and probability to a significantly greater degree than their low-risk counterparts when observed using the discounting question task used in the present study (Crean, de Wit, & Richards, 2000).

The task presented approximately 80 hypothetical choices between delayed or probabilistic versus immediate and certain amounts of money. These options were represented on the computer screen by two large buttons on which the associated contingency was printed. Above the buttons during each choice trial the words "Which do you prefer?" appeared. A typical delay choice trial, for example, might have had one button reading "5 dollars now" and another reading "10 dollars 365 days from now," and a probability trial might have had one reading "5 dollars for sure" and another reading "10 dollars with a 25% chance."

The task used an adjusting-amount procedure to obtain indifference points for five different delays (1, 2, 30, 180, and 365 days) and five different probabilities (1.0, .9, .75, .5, and .25). That is, the amount of immediate certain money given as an option along with a particular delay or probability of receiving $10 was adjusted over successive trials until the "subjective value" for the discounted $10 was determined. The procedure used by the software to determine indifference points is described in greater detail in Richards et al. (1999). The original instructions of Richards et al. were modified for use in this study (see Appendix A).

After a participant had completed the task, one of the responses made was chosen at random. The option that the participant chose for that question was then delivered, with probabilistic options being delivered using a random selection from a bag of chips reflecting the appropriate odds of winning, and delay options resulting in the money being put in an envelope to be delivered after the specified delay. That the contingencies from one random choice in the task were actually contacted was intended to induce participants to attend fully to each choice that they made.

Experiential discounting task (EDT). The EDT is a newly-developed measure of impulsive responding in humans, which has shown promise in preliminary data with children (Reynolds et al., 2001) and adults (Reynolds & Schiffbauer, 2002). As used in this study, the task consisted of a computer program that presented participants with repeated choices between a standard probabilistic amount of money and an adjusting, typically smaller, immediate amount of money. This task differed critically from the question-based task in that the consequences of *each choice* are contacted directly during the experimental session. That is, when a participant chose a delayed reward, he or she had to experience the delay (e.g., 60 seconds) before the resultant amount was delivered into a "bank," which kept a running total of earned money on the screen. In this way, participants got “real-time” feedback for each of their responses. The total in the bank was exchanged for cash at the end of the experimental session.

Repeated choices were presented in the form of two response buttons. These buttons bore the image of light bulbs, which “illuminated” when they could be pressed. Choices to the left button were followed by a delay and the potential delivery of a (relatively) large monetary reward, which was always $0.30 with a 35% probability of delivery. Choices to the right button were followed by the immediate delivery of an amount of money that had been adjusted up or down according to the previous choices made. Choices to the delay (left) side caused an increase in the amount of money available on the immediate (right) side in the next trial. Choices to the immediate side were followed by a decrease in the amount of money available on that side in the next trial. At some point, nearly every participant reached an indifference point at which they chose with approximately equal frequency the left and right buttons, holding the adjusting immediate amount relatively constant. The program terminated the sub-session at this point. For a given participant, the value of the immediate adjusting amount at this indifference point is taken to be an indication of the subjective value of the delayed probabilistic reward in terms of immediate money. Within each experimental session, indifference points were assessed over four sub-sessions, each having a different delay interval: 0 s, 15 s, 30 s, and 60 s. A “distracter” sub-session also occurred between the 15-s and 30-s measurements, set to last 60 s, with a delay of 15 s. This un-analyzed sub-session was included to make the increasing pattern of delays less obvious and to appear more random.

Convergent Measures and Manipulation Checks

Balloon Analogue Risk Task (BART). The BART is a computerized behavioral task designed to manifest and record "risk-taking" behavior. The BART, as developed and described in Lejuez et al. (in press), has demonstrated sound psychometric properties and has been shown to correlate with self-report measures of impulsivity. It was included in the present study to examine the relation between the discounting measures and a construct presumed to be convergent to them, risk-taking.

On the screen a small graphical balloon appears alongside a pump, a reset button reading "Collect $$$", a "Total Earned" display, and a "Last Balloon" display indicating the money earned on the last balloon.

Each time the participant clicked the balloon, it inflated by one degree (approximately .125" in all directions). Five cents were added to a temporary reserve, which was invisible to the participant, with each click. Each balloon, however, had a randomly-selected popping point (also unknown to the participant) at which a "pop" sound was emitted by the computer. If a balloon pop occurred, all money in the temporary reserve was lost and a new balloon appeared on the screen, signaling the start of a new trial. During the inflation of each balloon, the participant could choose to press the "Collect $$$" button and earn the money in the temporary reserve by moving it to the "Earned Money" display, thus averting a balloon pop and proceeding to a new balloon trial.

The program cycled through 40 balloon trials. With each successive pump the probability of popping increased (described in greater detail by Lejuez, et al., in press). The original instructions of Lejuez et al. were modified for use in this study (Appendix B).

Stop task. A preexisting version of the stop task (de Wit, Crean, & Richards, 2000) was used. The task is described in detail by Logan, Schachar, & Tannock (1997). In this computerized task, a go signal appeared on the screen, which could be either an "X" or "O" symbol. Participants were told to respond as quickly as possible to the "X" symbol by pressing the "z" key and to the "O" symbol by pressing the "/" key. Reaction times between go signal and response, the go reaction times (GRTs), were recorded for each of the go signals, which occurred at 2-s intervals. On 25% of the trials (25% of "X" and 25% of "O" trials) a stop signal tone was emitted by the computer after the go signal had been shown. Participants were asked to refrain from making a response during a trial where the stop signal had been emitted. The initial delay between the onset of go and stop signals was 200 ms. When a participant fails to stop, the delay between go and stop signals was shortened by 50 ms for the next trial in which a stop signal was to be emitted. When a participant successfully stopped, the delay between go and stop signals was lengthened by 50 ms for the next stop trial. Eventually, the participant reached a delay between go and stop signals at which he or she could successfully stop on 50% of the stop trials. The average reaction time for the go trials was subtracted from this delay to yield a stop reaction time (SRT). Accuracy in responding to the two go signals was also recorded.

The 256 total trials were broken into blocks of 64 trials, in between which brief breaks were permitted. At the beginning of each block of 64 trials, the delay between stop and go signals was reset to 200 ms. The entire procedure took approximately 10-15 min.

An individual's SRT on the stop task has been shown to have a significant relation to impulsivity as measured by a questionnaire (Logan et al., 1997), with higher-impulsive people having longer SRTs. Additionally, ethanol administration, which increases discounting in rats (Evenden et al., 1999), also has been shown to increase SRTs in humans on the stop task (de Wit et al., 2000). Both of these facts support the use of the stop task as a convergent impulsivity measure with delay discounting.

Williamson et al. (2000) also found that simple reaction time was highly affected by sleep deprivation. Therefore, an individual's GRT from the stop task will also be used as a manipulation check on sleep deprivation.

Time perception task. A face-valid computerized time perception task, based on similar tasks used by other researchers (e.g., Barkley, Murphy, & Bush, 2001; van den Broek et al., 1992), was developed for use in this study in hopes of uncovering a mechanism by which any potential effects of sleep deprivation on discounting might occur. This time perception task is of the "time production/reproduction" variety, in which participants are asked to signal when a certain interval has passed.

In the first segment of the task, which required participants to produce a standard interval of time, a stimulus appeared on the computer screen to begin the trial. In this *standard production* phase, participants were asked to signal by pressing the mouse button after one minute (60 s) had passed since the onset of the stimulus. This same procedure was repeated again for a 2-min interval.

The second segment of the task, the *direct reproduction* phase, involved the reproduction of intervals that were directly observed. These direct observation trials presented a stimulus for a certain amount of time (the precise duration of which was unknown to the participant), after which the stimulus disappears. Participants were then asked to reproduce the interval of the stimulus that had just been presented by signaling (as before) after the same amount of time had passed. There were 5 such direct observation trials, with delays of 15 s, 60 s, 30 s, 45 s, and 5 s, presented in that order. Participants were asked to refrain from counting to themselves during this task and instead to simply *estimate* the passage of time. A large message appeared above the response buttons saying "REMEMBER: Do NOT count to yourself."

Mackworth clock vigilance task. Williamson et al. (2000) found that a version of the "Mackworth clock vigilance task" (Mackworth, 1970), was one of two tasks showing the strongest sleep-deprivation effects among the eight various performance measures they used. The task is designed to assess the ability to sustain attention while being presented with monotonous, repetitive stimuli. Given that the Mackworth task has been shown to be highly affected by sleep deprivation, it was used as a manipulation check. Researchers designed for the present study a program that roughly approximates the specifications described by Williamson et al. This computerized version of the Mackworth task used a circle comprising 24 equally-spaced gray dots, forming a figure much like a clock face. In the "off" state, dots remained gray but in the "on" state they became red. Starting at the top of the circle, one dot flashed briefly from off to on. Then the next dot (proceeding clockwise) flashed similarly. This pattern continued with successive flashes (each lasting .25 s) around the circle until the flash reached the top again, at which point the whole sequence seamlessly started anew, continuing around the clock repetitively until the task ended. At 15 random intervals during the 15-min session, the flash of one dot was omitted from the sequence—that is, the dot remained gray when it would normally have flashed red. The omitted flash created the visual effect of a brief "skipping" in the otherwise smooth circular sweep of the red flash around the clock face.

Participants were instructed to make a click on the mouse when the omission of a flash occurred. At the beginning of an omission, a 2.5-s window of opportunity opened in which a response would be counted as correct. The latency between the beginning of an omission and a response within this window (reaction time) was recorded, along with the number of misses and false positives.

Additional Measures

Before all other data collection began, preliminary data on participant demographics were collected (see Appendix C). Before each occasion of measurement, participants completed a questionnaire about the circumstances of their life during the previous week (see Appendix D). Amount of sleep, level of stress, and occurrence of illness were assessed. These measures were included to account for—and exclude—any stressful life circumstances or sleep disruptions that might interfere with the intended manipulation.

Procedure

All participants were observed on three occasions each, once every other weekend over five consecutive weeks. Each experimental session consisted of the stop task, the discounting question task, the Mackworth clock vigilance task, the EDT, and the time perception task, and the BART, in that order. All of the tasks together took approximately 2 hours. The measurements occurred at the National Institute for Occupational Safety and Health in Morgantown, WV.

Participants were acutely deprived of sleep in *Condition B* of a repeated-measures cross-over design, half receiving a BA sequence and half receiving an AB sequence, where *Condition A* served as a baseline (no sleep deprivation). Both groups were also administered a practice session before the two experimental sessions under conditions that precisely replicated the “A” (baseline) condition. This was intended to minimize the effects of acclimation to the tasks and to the novelty of the research experience. For each Condition A measurement, participants underwent the above tasks on the Saturday afternoon of that weekend. However, one participant fell ill on the day before her Condition-A measurement and had to come in under similar “A” conditions during a weekday of the following week. All requirements, including the morning call, were imposed on this participant’s data collection session. For the Condition B weekend, participants were exposed to sleep deprivation on Saturday night. Condition B participants were then given the tasks in the early morning of Sunday (starting between 0300 hrs and 0500 hrs). The AB and BA groups participated on alternating weeks, spanning a 5-week period of data collection (6 weekends in total).

For all three measurements sessions, participants were asked to wake between 0600 hrs and 0800 hrs on the Saturday of their participation, to record their time of waking, and to phone the experimenters within 30 min to confirm that time. They were asked to stay awake that morning and to report to NIOSH at 0900 hrs after having had a normal breakfast. Once they had arrived, participants were observed to insure that they did not fall asleep for the entire duration of their time on-site. As in the Williamson et al. (2000) study, participants were allowed to watch TV and videos, read, chat, play games, and take walks. Caffeine-free refreshments (light snacks and beverages) were available throughout the period when participants were on-site. Lunch from a local sandwich shop was provided for all participants in all conditions. During Condition B, participants were provided with take-out dinners from local restaurants in the evening.

During their stay at the experimental site, participants were kept in a lounge room set up specifically for the research study. The room was partitioned by a divider. On one side of the divider was “recreation room,” labeled as such, where participants were allowed to watch movies and snack. On the other side of the partition was a “study room,” also labeled as such, in which participants were allowed to read and study but were asked not to talk. It was possible at all times for experimenters to see participants on both sides of the partition to verify their wakefulness. Only two instances of sleep onset were observed. Each lasted no more than 30-60s, at which point the participant was tapped on the shoulder and asked to awake. The entire group was then immediately led around the building on a walk to encourage participants to stay awake.

For condition A, participants were administered the tasks starting at 1300-1500 hrs, adjusted for each participant to begin 7 hrs after his or her self-reported waking time from earlier that morning. One participant’s Condition A was a slightly non-standard administration, not in terms of the task administration but in terms of the morning leading up to it. This participant was called to work unexpectedly that morning and was forced to report to the research site at approximately 1130 hrs rather than 0900 hrs. However, that participant did phone in an appropriate wake-up time that morning and offered assurances of having not returned to sleep that morning.

For condition B, the impulsivity tasks were administered in the early morning hours of Sunday, 21 hours after each individual participant’s self-reported waking time from the previous morning. Deprivations of approximately 21 hours since waking (generally occurring between 0300 hrs and 0500 hrs) have been associated in numerous studies with a circadian nadir (low-point) in performance on various tasks and measures (e.g., Babkoff, Caspy, & Mikulincer, 1991; Campbell, 1997; Walsh & Lindblom, 1997; Williamson et al., 2000). This is, therefore, a time at which acute sleep deprivation seems to show relatively maximal effects. Participants were sent home by taxi or with friends who had slept the night in the early morning hours following their participation in Condition B to avoid any increased risk of a motor-vehicular accident that might result from the effects of sleep deprivation.

The administration of the measurements to the different groups was conducted so as to limit the number of participants receiving the sleep deprivation condition to three on any given weekend. Logistically, this insured that the experimenters were able to monitor closely participants to verify that they remained awake during Condition B. Methodologically, this approach also had the advantage of permitting separate testing of males and females, which should decrease any confounding "social arousal" factors that might arise from the potentially intimate experience of enduring sleep deprivation with a small group of others. The resulting sequence of participant administrations is depicted below (P signifies "practice session").

		Weekend					
		One	Two	Three	Four	Five	Six
	Gender						
Group 1:	Male (n=3)	1P		1B		1A	
(BA)	Fem. (n=3)		1P		1B		1A
Group 2:	Male (n=3)	2P		2A		2B	
(AB)	Fem. (n=3)		2P		2A		2B

Participants earned $30-45 for each of the three sessions in which they participated, depending upon their performance on the discounting tasks and the BART, which contributed to a total of $90-135 dependant upon performance. Additionally, a bonus of $60 was offered that was only delivered if the participant showed up for and participated in all three sessions. Therefore, the overall range of payment for the study was $150-195 for each participant. All participants showed up for each of their three sessions. Each, therefore, got his or her $60 bonus.

Analyses

The statistical package *SPSS* was used to conduct a repeated-measures analysis of variance to look at the effects of the manipulation on the various task measures. The analysis of variance had one factor, sleep condition, with two levels (sleep-deprived, non-sleep-deprived).

Discounting data, in the form of indifference points, were fit using a non-linear curve-fitting program (Origin 4.1, 1995). See Richards, et al. (1999) for a more in-depth description of the discounting analyses. Discounting parameters, as yielded by the curve-fitting program, were log-transformed because they were not normalized. The log transformation normalized the discounting data.

Results

Means and standard deviations for the two conditions are reported in Table 1.

Manipulation Checks

The manipulation was effective in eliciting previously known effects associated with sleep deprivation. Response latencies on the Mackworth sustained attention task were significantly longer under sleep deprivation, $F(1,10) = 4.92$, $p = .05$. The number of missed “skips” on the Mackworth increased significantly under the manipulation, $F(1,10) = 7.09$, $p < .05$. Simple reaction times (i.e., GRTs) from the Stop Task were longer under the manipulation to a degree very closely approaching significance $F(1,10) = 4.70$,

$p = .055$.

Task Measures of Discounting

All three discounting measures were significantly affected by the manipulation. Sleep deprivation significantly increased discounting in the EDT, $F(1,10) = 5.74$, $p < .05$ (Figure 1). Sleep deprivation significantly decreased discounting on the discounting question task for both delay discounting, $F(1,10) = 8.49$, $p < .05$ (Figure 2), and probability discounting, $F(1,10) = 5.29$, $p < .05$ (Figure 3).

Convergent Measures

In the standard production phase of the time perception task, participants underestimated standard delay intervals to a significantly greater degree while sleep-deprived, $F(1,10) = 11.36$, $p < .01$. However, the direct reproduction phase of the time perception was not affected by the manipulation. Sleep deprivation had no effect on inhibitory control in the Stop Task or on risk-taking in the BART.

Discussion

All discounting tasks in this study gave an affirmative answer to the critical question of the study, which was whether impulsivity (as measured by discounting) can be affected by a situational manipulation. Yet, the two primary impulsivity-related findings of the study appear, *prima facie*, to be contradictory. That is, the sleep deprivation manipulation significantly *increased* impulsive behavior on one task and significantly *decreased* it in the other. This is quite different, of course, from one task showing a significant effect and another simply showing no effect at all. Rather, sleep deprivation appeared to have *opposite* effects on the two impulsivity tasks.

This apparently contradictory finding must, however, be considered in light of the results yielded by the time perception task. The time perception task was divided into two components, a standard production procedure and a direct reproduction procedure. The time production component is analogous to the type of behavior with respect to time that is required in the discounting question task. In both the discounting question task and the time production component of the time perception task, participants were tasked to deal with standard, verbally specified, time periods—for example "2 minutes" or "30 days." Sleep deprivation caused participants to signal significantly earlier to say that a standard interval had passed in the standard production component of time perception procedure. It also caused participants to behave less impulsively when they were asked to think about reward delays that occurred at standard intervals. Given that decreasing delay lengths are widely understood to cause decreased discounting (e.g., Green, et al., 1994), it is not surprising to find decreased discounting under sleep deprivation conditions where standard delays are perceived to be shorter. That is, if a hypothetical "30 days," because of the effect of sleep deprivation on standard delay length perception, seems shorter, one would be more likely to favor rewards at the 30 day delay because that amount of time, quite simply, seems closer.

In contrast, it is important to note that no significant effect was found for the direct reproduction component of the time perception procedure. This procedure requires participants to deal with delays in a way that more closely approximates the EDT. Participants in the direct reproduction phase of the time perception task were required to observe short delay periods and then to reproduce them, signaling when the same interval had passed. The same is true in the EDT, where delay lengths are not signaled and must be directly observed, which is the principal distinguishing feature of the EDT in relation to other discounting tasks.

Given the above, the following theoretical explanation seems the most plausible way to account for the seemingly discrepant discounting findings. Sleep deprivation does appear to increase impulsivity as measured by the EDT. This finding would seem to be the more "pure" measurement, in a sense, of the effect of sleep deprivation on impulsivity since the type of time perception involved in the EDT was not significantly affected by the same manipulation that caused increased impulsive behavior on that task. Therefore, for short-term choices where delays are directly experienced, it seems that sleep deprivation acts directly to increase discounting. On questions where standard, relatively distal, delays are involved, the effects of sleep deprivation on standard delay time perception appear to be the most important determinant of discounting choice behavior, thus decreasing discounting indirectly by perhaps causing standard delay lengths to seem subjectively shorter than they would without the effects of sleep deprivation.

One may reasonably ask, however, why probability discounting, which has no manifest relation to delay perception might also be disrupted by the sleep deprivation manipulation so as to decrease discounting. There are multiple potential accounts for this finding, none of which can be conclusively addressed because the present study did not include a task whereby any changes in perceptions about probabilities could be assessed. It is possible, however, that whatever effect sleep deprivation exerted on standard delay perception—and by extension on delay discounting in the question task—was the product of another underlying process that also affected probability perception. Again, this cannot be adequately addressed given the research design used. However, it is worthwhile to note that not only have discounting theorists argued that delay and probability discounting are fundamentally the same (Logue, 1988; Mischel & Grusec, 1967) but that also a study using precisely the same discounting task as the one used in the present study found a strong positive within-subjects correlation between performance on the delay and probability tasks (Richards et al., 1999).

Another plausible explanation originates from the hypothetical nature of the question-type task. In that only one of the many contingencies chosen between in the procedure is actually delivered, the question task can be regarded as a largely hypothetical procedure, open to more “idealized” behavior. It is possible, for example, that participants, either through past experience or conjecture, expected to have an increased tendency to behave impulsively and compensated for that tendency to the point of overcompensation, sending their discounting curves in the opposite (less impulsive) direction. However, perhaps it was more difficult for participants to regulate their behavior in a similar way on the EDT because the contingencies actually had to be experienced for each choice, making it more difficult to hold to any idealized pattern of behavior and making it more likely that one would succumb to the “temptations,” so to speak, of impulsive choice, especially under the effects of sleep deprivation.

There are some applied implications to the “time perception” account for the discounting findings in this study. If it is the case that the effects of an “all-nighter” manifest themselves only in situations where delays are dealt with directly and where relatively small reinforcers are at stake, then special attention ought to be paid to those instances where, in the early morning hours of a bout of sleep deprivation, one is faced with similar circumstances. The present findings would seem more relevant, for example, to minor shortcuts while driving an automobile that might compromise safety to get one a destination a few moments earlier than to “larger” decisions that affect more significant and distal rewards. One might potentially be more likely, for example, to overeat or to give up in a frustrating task than necessarily to sacrifice a longstanding goal, which might, in fact, actually potentially seem closer and therefore of higher value due to the effects on standard delay perception. In fact, a study of 68 college students found that those who were chronically sleep-deprived did tend to overeat (Hicks, McTighe, & Juarez, 1985), a finding mirrored in a rat analogue study (Elomaa, & Johansson, 1981.) In view of the type of potential applied situations mentioned in the introduction above, it would seem that “lower-level” decisions of individuals like emergency first-responders would be more likely to see an effect of an “all-nighter” in something like moment-by-moment safety decisions rather than more “high-level” decision makers who are forced to forego sleep to deal with an emerging crisis and make important decisions about long-term budgets or even, as in the case of 9/11, whether to take immediate military action. Future intervention strategies could therefore be targeted to the specific groups who are likely to be most affected by the sleep deprivation.

The failure to find a significant effect of sleep deprivation on either risk-taking or inhibitory control suggests that the form of “impulsivity-like behavior” that these tasks measure, while potentially related (based on the findings cited in the introduction above) to discounting, a different processes underlies those behaviors, or that they are controlled by a different set of environmental variables. Regardless of what underlying processes mediated the changes in impulsive responding in this study, what is perhaps most significant is that within-subjects changes were observed at all. This is the first study of which the authors are aware to have shown such a change in response to a situational manipulation. This preliminary finding that impulsive behavior may be a malleable behavior pattern is both important and encouraging. It suggests that more effort ought to be devoted to discovering what other types of environmental variables can increase impulsive responding—and also, perhaps more importantly, to finding environmental variables by which impulsive responding might be reduced. Further research, for example, may investigate how stress, psychotropic drugs, relaxation techniques, or delay-of-gratification training might change impulsivity. For all who look to decrease their own impulsive behavior, whether it be gambling, overeating, smoking, etc., further research showing that impulsivity is a changeable behavior pattern and not an inescapable personality trait will stand as a sign of hope and, perhaps in the future, an empowering tool for change.

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Appendix A

You will have the opportunity to choose between different amounts of money available after different delays or with different chances. The [program] consists of about [80] questions, such as the following: (a) Would you rather have $10 for sure in 30 days or $2 for sure at the end of the session, or (b) would you rather have $5 for sure at the end of the session or $10 with a 25% chance? At the end of the session, one of the choices you made will be selected at random and you will receive whatever you chose in response to that question. If on that trial you selected an immediate amount of money, you will receive the money in cash at the end of the session. If you selected delayed money, the money will be placed in an envelope with your name on it, and it will be available to you when the [delay] has elapsed. If you selected a probabilistic amount, you will select a token from a bag containing two colors of tokens in the proportion that reflects the probability. For example, if the trial you selected was $10 with a 25% chance, you will select one token from a bag containing 1 [red] token representing “get $10” and 3 [white] tokens representing “get $0.” You will receive the amount of money indicated by the color of the token immediately in cash. (p.125)

Appendix B

Throughout the task, you will be presented with [60] balloons, one at a time. For each balloon you can click on the button labeled “Click this Button to Pump Up the Balloon” to increase the size of the balloon. You will accumulate 5 cents in a temporary bank for each pump. You will not be shown the amount you have accumulated in your temporary bank. At any point, you can stop pumping up the balloon and click on the button labeled “Collect $$$.” Clicking this button will start you on the next balloon and will transfer the accumulated money from your temporary bank to your permanent bank labeled “Total Earned.” The amount you earned on the previous balloon is shown in the box labeled “Last Balloon.” It is your choice to determine how much to pump up the balloon, but be aware that at some point the balloon will explode. The explosion point varies across balloons, ranging from the first pump to enough pumps to make the balloon fill the entire computer screen. If the balloon explodes before you click on “Collect $$$,” then you move on to the next balloon and all money in your temporary bank is lost. Exploded balloons do not affect the money accumulated in your permanent bank. At the end of the task, you will receive [money] in the amount earned in your permanent bank. (pp.13-14)

Appendix C

Preliminary Questionnaire

1.) How old are you? ______________

2.) Which applies to you? **(circle one for each item)**

a.) male female

b.) freshman sophomore junior senior+

3.) Estimate your average annual family income: **(circle one)**

Below-$20,000 $20,000-40,000 $40,000-60,000

$60,000-80,000 $80,000-100,000 $100,000-Up

5.) What is your academic major? ______________

6.) What is your cumulative GPA? ______________

7.) How many hours of sleep do you typically get on weeknights? ______________

8.) How many hours of sleep do you typically get on a Friday night? ______________

9.) How many hours of sleep do you typically get on a Saturday night? ______________

Subject ID: __________

Appendix D

Sleep and Stress Questionnaire

1.) Indicate how much sleep you've gotten this week relative to what you feel is an average week for you: **(circle one)**

A lot less Somewhat less The same Somewhat more A lot more

2.) Regardless of the number of hours you slept, how **well-rested** have you felt this week compared to what you feel is an average week for you? **(circle one)**

A lot less Somewhat less The same Somewhat more A lot more

3.) How many hours per night of sleep did you average this week (Sunday night through Friday night)? ____________

4.) How many hours of sleep did you get last night? ____________

5.) Indicate how stressed have you felt this week:

(place a mark on the line indicating how you feel)

For example: *[the below examples are reduced in size for illustrative purposes]*

Not stressed Very stressed	Not stressed Very stressed
‖-----|----------------------------------‖	‖------------------------------|----------‖
(This would indicate low stress.)	(This would indicate higher stress.)

(place your mark on the line below)

Not stressed Very stressed

‖--‖

Sleep and Stress Questionnaire (Page 2)

6.) Did you have any exams or assignments this week that you missed sleep to study for or complete? **(circle one)** Yes No

If yes, please describe: ____________________________________

7.) Have you had any illness(es) this week (e.g., cold, flu, injury, etc.)?

(circle one) Yes No

If yes, please describe: ____________________________________

SessionID: __________ Subject ID: __________

Table 1

Dependent variable means and standard deviations by condition

Measure	Mean Condition *A*	Mean Condition *B*	Standard Deviation Condition *A*	Standard Deviation Condition *B*
Latency to respond in sustained-attention task (seconds)	61.69	67.38	5.53	10.98
Number of missed events in sustained-attention task	1.36	3.64	0.81	2.66
Simple Reaction Time (milliseconds)	465.05	516.00	143.25	152.78
EDT impulsivity, (log-transformed k-values)	-2.09	-2.01	0.50	0.68
Question task impulsivity, delay (log-transformed k-values)	-2.08	-2.32	0.57	0.70
Question task impulsivity, probability (log-transformed h-values)	-0.02	-0.11	0.23	0.29
Time Perception Task, Time Production (milliseconds from actual)	-9253.45	-11138.27	2516.67	1844.04
Time Perception Task, Time Reproduction (milliseconds from actual)	-5178.45	-6098.55	1215.99	2242.69
BARt Risk-taking Task (number of pumps)	41.64	39.72	10.58	11.67
STOP Task of Inhibition ("Stop Reaction Time," milliseconds)	216.77	230.09	69.42	67.47

Figure Captions

Figure 1. Temporal discounting functions for sleep-deprived and non-sleep-deprived conditions from the EDT. Points show median indifference points for money as a function of delay. Curves show best-fitting discounting functions.

Figure 2. Temporal discounting functions for sleep-deprived and non-sleep-deprived conditions from the Discounting Question Task. Points show median indifference points for money as a function of delay. Curves show best-fitting discounting functions.

Figure 3. Probability discounting functions for sleep-deprived and non-sleep-deprived conditions from the Discounting Question Task. Points show median indifference points for money as a function of odd against receipt of the reward. Curves show best-fitting discounting functions.

Figure 1.

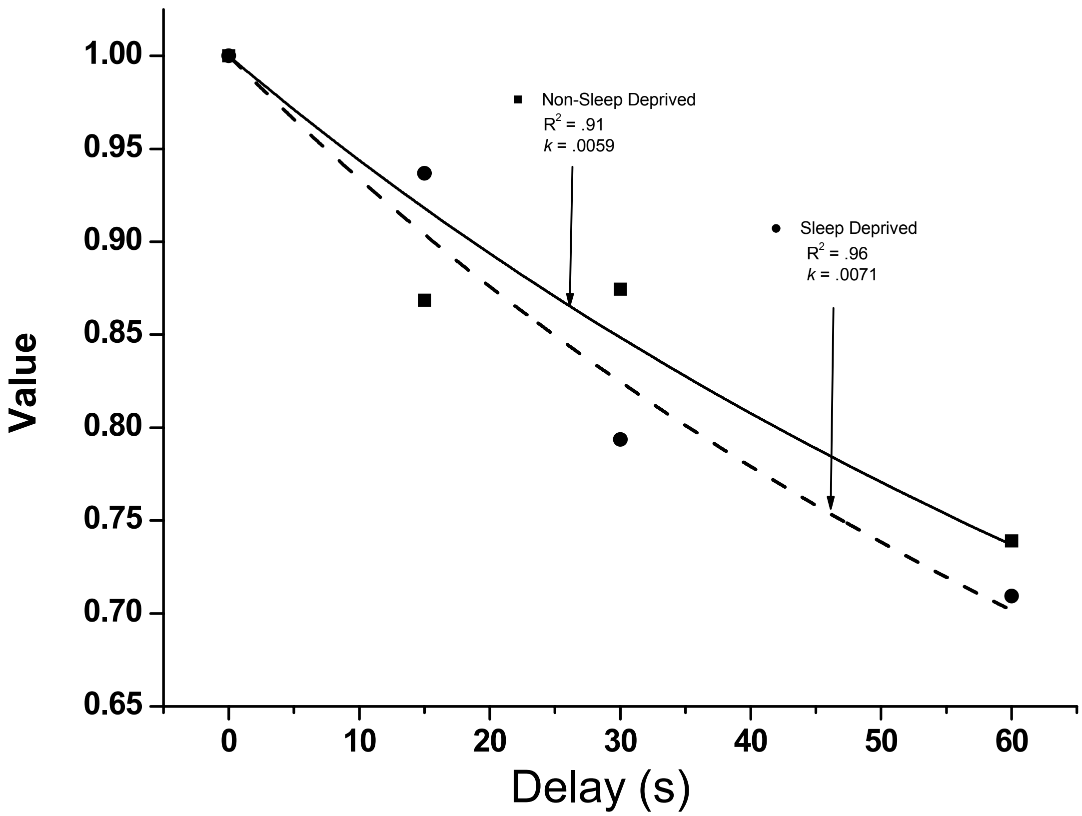

Non-Sleep Deprived
R² = .91
k = .0059
Sleep Deprived
R² = .96
k = .0071
Value
1.00
0.95
0.90
0.85
0.80
0.75
0.70
0.65
0
10
20
30
40
50
60
Delay (s)

Figure 2.

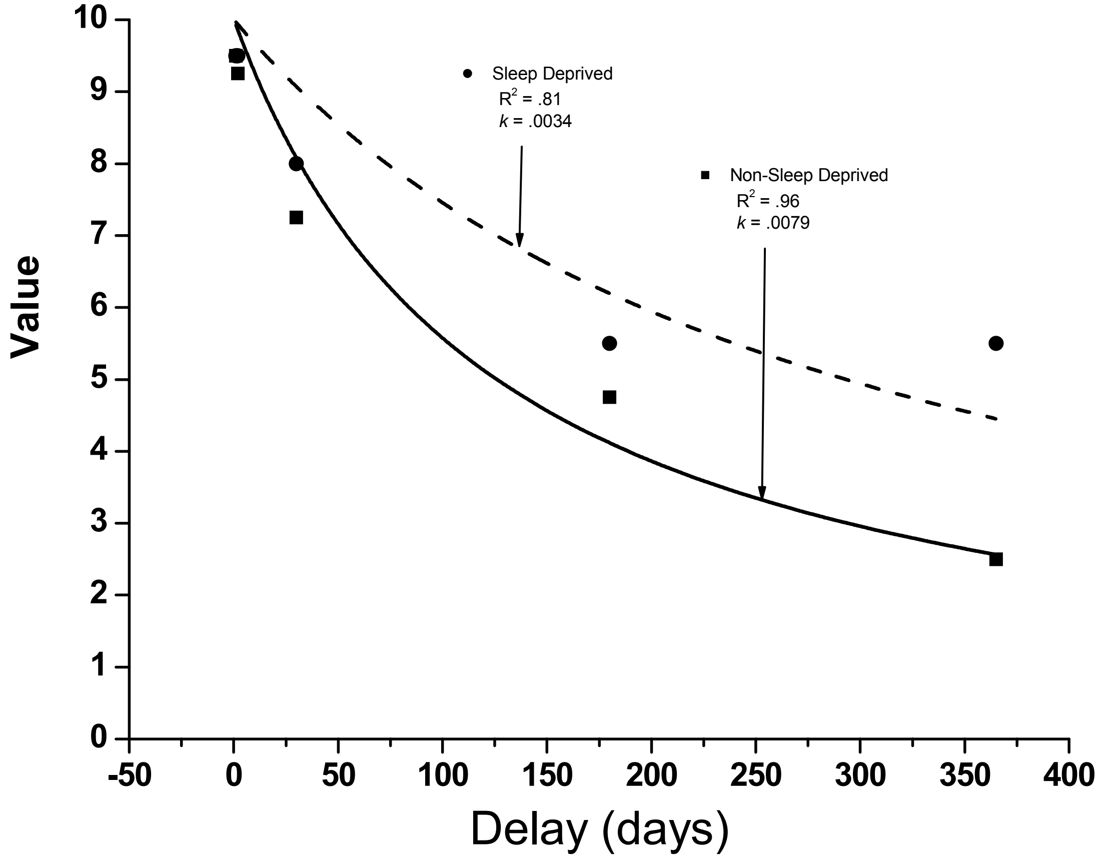
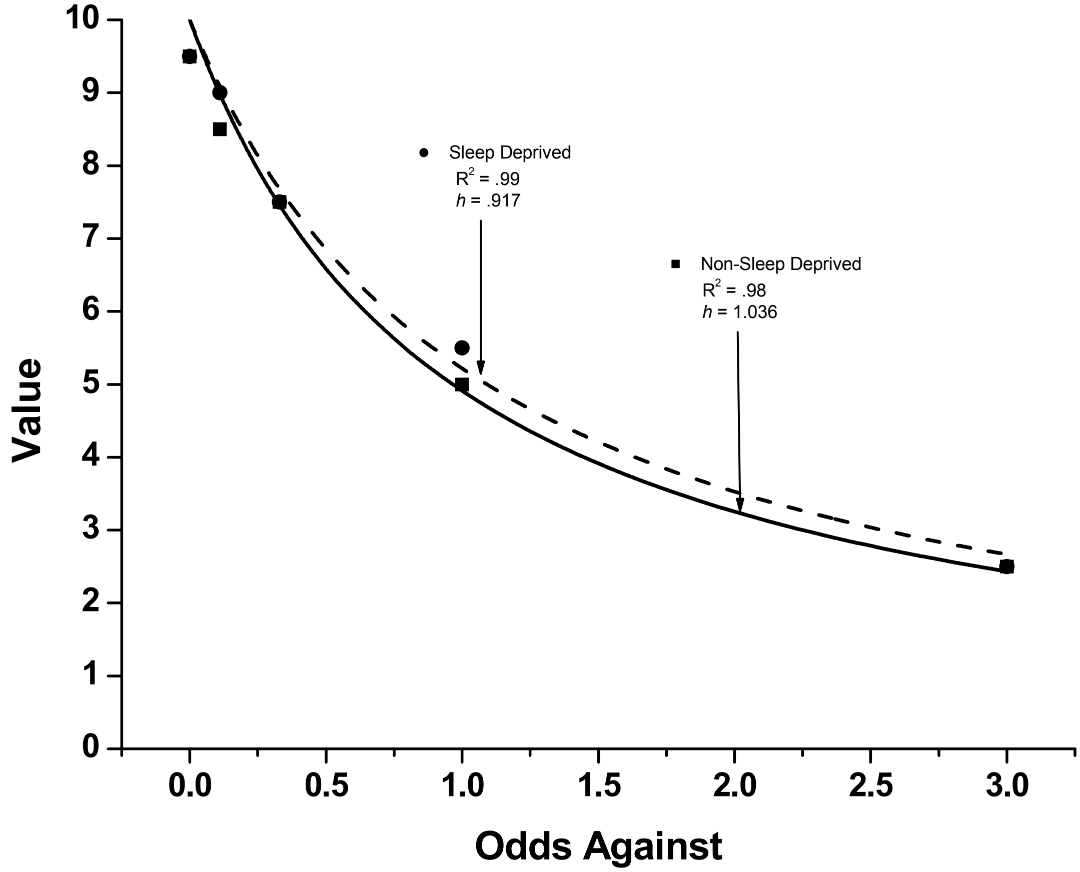

Value
10
9
8
7
6
5
4
3
2
1
0
-50
0
50
100
150
200
250
300
350
400
Delay (days)
Sleep Deprived
R2 = .81
k = .0034
Non-Sleep Deprived
R2 = .96
k = .0079

Figure 3.



10
9
8
7
6
5
4
3
2
1
0
Value
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Odds Against
Sleep Deprived
R^2 = .99
h = .917
Non-Sleep Deprived
R^2 = .98
h = 1.036