A Comparison of Chronotype on Indices of Executive Function and Impulsivity

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Abstract

A Comparison of Chronotypes on Indices of Executive Function and Impulsivity

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Judgment, decision-making, and planning are higher-order components of executive function that regulate behavior. Deficits in these cognitive processes can result in behavior that is deleterious to one's health and well-being. Recent research has found that evening types exhibit personality, lifestyle, and behavioral characteristics that reflect poor judgment, planning, and decision-making compared to morning- and intermediate-types. This study investigated impulsivity, planning, and decision-making abilities between chronotypes. This study included a total of 84 healthy young adults comprised of 14 morning-type, 39 intermediate-type, and 31 evening-type students at Drexel University. Evening-types reported significantly higher attentional impulsivity, compared to morning- and intermediate-types. Chronotypes did not significantly differ in motor, non-planning impulsivity, or performance on neurocognitive measures. Higher trait impulsivity may contribute to a higher frequency of addictive and illegal substances, greater lifestyle irregularity, impulsive eating behaviors, and more conduct problems in evening types. Future research should utilize neurocognitive measures that are more sensitive to attentional impulsivity to detect behavioral differences between the groups.

INTRODUCTION

Chronotype refers to interindividual differences in circadian timing based on preference for sleep-wake timing and peak activity (Horne & Ostberg, 1976). Chronotype can be measured along a continuum from morningness to eveningness or separated into distinct categories (i.e., morning-, intermediate-, and evening-types). Chronotypes differ in biological measures of circadian timing, including melatonin and cortisol secretion, alertness, body temperature, meal timing, and appetite preference (Bailey & Heitkemper, 2001; Lack, Bailey, Lovato , & Wright, 2009; Minors, Rabbitt, Worthington, & Waterhouse, 1989). Of the three types, morning-types (MTs) are most closely synchronized with sunrise and experience the earliest peak in body temperature, alertness, and sleep onset, followed by later circadian timing in intermediate-types (ITs) and evening-types (ETs), respectively (Kerkhof, 1985; Kerkhof & Van Dogen, 1996; Tankova, Adan, & Buela-Casal, 1994).

Past studies have found that chronotypes differ beyond variations in circadian timing, indicating personality, behavioral, and health-related disparities between morning types (MTs), intermediate types (ITs), and evening types (ETs). The behavioral manifestations and personality characteristics associated with eveningness include greater lifestyle irregularity, impulsivity, substance abuse, conduct problems, and attentional difficulties. Such patterns are indicative of higher impulsivity and lower self-control. These characteristics are also associated with deficits in executive function. The executive system of the prefrontal cortex is the supervisory system that allows us to integrate information in order to produce controlled, goal-directed behavior. Problems with the executive function can result behavioral and cognitive manifestations, including personality changes, attention difficulties, perseverations, impulse control problems, impaired decision-making, and poor planning abilities. Disruption to this system, referred to as executive dysfunction, can be transient or longstanding and can result from multiple etiologies including damage to the prefrontal cortex or connected neuronal systems, psychopathology alcohol or drug intoxication, or sleep deprivation.

This study aims to use neuropsychological measures of executive function in conjunction with a measure of self-reported impulsivity to determine whether planning and decision-making abilities vary by chronotype in healthy young adults. To our knowledge, this will be the first study to use objective behavioral measures of planning and decision-making in tandem with self-report data to investigate executive function between chronotypes. Assessing these domains of cognition may help elucidate the underlying cognitive mechanisms that contribute to differences in health and dysfunctional behavioral patterns associated with ETs.

Characteristics of Chronotypes

Recent studies have expanded beyond investigating the disparities in biological and circadian timing between MT, IT, and ET individuals. A number of researchers have begun to investigate personality traits, behavior, and lifestyle differences between chronotypes in order to elucidate the characteristics that may contribute to, and arise from, differences in circadian timing. For instance, studies using self-report measures of personality based on the Five Factor Model have found MTs to be more agreeable, conscientious, introverted, and stable, while ETs tend to be more extroverted and neurotic (Adan, Natale, Caci, & Prat, 2010; DeYoung et al., 2007; Hogben, Ellis, Archer, & von Schantz, 2007; Soehner, Kennedy, & Monk, 2007; Tonetti et al., 2010; Tonetti, Fabbri, & Natale, 2009). Subsequent research has focused on lower order personality traits related to behavioral regulation, such as impulsivity, sensation seeking, and self-control in order to gain a more finite understanding of how personality may differ between chronotypes. Trait impulsivity is of particular interest in this study because of its relation to frontal lobe processes of planning and decision-making. Taken together, these constructs may increase our understanding of factors that may contribute to behavioral and lifestyle differences between chronotypes. Increasing our understanding of these contributing factors may help clinicians develop therapeutic targets for improving health behaviors in at-risk individuals.

Impulsivity

Impulsivity is characterized as a tendency towards rapid, unplanned actions, which can manifest as reduced planning and disadvantageous decision-making. A trend has emerged between higher impulsivity and eveningness (Adan et al., 2010; Caci et al., 2005; Selvi et al., 2011). Caci et al (2005) utilized The Impulsivity-Venturesomeness Empathy Questionairre-7 is a self-report measure of impulsiveness (behaving without thinking) and venturesomeness (defined as the desire to pursue a realized risk for the thrill) in order better understand the established relationship between ETs and trait extroversion. Additionally, they found a negative correlation between impulsivity and morningness, but surprisingly, no relationship between chronotype and venturesomeness (Caci et al., 2005). Furthermore, Adan et al. (2010) found lower dysfunctional impulsivity in MTs and an interaction between gender and chronotype, where ET and IT males demonstrated high dysfunctional impulsivity, defined as a tendency towards rapid decisions with negative consequences. Finally, Selvi and colleagues (2011) found greater impulsivity, as measured by the Barratt Impulsiveness Scale, in ETs who attempted suicide. ETs in this were also more likely to attempt suicide by more violent and impulsive means than their MT counterparts (Selvi et al., 2011). These data suggest that impulsivity in ETs can potentially manifest in harmful, potentially fatal, behaviors.

Other studies have failed to find a relationship between trait impulsivity and chronotype (Digdon & Howell, 2008; Hogben et al., 2007; Muro, Goma-i-Freixanet, & Adan, 2009). This inconsistency is not surprising due to the lack of reliability between the various scales designed to measure impulsivity. This inconsistency may, in part, be due to the lack of a universally accepted operational definition of impulsivity. Impulsivity is a broad, multifaceted construct and, therefore, different self-report measures of impulsivity may be measuring different constructs of impulsivity. This highlights the importance of expanding the current findings between chronotype and trait impulsivity to investigate neuropsychological correlates of impulsivity. Neurocognitive tests measure behavior with objective, standardized methodology that can assess discrete aspects of cognition without the bias of self-perception or limits of metacognitive awareness associated with self-report measures. Therefore, this study aims to address the multidimensional nature of impulsivity by using Barratt's model of impulsivity, which conceptualizes trait impulsivity as being composed of three components: motor (acting without thinking), attentional (inability to focus on what is at hand), and non-planning (lack of forethought) to investigate impulsivity between chronotypes (Patton, Stanford, & Barratt, 1995). Furthermore, these components have been shown to correlate moderately with the neuropsychological measures (name) that employed in this study. Taken together, trait impulsivity and behavioral measures of planning and decision-making ability may help us to understand the lifestyle and behavioral differences present between chronotypes.

Self-Control and Sensation-Seeking

The connection between trait impulsivity and chronotype may further extend to related constructs, such as self-control and sensation seeking. Self-control, which requires impulse regulation and delay of immediate gratification (Baumeister & Heatherton, 1994), is associated with eveningness (Digdon & Howell, 2008). A study among college students showed differences in self-control manifested in an increased tendency towards procrastination in ETs (Digdon & Howell, 2008). Notably, procrastination relates to planning and organizational abilities as well as decision-making that favors immediate gratification but often results in negative outcomes (Rabin, Fogel, & Nutter-Upham, 2011). ETs also have a higher propensity towards sensation-seeking compared to their MT and IT peers (Caci, Robert, & Boyer, 2004; Tonetti et al., 2010). Caci and colleagues (2004) found a *negative* correlation between morningness and novelty seeking, impulsiveness, extravagance, and disorderliness in a sample of young men. Interestingly, impulsivity, lack of self-control, and high sensation seeking are characteristic of both *delayed* circadian typology – consistent with eveningness – and certain clinical populations with dysexecutive problems. Therefore, studying neuropsychological performance in this population may help elucidate potential neurobehavioral mechanisms underlying the personality traits and behavioral patterns identified in ETs.

Lifestyle and Psychological Correlates of Chronotypes

Lifestyle. The proposed differences in decision-making, planning, and impulsivity between chronotypes may explain the differences in lifestyle and behavioral patterns seen between MTs, ITs, and ETs. As a group, ETs tend to have more inconsistent and irregular lifestyle and sleep-wake habits than ITs and MTs. Furthermore, ETs are most likely to consume harmful and addictive substances, while MTs and ITs at a low risk for engaging in these types of health impairing behaviors (Urban, Magyarodi, & Rigo, 2011). The aforementioned behavioral patterns of ETs are consistent with higher impulsivity and lower self-control consistent with past research, and may also be reflected in analogous neuropsychological measures of planning and decision-making styles that appear to be highly correlated with trait impulsivity (Malloy-Diniz et al., 2007; Pietrzak, Sprague, &

Snyder, 2008).

According to the Social Rhythms Metric, MTs show the greatest lifestyle regularity, followed by ITs, then ETs (Monk et al., 2004). ETs tend have a more irregular sleep-wake schedule, poorer subjective sleep quality, report feeling sleepier during the day, accumulate a greater sleep debt, and consume more sleep-promoting substances and caffeinated beverages than ITs and MTs (Giannotti, Cortesi, Sebastiani, & Ottaviano, 2002; Monk et al., 2004; Monk, Petrie, Hayes, & Kupfer, 1994). Greater sleep and lifestyle irregularity may indicate poorer self-regulation in ETs.

In addition, substance abuse, which is associated with poor judgment and impaired decision-making, is more prevalent in ETs. Adolescent and young adult ETs consume more alcohol and tobacco (Gau et al., 2007; Giannotti et al., 2002; Ishihara et al., 1985; Nakade, Takeuchi, Kurotani, & Harada, 2009; Urban et al., 2011) and are more likely to experiment with smoking (Urban et al., 2011) than their IT and MT peers. In addition, adults with a propensity for eveningness are more likely to consume addictive and illegal substances (Taylor et al., 2011), and have higher rates of alcoholism (Adan, 1994; Prat & Adan, 2011; Wittmann, Dinich, Merrow, & Roenneberg, 2006). Finally, ETs have a higher tendency towards impulsive eating habits, including binging and purging (Kasof, 2001). These behaviors are all consistent with the qualities of poor self-regulation and dysfunctional impulsivity that have been associated with eveningness in previous studies.

In neuropsychology, the construct of self-regulation is mediated by executive function, which encompasses attention, planning, decision-making, and inhibitory control (Beaver, Wright, & Delisi, 2007). Individuals with a tendency to engage in the impulsive, risky behaviors associated with eveningness, including substance abuse and impulsive eating, tend to show deficits in decision-making as measured by the Iowa Gambling Test (IGT) (Buelow & Suhr, 2009). This suggests that ETs may also demonstrate disadvantageous performance on the IGT. If chronotypes do indeed differ in these constructs, these differences could help explain the behavioral patterns associated with MTs, ITs, and ETs because performance on the IGT is likely to translate to real life decision-making, such as decisions about whether or not to experiment with alcohol, drugs, and tobacco, and engage in other impulsive behaviors associated with eveningness.

Psychopathology. In addition to variations in behavioral tendencies between chronotypes, past studies have found a link between circadian preference and psychopathology, with a higher propensity towards eveningness in select pathologies, and a higher frequency of certain dysfunctional traits associated with these pathologies, including attentional difficulties, impulsivity, and aggression. In comparison to their MT and IT peers, adolescent ET males tend to have higher rates of attentional difficulties, conduct problems, and hyperactivity, while adolescent ET females tend to have higher rates of relational aggression (Lange & Randler, 2011; Susman et al., 2007). Furthermore, impulsivity is a personality trait commonly associated with bipolar disorder, substance use disorders, and antisocial personality disorder, and is found in higher prevalence in ETs as well. Likewise, eveningness is associated with a higher prevalence of depression (Chelminski, Ferraro, Petros, & Plaud, 1999; Gau et al., 2007; Hirata et al., 2007; Kitamura et al., 2010), anxiety (Diaz-Morales & Sanchez-Lopez, 2008; Mecacci & Rocchetti, 1998), bipolar disorder (Cho, Ennaceur, Cole, & Suh, 2000; Hakkarainen et al., 2003), seasonal affective disorder (SAD) (Johansson et al., 2004; Johansson et al., 2003; Murray, Allen, & Trinder, 2003; Natale, Adan, & Scapellato, 2005), Attention Deficit Hyperactivity Disorder (ADHD) (Caci, Bouchez, & Bayle, 2009), substance abuse (Adan, 1994), and impulsive personality disorders (Siever et al., 1999) — each of which exhibit various deficits in executive control.

Intelligence and Academic Achievement. A meta-analysis found a small effect of eveningness on “cognitive ability”, as measured by intelligence testing and vocational aptitude, and morningness on academic achievement, as measured by GPA and college entrance examination (Preckel, Lipnevich, Schneider, & Roberts, 2011). For example Roberts and Kyllonen (1999) found better performance in ETs compared to? on a measure of intelligence and aptitude (i.e., Armed Services Aptitude Battery). Killgore and Killgore (2007) found eveningness associated with higher verbal intelligence in adult women, but not men. Despite evidence of higher intelligence in ETs, MT adolescent and college students have been found to have higher grade point averages (GPA) (Medeiros, Mendes, Lima, & Araujo, 2001) and college entrance exams than their ET peers (Besoluk, 2011). Researchers theorize that school and test start-times, attentional difficulties, and effects of poor sleep may explain this discrepancy between intelligence testing and academic performance.

Psychophysiological Basis for the Proposed Relationship between Executive Function and Circadian Typology

The aforementioned characteristics and behavioral tendencies associated with ETs are similar to the characteristics and behavioral problems seen in individuals with low serotoninergic function (Soloff, Lynch K. G., & Moss, 2000). This is not surprising because serotonin is essential for both stability of circadian rhythmicity *and* impulse regulation, two areas that appear to be suboptimal in ETs. Serotonin is a precursor to melatonin and is highly involved in circadian rhythm regulation (Yannielli & Harrington, 2004; Yuan, Lin, Zheng, & Sehgal, 2005). Exposure to morning light activates the serotonergic system (Cagampang, Yamazaki, Otori, & Inouye, 1993). Impulsive, violent offenders with the lowest serotonin turnover demonstrate alterations in diurnal rhythmicity (Virkkunen, Goldman, Nielsen, & Linnoila, 1995), and relatively low serotonin turnover is predictive of impulsive behaviors in humans and monkeys (see Kohyama, 2011 for review).

Furthermore, evidence suggests that there is sufficient overlap between circadian gene polymorphisms and the genes associated with mood disorders, specifically bipolar disorder, SAD, and schizophrenia (see Rosenwasser, 2010 for review). Interestingly, these disorders are associated with unique deficits in executive function as well as changes in sleep and circadian function. Harvey (2008) theorizes that genetic variations in circadian genes predispose individuals to being more or less sensitive to the zietgebers that entrain our circadian rhythm. Those whose circadian rhythms are less easily entrained are more likely to experience sleep disturbances and follow a sleep-wake cycle that is further removed from external zietgebers, like sunlight. This creates a reciprocal feedback between circadian irregularity and suboptimal sleep that is sustained by genetic predisposition for reduced entrainment. The neurochemical underpinnings of this relationship may be serotonin, which is intimately connected to circadian rhythmicity, executive function, and mood regulation. As a result, disruption to this feedback loop (see Figure 1) may help to explain the relationship between mood disorders and circadian disturbance. Likewise, due to the relationship between serotonin and executive function, alterations the serotonin system stemming from sleep disturbances and circadian disruption may manifest in mood changes and executive dysfunction. Therefore, it is likely that those individuals with more advanced circadian rhythms (i.e., MTs and ITs) are more likely to have intact serotonergic function and perform better on tasks sensitive to serotonergic function compared to their delayed ET peers.

Figure 1: Theoretical Model for Variations in Executive Function.

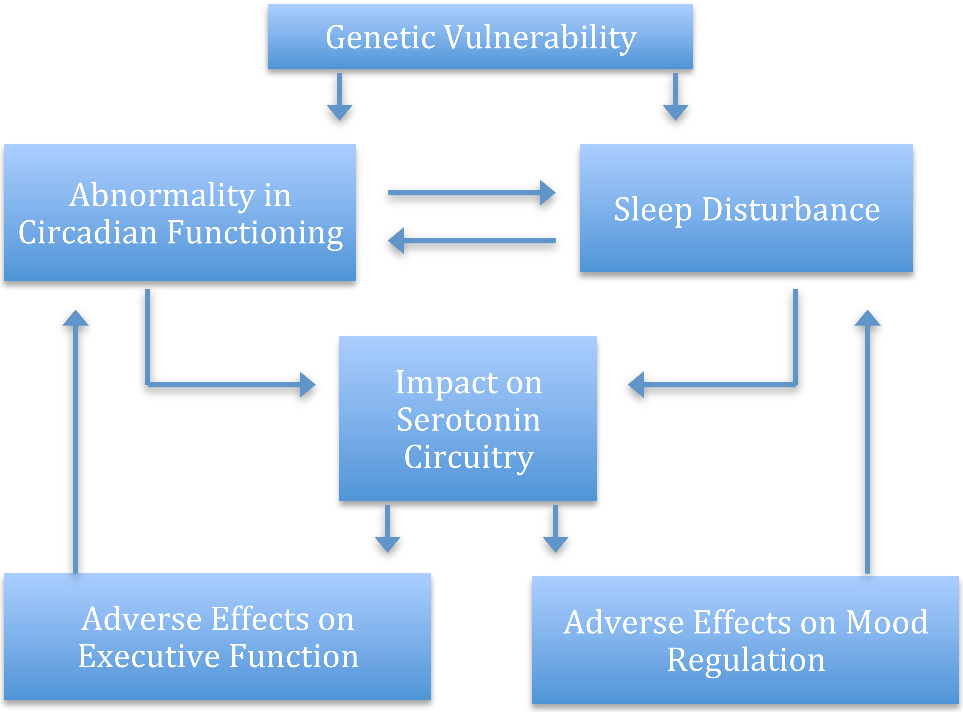

Figure 1. Modified from (Harvey, 2008) the theoretical psychophysiological model for the proposed differences in executive function between chronotypes.

College students, whose social and academic pressures often promote delayed sleep schedules, may be particularly vulnerable to falling into this unhealthy cycle. Those students who have stronger self-control, planning, and impulse control will make better decisions, procrastinate less, plan better, and potentially be able to maintain a healthier sleep schedule. The link between lifestyle regularity, trait stability, and morningness is consistent with the neurobiological model that attributes differences in serotonergic function as a primary source of functional stability and lifestyle regularity.

Finally, circadian clock genes have been associated with a host of psychopathologies and appear to be implicated in addiction and reward processing, a key neurochemical system in the psychophysiology substance abuse (see Rosenwasser, 2010 for review). Current theory suggests that expression of many genes, including those genes related to mood and reward processing are regulated, to some degree, by clock genes. Therefore, the variations in clock genes associated with an evening circadian phenotype might also predispose people to the aforementioned psychopathologies, behaviors, and traits. This suggests some commonality between the neurochemical and/or neuroanatomical underpinnings of eveningness and certain psychopathologies. While the study of the neurochemical pathophysiology of circadian dysfunction is beyond the scope of this study, these data lend credence to the theory that circadian preference is likely marked by genetic and neurophysiological differences that may manifest in neuropsychological and behavioral disparities between chronotype. Therefore, we seek to determine whether ETs, MTs, and ITs differ on neuropsychological measures of executive function aimed to measure impulsivity.

Neuropsychology of Executive Function and Impulsivity

Executive function is an umbrella term that refers to the supervisory attention system involved in the integration of cognitive process that enables us to filter out irrelevant information and inhibit unnecessary output in order to maintain goal directed behavior (Funahashi, 2001). The many subcomponents of executive function include mental flexibility, impulse inhibition, judgment, responding adaptively to novel situations, planning for future goals, anticipating consequences, and integrating information to accomplish goal-directed behavior (Gioia, Isquith, Guy, & Kenworthy, 2000). Executive function mediates those aspects of higher-order cognitive processing required for judgment, decision-making, and planning. Furthermore, executive function within the frontal lobe is related to personality and emotional regulation. Deficits in executive control can sometimes manifest behaviorally as impulsiveness, problems with self-control, poor judgment, organizational problems, and a tendency towards immediate gratification which can result in significant and long-term implications for health and quality of life (Gorenstein, 1982). Eveningness is associated with trait impulsivity as well behavioral features that tend to be associated with poor regulation and inhibitory control. Impulsivity is a multidimensional construct characterized by a lack of control over thoughts and actions, usually resulting in undesirable outcomes (Evendeen, 1999). Furthermore, impulsivity is a trait found in many forms of pathology, particularly personality disorders, substance abuse, and attention-deficit disorder and presents with measureable deficits in executive functioning.

Impulsivity can result in deleterious judgment or decision-making, which requires weighing the short and long-term, positive and negative, consequences of an action to arrive at a decision. Planning is a goal directed executive task that requires self-control, working memory, and decision-making. Impulsivity can be broken down into motor impulsivity, attentional impulsivity, and poor planning based on distinctive presentations and unique cortical regions and neurotransmitters involved. This study attempts to focus on the neuropsychological correlates of these subtypes of impulsivity in order to better understand the behavioral and personality correlates associated with diurnal preference.

Circadian Rhythm of Cognition

Our circadian pacemaker regulates the ebb and flow of hundreds of bodily processes to our 24-hour day, including temporal fluctuations in cognitive performance (see Schmidt, 2007 for review). The circadian rhythm of the sleep-wake cycle parallels a drop in core temperature and a rise in melatonin levels as one's propensity towards sleep increases (Minors & Waterhouse, 1981). Attention, alertness, and higher cognitive processes fluctuate throughout the circadian period. Performance on simple cognitive tasks follows a circadian pattern that parallels core body temperature; however performance on more complex tasks tends to peak in the morning and decline over our waking hours as the pressure to sleep builds (Harrison, Jones, & Waterhouse, 2007; Minors & Waterhouse, 1981; Valdez, Reilly, & Waterhouse, 2008).

Executive function is particularly sensitive to the effects of sleep loss and time-of-day, due to fluctuations in the circadian rhythmicity of cognition (Valdez et al., 2008). These time-of-day differences may depend on chronotype, where MT, ITs, and ETs differ in times of peak alertness and performance (Bennett, Petros, Johnson, & Ferraro, 2008; Hahn et al., 2012). Inhibitory control tends to peak in the early afternoon and evening, with poorer performance in the early morning and at night (Manly et al., 2002). These peaks in inhibitory control correspond with peaks in subjective alertness, which vary by chronotype. For example, MTs tend to reach their peak activity levels in the morning, while ETs reach their peak in the late afternoon (Adan et al., 2012). Inhibitory control appears to be poorer during “non-optimal times of day” when subjective alertness is low (May, 1999; May & Hasher, 1998). In order to account for the varying peaks in alertness between chronotypes we randomized to participant testing time and, stratified by chronotype

Aims and Hypotheses

Our primary aim was to examine how chrontoypes differ on trait impulsivity comprised of three subcomponents of impulsivity (i.e., motor, attentional, and non-planning). We hypothesized that ETs would show higher trait impulsivity, particularity for the non-planning component of the Barratt Impulsivity Scale (BIS-11). The secondary aim of this study was to examine the relationship between chronotype and executive function among college students (Aim 2). We hypothesized that ETs would perform poorer than ITs and MTs on tasks of executive function that measure planning and decision-making. Finally, we aimed to address how the three subscales of the BIS-11 (i.e., motor, attentional and non-planning) related to the neuropsychological constructs planning and decision-making (Aim 3). Based on past literature using healthy young adults, we hypothesized that the non-planning subscale of the BIS-11 will correlate most strongly with decision-making, as measured by the Iowa Gambling Test (IGT) and planning as measured by mazes, while the attentional and motor impulsivity subscales of the BIS-11 will most closely relate to planning, as measured by the raw score on the Zoo Map test.

Significance of the Present Study

The impulsive and dysfunctional traits associated with delayed circadian preference place ETs at higher risk for substance abuse and other deleterious health behaviors. This is particularly important to study in college students because this time represents a major developmental period and transition into autonomy for most adults. In addition, college students tend to have a more delayed circadian preference and abnormal, unhealthy sleep schedules. The present study aims to increase our understanding of cognitive factors that may contribute to the health and behavioral disparities between chronotypes by implementing objective and ecologically valid measures of constructs that have previously been studied using self-report assessments in this population. It is important that we increase our understanding of how planning and decision-making is related to circadian typology because those behavioral and health patterns acquired in college often continue into adulthood. Decisions made during this time of development could potentially lead to serious, long-term consequences. Furthermore, this study may open the door to future studies that might help us to understand whether these differences in executive function are related to transient and treatable variables, such as poor sleep quantity and quality, or related to more persistent characteristics that are inextricably linked to eveningness.

METHODS

Participants

Ninety-three undergraduate participants were administered questionnaires and neuropsychological measures in exchange for extra credit. Participants were required to be 18 – 45 years or old and enrolled in a psychology undergraduate course at Drexel University in order to received compensation for participation in this study. Participants with less than five years of English fluency were excluded from all analyses (*n* = 9). A power analysis suggested a sample size of N = 148 participants to detect an effect based on a presumed moderate effect size (*f* = 0.30) as reported in past research(Malloy-Diniz et al., 2007; Pietrzak et al., 2008). However, past studies using similar designs and measures have been able to detect an effect with using between 72–101 participants, therefore we propose a target sample within this range (Malloy-Diniz et al., 2007; May & Hasher, 1998). The final sample included a total of 84 undergraduate participants (14 morning type, 39 intermediate type, and 31 evening type adults).

Measures

Descriptive Information. A demographic questionnaire was used to collect information about participant’s age, gender, ethnicity, academic status (i.e., fulltime or part-time and grade point average), employment status, and number of hours spent working outside of school per week. PSQI total scores classify 54% of the sample as poor sleepers using a cut-off score of 5.

Morningness-Eveningness Questionnaire (MEQ). The MEQ was used to measure chronotype along the spectrum of morningness to eveningness (Horne, 1976). The MEQ is a nineteen-item question questionnaire with score that range from 16 to 86. The MEQ can be used to categorize participants into definitely morning (70 to 86), moderately morning (59 to 69), intermediate type (42 to 58), moderately evening (31 to 41) and definitely evening (16 to 30) (J.A. Horne & O. Ostberg, 1976) or simplified into morning, neither, and evening type (Natale & Cicogna, 1996) for analyses. Chronotype was also measured along a continuum for regression analyses, with lower scores indicating a propensity for eveningness. The MEQ is highly reliable (α = .82) (Smith, Reilly, & Midkiff, 1989) and valid (Natale & Cicogna, 1996). MEQ scores were used to examine differences in executive function across the spectrum of diurnal preference and assess the relationship between chronotype and three sub-types of self-report impulsivity.

Barratt Impulsiveness Scale, version 11 (BIS-11). The BIS-11 is a 30-item self-report measure containing three subscales that measure motor impulsivity (e.g., “I act on the spur of the moment”), non-planning (e.g., “I plan tasks carefully”), and attentional impulsivity (e.g., “I am restless at the theater or lectures.”) (Patton et al., 1995). The BIS is scored on a one to four Likert scale, corresponding to the statements rarely/never to almost always/always (Patton, Stanford, and Barratt, 1995). Internal (r = .93) and test-retest reliability (r = .89) for the BIS are high. Higher scores reflect greater impulsivity (specified items reverse scored).

The Stanford Sleepiness Sale (SSS). The SSS is a brief assessment of an individual's level of alertness at a given time (Natale & Cicogna, 1996). The participants are asked to identify with the statement that best describes their current level of sleepiness/alertness on a scale of 1-7. The statements range from (1) "feeling active and vital" to (4) "somewhat foggy and let down" to (7) "almost in reverie; sleep onset soon; lost the struggle to remain awake".

About Your Sleep Last Night. Participants were asked about the quality and duration of their previous nights sleep, as well as caffeine consumption. This information was collected during the neuropsychological testing session.

Pittsburgh Sleep Quality Index (PSQI). The PSQI is a 19-item questionnaire used to measure subjective sleep quality. The PSQI is a reliable ($\alpha = .85$) and valid tool (Backhaus et al., 2002) used to identify "good" and "poor" sleepers according to sleep duration, sleep disturbance, sleep efficiency, sleep latency daytime dysfunction, and sleep medication use (Smyth, 1999). Participants were administered the PSQI at the time of neuropsychological test administration.

Profile of Mood States (POMS). The *POMS* is a 65–item questionnaire used to assess and individual's mood over the past week (McNair, Loor, & Droppleman, 1981)The POMS consists of six clinical scales (i.e., Tension-Anxiety, Anger-Hostility, Fatigue-Inertia, Depression-Dejection, Vigor-Activity, and Confusion-Bewilderment). The POMS scales have been shown to have adequate convergent and divergent validity based on high correlations with other mood measures (Nyenhuis et al., 1999).

Trail Making Test. Trail Making parts A and B are brief pencil-and-paper measures taken from the Halstead-Reitan neuropsychological battery. Part A requires speeded visual search and attention, while Trails B is a more difficult test of visual search, attention, mental set shifting, and working memory (Sanchez-Cubillo et al., 2009). Both measures require participant to connect 25 circles scattered on a page as quickly as possible. Part A requires participant to connect the circles containing a number 1-25 in ascending order. Part B requires participants to connect each circle, containing either a number or a letter in ascending numerical and alphabetical order, alternating between number and letters (i.e., 1 to A to 2 to B, etc.). Soring for each trial is based on seconds to completion. Number of errors is also recorded.

Iowa Gambling Task (IGT). The IGT is a measure of decision-making that is particularity sensitive to the type of impulsive decision-making that increases risk for substance abuse, and is sensitive to differences in serotonergic function (Bechara, Damasio, Damasio, & Anderson, 1994). The IGT is a computerized assessment in which participants are instructed to choose cards from any of four decks. Two of these decks dispense low loss and low reward, but are overall more advantageous. The other two decks offer opportunities for high loss and high reward, thus being disadvantageous overall. A net score is calculated in addition to a score for blocks of 20 trials each. Participants are not compensated for performance, as there appears to be no differences in performance using real and play Money (Turnbull, Berry, & Bowman, 2003). No studies have directly examined the reliability of the IGT due to the high potential for practice-effects. However, the construct validity of the IGT is supported by evidence of poorer performance in clinical populations who are high in risk-taking, including healthy adolescents, adolescents with attention hyperactivity disorder and conduct disorder, substance abusers, pathological gamblers, patients with schizophrenia, and those with damage to the Ventral medial Prefrontal Cortex and therefore it appears to be an ecologically valid assessment of risky decision-making (Buelow & Suhr, 2009). Performance on the IGT is also moderately correlated with the BIS-11 total score and the non-planning subscale (Malloy-Diniz et al., 2007).

Zoo Map Task. The Zoo Map task is a measure of planning that requires participants plan a route needed to visit designated locations on a fictional map of a zoo while following a series of rules (Norris & Tate, 2000). This measure has created to have high face-validity and is moderately correlated with the BIS-11 total score as well as the attentional and motor subscales (Pietrzak et al., 2008). This task consists of two trials with identical maps, but varied instructions. The first trial requires the participant to plan their route on their own, whereas the second trial measures their performance when they are given the explicit instructions for the most direct route. Performance is scored both using a raw score based on ability to follow instructions and choose the most efficient routes, as well as time scores reflecting planning time, or time to first move, and total time to complete the task.

The Maze Test. The mazes was taken from Salthouse & Siedlecki, 2007, which are a simplified version of the maze test used in the Neuropsychological Assessment Battery. This measure is moderately correlated with the BIS-11 total score as well as the non-planning subscale (Pietrzak et al., 2008). The Maze Test is a paper-and-pencil test that consists of three mazes that increase in intensity followed by a baseline trial where participants trace a line representing the most efficient route for each maze in order to account for differences in motor speed tracing time is then subtracted from time to complete the three mazes. The Maze Test is sensitive to trait impulsivity, and is moderately correlated with overall impulsivity and non-planning on the BIS-11. See Table 1 for a list of measures.

Table 1.

Measures

Construct	**Measure**	**Format**
Demographic Information	Demographic Questionnaire	In-lab (computerized)
Chronotype	Morningness-Eveningness Questionnaire	Online
Self-report impulsivity	Barratt-Impulsivity Scale	In-lab (computerized)
Sleepiness	Stanford Sleepiness Scale	In-lab (computerized)
Sleep Quality	Pittsburg Sleep Quality	In-lab (computerized)
Decision-Making	Iowa Gambling Test	In-lab (computerized)
Planning	Zoo Map Test	In-lab
Planning	The Maze Test	In-lab
Attention and Visual Search	Trails parts A	In-lab
Attention, Visual Search, and set-shifting	Trails parts B	In-lab

Participants first completed the MEQ coming in for an hour-long in-lab testing session composed of multiple questionnaires and three neuropsychological assessments.

Procedure

The primary objective of the present study was to examine components of executive function (i.e., planning and decision-making) that may explain differences in the behavioral and personality differences found across the spectrum of diurnal preference in young adults. Participants were recruited from Drexel University online through SONA System, flyers, and classroom announcements. Compensation consisted of one extra credit point per half hour of participation, in concordance with Drexel University's research procedure policies. Data was collected at two time points. Drexel University students were recruited through SONA system, where they read a detailed description of the study prior to deciding whether to participate. If they decided to participate, students then completed the MEQ online and provided their email address. The results of their MEQ were then used to schedule their testing session. Once they arrive for their scheduled testing appointment, participants were informed and consented, and administered a demographic questionnaire, BIS-11, PSQI, SSS, the IGT, Zoo Map, The Maze Test, and the Trail Making Test. Due to possible time of day differences in performance between chronotypes, scheduling for neuropsychological testing was randomized and counterbalanced across three time periods, 800 to 1000, 1100 to 1300, and 1400 to 1600 based on MEQ scores (see Table 2).

Table 2.

Number of Participants by Chronotype and Testing Time

Chronotype	800 to 1000	1100 to 1300	1400 to 1600	Total
Morning-Type	5	5	4	14
Intermediate-Type	12	15	12	39
Evening-Type	11	10	10	31
Totals:	**28**	**30**	**26**	**84**

Results

Sample Characteristics

The final sample is comprised of 84 students, 59.5% female and a mean age of 20.40 (*SD* = 2.82). The majority of the sample was Caucasian (55.7%), followed by Asian or Pacific Islander (19.0%), Hispanic (4.8%), African American, Indian (4.8%), 13.1% of the sample reported "other", and 2.4% of respondents reported more than one race. Participants were stratified by chronotype based on MEQ scores. The final sample includes 16.7% MT, 46.4% ITs (combined 63.1%), and 36.9% evening-type. The sample includes 34.5% freshmen, 21.4% sophomores, 26.8% juniors, and 14.6% seniors.

Brief descriptive data on psychiatric history was taken. Eight participants reported a current diagnosis of a mood disorder (anxiety only = 1; both depression and anxiety = 5; obsessive-compulsive disorder = 2). Seven participants report a history of ADHD, three of these report current diagnoses and a total of four are currently medicated for

ADHD. No participants in this sample reported a current diagnosis of Bipolar Disorder or Schizophrenia. Ten participants report a history of one or more concussions.

Preliminary Analyses

Reliability. The internal reliability of the BIS-11, MEQ, and PSQI were measured using Cronbach's Alpha. Analyses indicate good internal consistency for the BIS-11 ($\alpha = 0.85$), MEQ ($\alpha = 0.84$), and PSQI ($\alpha = 0.84$).

Outliers. MANOVAs and ANOVAs are highly vulnerable to the effects of outliers. Therefore, we used the outlier labeling rule as proposed by Hoaglin, Iglewicz, and Tukey (1986). As a results, outliers were removed from: Trails B (1), Maze trace time (2), ZMT trial two total solve time (2), ZMT trial one total solve time (1), Zoo Map trial one total score (2). It is of note that invalidated scores were also removed due to administration error or environmental distractions. This included removing the following tasks from select participants: Trails B ($n = 1$), Maze trace time ($n = 1$), and ZMT ($n = 1$).

Normality. All dependent variables were analyzed using the Kolmogorovo-Sirnov test of normality. The Maze Test trace time, solve time, and difference score, all ZMT variables, IGT total score, the last block of the IGT, Trails B time all violated the assumption of normality ($p < 0.05$). Data for ZMT trial one plan time and total time, Maze solve, trace, and difference score, Trails B time, IGT total, and IGT last block were appropriately normalized using a square-root transformation. Transformed variables will be used for analyses including these variables. Square-root transformation did not appropriately normalize ZMT trial two plan and solve times and total score for trials one and two. Therefore, non-parametric tests (i.e., Mann Whitney analyses) were used for analyses including these variables. It is of note that most participants (95%) received a perfect score on this ZMT trial two, as would be expected for this population.

Sample Means. Mean sample total and subscale scores for the BIS-11, IGT, Trails A, Trails B, ZMT, and Mazes are presented in Table 3. An independent t-test revealed no significant differences between males and females on any dependent measures (i.e., BIS-11 or neuropsychological variables). BIS-11 mean total score is consistent with previously published means in samples college students (Patton et al., 1995; S. S. Stanford et al., 1996).

Performance on neuropsychological testing fell within normal limits expected for healthy university students age 18 – 24. Mean scores place the sample normatively in the low average range for Tails A time (20th%ile) and the average range on Trails B time (30th%ile) with scores ranging from the superior to impaired range across participants. Mean performance on the ZMT places this sample in the average range compared to other healthy adults (58th%ile). Performance on the Maze trace condition (53rd%ile), solve condition (45th%), and difference score (37th%) were average. See Table 3 for sample statistics for BIS-11 and Neurocognitive measures.

Table 3.

Sample Statistics

Measure	Mean (Standard Deviation)	Range
Barratt-Impulsivity Scale	61.66 (10.57)	34 – 71
Attention	17.33 (3.42)	9 – 27

Planning	21.55 (4.44)	12 – 33
Motor	22.79 (5.18)	12 –36
Iowa Gambling Test total score	1733.72 (607.50)	350 – 3200
Last 20 trials	44.94 (674.16)	-1175 – 1375
Zoo Map Test Trial 1 score	3.80 (3.36)	-4 – 8
Plan Time	36.73 (36.75)	1 – 162
Solve Time	138.34 (52.70)	0 – 281
Zoo Map Test Trial 2	7.89 (0.56)	4 – 8
Plan Time	8.60 (14.22)	1– 88
Solve Time	55.42 (22.03)	23 –150
Zoo Map Profile Score	2.69 (1.00)	0 – 4
Maze Test: Trace (seconds)	28.70 (8.39)	14 – 51
Maze Test: Solve (seconds)	66.21(21.22)	37 – 119
Maze Test: Difference (seconds)	37.13 (17. 13)	7 – 84
Trails parts A (seconds)	27.51 (8.49)	14 – 54
Trails parts B (seconds)	51.89 (13.00)	32 – 85

Group Differences Between Chronotypes. Independent samples t-tests revealed no significant age differences between morning/intermediate types and evening types $t(82) = 0.52$, $p = 0.60$. Chronotypes did not differ in GPA or years English fluency ($p > 0.05$). Chi-squared analyses revealed no significant difference in ethnicity, gender, or class standing ($p > 0.05$).

Independent t-tests were used to compare PSQI scores, state sleepiness, habitual sleep duration and sleep duration the night before testing for ET compared to MTs and ITs (see table 4). Independent sample t-tests revealed no significant differences in state sleepiness or hours of sleep the night before testing ($p = 0.05$). However, ETs reported worse sleep quality compared to MT and ITs combined t(79) = -2.99, $p < 0.05$. There was a trend for habitual sleep duration to differ between these groups t(79) = 1.77, $p = 0.08$, with evening types having a shorter? Sleep duration that MT/ITs.

Table 4.

Comparison of Sleep Between Chronotypes

	MT/IT Mean (Standard Deviation)	ET Mean (Standard Deviation)
PSQI total score*	6.23 (3.08)	8.4 (3.24)
Habitual Sleep Duration	7.28 (1.13)	6.79 (1.36)
“last night” sleep duration	7.00(1.26)	6.70 (1.82)
SSS	2.60 (1.20)	2.87 (1.18)

* Significant difference between chronotypes ($p < 0.05$)

Potential differences in mood between chronotypes during the week prior to testing were assessed using the POMS (see table 5 for mean values). There were no significant differences in depression, tension, vigor, anger, confusion, or total score ($p > .05$). However, ETs reported significantly more fatigue than morning- and intermediate-type according to the POMS fatigue subscale t(82) = –2.00, $p = .05$.

Table 5.

Comparison of Mood Between Chronotypes

	MT/IT Mean (Standard Deviation)	ET Mean (Standard Deviation)
POMS total score	79.71 (32.79)	83.35 (27.64)
POMS Depression	26.38 (10.69)	26.26 (9.84)
POMS Tension	19.42 (6.73)	20.58 (6.33)
POMS Fatigue*	18.87 (5.52)	21.322 (5.27)
POMS Vigor	23.38 (5.06)	21.84 (5.03)
POMS Confusion	15.72 (5.06)	16.62 (4.10)
POMS Anger	1.36 (0.65)	1.41 (0.50)

Correlations Between Self-Report Measures and Neuropsychological Variables. Given the potential for neuropsychological measures to be affected by state-related differences in mood, sleep, and sleepiness, and age, we examined the correlations between these variables and neurocognitive performance. Correlations are presented below in Table 4. Age, sleep duration the night before testing were not significantly related to neurocognitive performance (see Table 6). State sleepiness correlated with performance on Trails A; sleep duration correlated with time to solve ZMT trial one, and total PSQI score was correlated with performance on Trails B (see Table 4). Higher scores on the PSQI indicate worse sleep quality and are associated with poorer performance on neuropsychological measures. All significant associations were in the expected direction.

Mood, as measured by the POMS total score, showed small to moderate correlations with several neuropsychological variables including, IGT total score, Maze trace time, ZMT total score trial one, ZMT trial two solve time, ZMT profile score, and Trails A time (see Table 6). Depression was associated with Maze trace time, ZMT trial one total score, ZMT trial two solve time, and ZMT profile score. Fatigue was associated wish trial two solve time. All significant associations were in the expected direction (worse mood was associated with poorer performance). Higher POMS scores indicate dysfunctional mood symptoms and are associated with poorer performance on neuropsychological measures (see Table 6). Finally, there was no relationship between GPA and neurocognitive performance. All significant associations were in the expected direction.

Table 6.

Correlations Between Self-Report and Neurocognitive Measures

	IGT Total	Maze Trace	Maze Solve	ZMT 1 Score	ZMT2 Score	ZMT1 Solve Time	ZMT2 Solve Time	Profile Score	Trails A	Trails B
Age	-.01	-.01	-.04	.04	.07	-.07	-.15	.08	-.02	.10
State Sleepiness	.03	.15	.04	-.07	.01	-.02	**.26***	-.12	**.26***	.05
PSQI total	-.01	.06	.10	.05	.16	-.21	.06	.06	.13	**.24***
Habitual Sleep Duration	.03	-.13	-.03	-.07	-.14	.12	-.12	-.05	-.15	-.05
POMS Depression	-.17	**.30****	.12	-.21	-.19	-.05	**.25***	**-.24***	**.25***	.07
POMS Fatigue	.01	.19	.10	.11	.09	-.07	**-31***	-.07	.14	.12
POMS total	**-.22***	**.30****	.20	**-.25***	-.14	-.07	**.32****	**-.27***	**.25***	.15
Last Night Sleep duration	-.04	-.18	-.16	.03	-.15	-.01	.19	.08	-.15	-.03

Note. *Correlation is significant at the 0.05 level (2-tailed).
**Correlation is significant at the 0.01 level (2-tailed).

We have identified covariates based on variables that differed between chronotypes (i.e., PSQI total score and POMS fatigue) *and* significant correlations with neurocognitive measures (i.e., POMS fatigue and PSQI total score). Therefore, analyses investigating the relationship between chronotype and Trails B time will control for PSQI total score and analyses investigating the relationship between chronotype, and ZMT solve time trial two will control for POMS fatigue.

Table 7

Correlations between Neurocognitive Measures

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. IGT Total	-	**.59****	-.14	-.01	-.02	.07	.00	.13	-.07	.16	**.21***	**.25***	-.10	.12
2. IGT Last Block		-	-.03	.01	.08	-.03	.08	.11	-.06	.03	-.04	.09	-.15	-.03
3. Maze: Trace			-	**.63****	**-.25***	-.03	.18	.04	-.07	**.45****	.03	-.02	**.26***	.15
4. Maze: Solve				-	**.91****	.10	**.23***	-.11	-.01	**.42****	-.13	-.09	**.20***	.17
5. Maze: Difference					-	.15	.13	-.08	.05	**27***	.17	-.05	.06	.11
6. ZMT 1 Plan Time						-	**.22***	**.42****	**.46****	.12	.01	**.32****	-.07	.10
7. ZMT 1 Solve Time							-	-.11	-.15	**.30****	-.20	**-.26****	.12	.04
8. ZMT 1 Score								-	.10	-.11	.08	**.86****	-.15	-.09
9. ZMT 2 Plan Time									-	**.43****	.03	-.11	.11	-.02
10. ZMT 2 Solve Time										-	-.05	**.40***	**.43****	.09
11. ZMT 2 Total Score											-	**-.22****	.03	.11
12. Profile Score												-	-.16	-.08
13. Trails A													-	**.48****
14. Trails B														-

Note. Two -Tailed inter-correlations between dependent neurocognitive variables. Correlations were used to determine which variables to include in the MANOVA.
$*p < 0.05$; $**p < 0.01$

Correlations Between Neuropsychological Variables. We examined the correlations between neurocognitive variables in order to select appropriately correlated variables for the MANOVA comparing chronotypes on measures of executive function. Dependent variables in a MANOVA should be moderately correlated (0.20 to 0.80)

(Meyers, Gamst, & Guarino, 2006). Therefore, Maze trace time, Maze solve time, ZMT trial two solve time and Trails A will be included one MANOVA (see table 7).

Primary Analyses

Aim 1. Investigation of the BIS-11 subscales indicate that participants differed in self-reported attentional impulsivity F(1,83) = 3.98, *p* = 0.05 (See Table 7 for mean values). Chronotypes did not differ in self-reported motor F(1,83) = 2.37, *p* = 0.13 or planning BIS subscales F(1,83) = 0.89, *p* = 0.34. Although the results were trending, chronotypes did not significantly differ in self-reported impulsivity according to the BIS-11 total score F(1,83) = 4.54, *p* = 0.08. (state the positive first—qualify after)

Aim 2. To test whether diurnal preference (i.e., chronotype) is associated with performance on tasks of planning and decision-making we ran two separate MANOVAs comparing ETs to MTs and ITs performance on neurocognitive measures with Pearson's correlations between 0.20 to 0.80 (Meyers et al., 2006). The final MANOVA included: The Maze trace time, Maze solve time, ZMT trial two solve time, and Trails A. This revealed no significant difference between chronotypes in performance on these measures Wilk's λ = 0.98, F(4,72) =1.92, *p* = 0.31. This remained non-significant when controlling for PSQI habitual sleep efficiency Wilk's λ = 0.91, F(4,71) =1.74, *p* = 0.15. This finding was not consistent with our hypothesis that ETs would perform worse than MTs and ITs on neurocognitive measures of executive function.

This omnibus MANOVA was followed by separate ANOVAs for each neurocognitive variable. Chronotypes did not differ in Maze Test trace time F(1,83) = 12.53, *p* = 0.12, solve time F(1,83) = 0.09, *p* = 0.76, or difference score F(1,83) = 0.49, *p* = 0.83. Likewise, chronotypes did not differ on Trails A F(1,82) = 0.40, *p* = 0.53 or Trails B F(1,82) = 0.22, *p* = 0.64, even when controlling for PSIQI total score F(1,79) = 0.01, *p* = 0.98. There was no significant difference between chronotypes in IGT total score F(1,83) = 0.12, *p* = 0.73. Analysis of ZMT performance revealed no significant differences in ZMT trial one plan time F(1, 83) = 0.52, *p* = 0.47, total solve time F(1,83) = 0.06, *p* = 0.94, total score F(1,82) = 1.34, *p* = 0.25, or the profile score F(1,83) = 0.30, *p* = 0.59 (See Table 8 for mean values). Finally, data that non-normalized data was analyzed using the Kruskal-Wallis test of significance. Chronotypes did not significantly differ in ZMT trial two total plan time H(2) = 2.12, *p* = 0.14, solve time H(1) = 0.19, *p* = 0.66, or trial two total score H(1) = 0.26, *p* = 0.60, even when controlling for POMS fatigue on trial two solve time. These findings were not consistent with our hypothesis that ETs would performance more poorly that morning- and ITs on measures of executive function, decision-making, and impulsivity. See Table 8 for mean values.

Table 8.

Mean Dependent Values by Chronotype

Measure	Morning and Intermediate Types Mean (Standard Deviation)	Evening Types Mean (Standard Deviation)
Barratt-Impulsivity Scale	60.13 (9.95)	64.29 (11.25)
Attention	16.77 (3.33)*	18.29 (3.42)*
Planning	22.38 (4.81)	23.48 (5.75)
Motor	20.98 (4.37)	22.52 (4.49)
Iowa Gambling Test total score	1761.54 (647.18)	1687.06 (540.10)
Last 20 trials	49.54 (9715.65)	37.06 (607.94)

Zoo Map Test Trial 1 score	3.38 (3.72)	3.77 (3.95)
Plan Time	39.57 (40.75)	31.88 (28.66)
Solve Time	142.54 (61.29)	136.85 (45.61)
Zoo Map Test Trial 2	7.85 (0.69)	7.79 (0.18)
Plan Time	10.55 (17.27)	5.03 (5.81)
Solve Time	55.97 (24.07)	54.49 (17.56)
Zoo Map Profile Score	2.64 (1.00)	2.77 (1.01)
Maze Test: Trace (seconds)	29.06 (11.13)	31.43 (7.70)
Maze Test: Solve (seconds)	65.81 (21.99)	70.10 (26.63)
Maze Test: Difference (seconds)	36.75 (17.90)	39.80 (24.83)
Trails parts A (seconds)	27.96 (9.26)	26.74 (7.07)
Trails parts B (seconds)	51.38 (12.92)	52.77 (13.19)

Note. * ANOVA is significant at the 0.05 level (2-tailed).

Post Hoc Analyses.

Extreme Eveningness. In the event, that we did not have enough power to detect an effect or that our variability was truncated among the extreme ends of out MEQ continuum, we conducted post-hoc analyses to examine trait and neuropsychological differences between “extreme” ETs (*n* = 9) (i.e., lowest 10th%ile on the MEQ) and the other participants in this sample (*n* = 75). Results indicate no significant difference between chronotypes on any of the dependent measures included in this study. Extreme ETs did not differ in trait impulsivity according to the BIS total score t(82) = 3.65, *p* = 0.21, attentional t(82) = 0.41, *p* = 0.68, or motor impulsivity. However, evening-types (M

= 19.33, SD = 6.00) did indicate *lower* mean planning impulsivity compared to the rest of the sample (M = 23.20, SD = 4.94) t(82) = 0.60, $p = 0.03$. This was not considered to be significant given that post-hoc analyses were held to a more conservative alpha level ($p = 0.01$). Participants did not significantly differ in performance on neurocognitive tests.

Time of Day. Additional post-hoc one-way ANOVAs were conducted to investigate the relationship between testing time and neurocognitive performance. Results were only considered significant if $p < 0.01$. A significant time of day effect on Trails B time indicated that participants performed worse in the morning compared to the afternoon testing time (see Table 9). No other time of day effects were significant at the $p < 0.01$. Interactions analyses between time of day and chronotype were underpowered. Therefore, the interaction between chronotype and time of day warrants future investigation with adequate power.

Table 9.

Interaction between Time of Day and Performance on Trails B

Chronotype	800 to 1000	1100 to 1300	1400 to 1600	Mean Chronotype
Morning-Type	56.40 (17.79)	42.60 (7.23)	48.00 (11.11)	49.07 (13.38)
	n = 5	*n* = 5	*n* = 4	*n* = 14
Intermediate-Type	58.08 (14.83)	47.57 (11.75)	51.24 (10.25)	52.77 (13.19)
	n = 12	*n* = 14	*n* = 12	*n* = 38
Evening-Type	57.68 (14.56)	51.50 (14.91)	48.00 (9.39)	52.77 (13.19)

	n = 11	*n* = 10	*n* = 9	*n* = 30
Mean TOD	57.68 (14.55)[a]	48.07 (12.08)	49.84 (9.84)[b]	51.89 (12.96)
	n = 28	*n* = 29	*n* = 25	*n* = 82

Means (standard deviations); TOD = time of day; a and b are significantly different $p < 0.01$.

Aim 3. Finally, analysis of the relationship between the BIS-11 and neuropsychological variables indicated significant one-tailed bivariate Pearson's r correlations between the BIS total score and ZMT trial one plan time. The BIS attentional subscale was significantly correlated with ZMT trial one solve time. The BIS motor impulsivity is significantly correlated with the ZMT trial 1 plan time. Lastly, the BIS planning subscale correlated with IGT total score, IGT last block, ZMT profile score, ZMT trial one score, Trails A time, ZMT trial solve time and total score. All correlations were in the expected direction, that is poorer performance was related to greater impulsivity (see Table 10 below). These correlations are consistent with our hypothesis that neurocognitive measures of executive function would correlate with self-reported trait impulsivity. Based on past literature, we hypothesized that the Maze solve time and difference score would significantly correlate with the BIS-11 planning subscale. The Maze solve score was not correlated the BIS-11 total score or subscales but the difference score was trended towards a significant correlation with the planning subscale ($r = 0.14$, $p = 0.09$).

Table 10.

Correlations Between BIS-11 and Neurocognitive Performance

	BIS Total	BIS attentional	BIS Motor	BIS Planning
IGT Total score	-.20	-.08	-.08	**-.29***
Maze: Trace	.14	.11	.07	-.00
Maze: Solve	.01	.02	.10	.08
Maze: Difference	.06	-.02	.08	.14
Profile Score	-.17	.03	-.06	**-.32****
ZMT1 Plan time	**-.29****	-.19	**-.33****	-.20
ZMT 1 total solve time	-.21	**-.31****	-.16	-.09
ZMv1Score	-.13	.06	-.08	**-.30***
ZMT 2 Plan Time	-.03	.11	-.15	.08
ZMT 2 total solve time	.10	.08	.03	.14
ZMv2 Score	-.15	.04	-.06	**-.28***
Trails A	.18	.02	.12	**.25***
Trails B	.05	.08	.04	.03

**. Correlation is significant at the 0.01 level (1-tailed). *Correlation is significant at the 0.05 level (1-tailed).

Discussion

The aim of this study was to investigate the neurocognitive profile of morning and intermediate-types compared to evening-types in order to increase our understanding previously reported trait and behavioral differences between chronotypes. First, this study aimed to replicate the findings reported by Slevi (2011) by comparing chronotypes on self-reported trait impulsivity on the BIS-11 in our sample of college students. Consistent with Slevi’s (2011) findings in a sample of suicide attempters, morning and intermediate types reported greater mean trait impulsivity on the BIS-11 total score, but this difference was not statistically significant. However, ETs reported greater attentional impulsivity. Our second aim was to compare performance on neurocognitive measures between chronotypes. Our findings did not support our hypothesis that MTs and ITs would perform better than ETs on tests of executive function. Finally, this study investigated the construct validity of the measures selected for analysis by examining bivariate correlations between self-report measures of impulsivity and impulsivity on the BIS-11. These findings revealed BIS total score showed a modest significant correlation with the ZMT trial one plan. The BIS-11 motor subscale was moderately correlated with ZMT plan time. The attentional subscale was moderately, significantly correlated with ZMT trial one total solve time. Finally, the planning subscale showed small to moderate significant correlations with the IGT final score, ZMT profile score, total score for both ZMT trials, and Trails A time. Finally, post-hoc analyses suggest that the interaction between testing time and chronotype is worth investigating in a larger sample.

Although we found a similar trend as the findings reported in Slevi (2011), mean trait impulsivity reported by ETs was significantly higher in Slevi's sample (M = 83.07) than in our sample (M = 64.29). Mean impulsivity in Slevi's sample (M_{MT} = 60.86; M_{IT} = 62.62) was consistent with our findings in MT and ITs (M = 60.13). This suggests that there may be something unique about ETs in a clinical sample that is worth investigating.

Slevi (2011) did not report mean values for the BIS-11 subscales. Therefore, this study expanded upon these findings by reporting that ETs reported greater attentional impulsivity in a young adult sample. Results also trended towards greater motor impulsivity in ETs and showed no difference on the BIS-11 planning subscale. Given that this study found the greatest difference between chronotypes on a measure of attentional impulsivity, future studies may aim to investigate neurocognitive measures that are more sensitive to variations in attention. For example, measures of sustained, selective, and divided attention and Go-No-Go tests may be more sensitive to these differences.

These results indicate that ET college students report greater trait impulsivity than MT and IT young adults, particularly in the area of “attentional impulsivity”. The attentional subscale on the BIS includes statements about thinking patterns, including, “I have ‘racing’ thoughts”, “I don’t ‘pay attention’”, “I am a steady thinker”, “I concentrate easily” (reversed), “I “squirm at plays or lectures”, “I change hobbies”, “I often have extraneous thoughts when thinking”, and “I am restless at the theater or lectures”. The factor analysis used to determine the subscales of the BIS-11 suggested that the attentional subscale could be broken down further into two components a.) Attention (e.g., difficulty concentrating or attending) and b.) Cognitive instability (e.g., racing thoughts, changing hobbies, and extraneous thoughts) (Patton et al., 1995). These constructs tap into inattention and restlessness symptoms often seen in mood disorders and ADHD.

Attentional impulsivity as measured by the BIS is related to impulsive behaviors such as suidicality amongst psychiatric patients as well as binging, purging, and overeating (Claes et al., 2006; Corruble et al., 2003; Yeomans, Leitch, & Mobini, 2008). The attentional subscale also tends to be elevated in males and females who are substance dependent, particularly those who become substance dependent at a young age, patients with depression, bipolar disorder, and ADHD, and violent male offenders (M. S. Stanford et al., 2009). Therefore, attentional impulsivity may explain the higher frequency of these behaviors in ET adults. Attentional impulsivity may also explain the discrepancy between intelligence and academic successes between chronotypes reported in previous studies. ETs may have a small tendency towards grater intellectual capacity than ITs or MTs, but they may have difficulty sustaining attention as needed for classroom learning or studying.

Despite differences in trait impulsivity, our findings did not support our hypothesis that MTs and ITs would perform better than ETs on tests of executive function. It is possible that the specific neurocognitive measures in this study may not have been sensitive to the types of previously reported differences. The neurocognitive measures employed in this study are sensitive to clinically significant differences executive function, planning, and decision-making. These measures may not pick up on slight differences in these abilities that can account for normal variability within a healthy, young population. Although there is an underlying construct that these neurocognitive measures pick up on in testing, they are more prone to state variation that may modulate performance and/or behavior within a certain context. Furthermore, the type of decision-making that suggests a propensity towards substance abuse or experimenting with illicit drugs may include other factors not measured in this study. These measures may not be sensitive to the specific aspects of impulsivity, such as tendency towards sensation seeking, that may explain the behavioral differences reported between chronotypes.

Furthermore, there is evidence that ET tend to perform better on intelligence testing than MTs (Preckel et al., 2011). Individuals with higher intelligence also tend to perform better on neurocognitive tasks in other domains of cognitive ability. One might speculate that even though there may be trait and behavioral differences between chronotypes, ETs may not perform worse on these measures given their higher level of intelligence. For example, the differences between chronotypes may only manifest face of 'real life' experiences and do not represent a deficit in cognitive ability, as measured in this study, but rather are representative of some other variable we did not capture. For example, ETs tend to be higher on extroversion scales. Therefore, it is possible that these differences in decision-making may be more sensitive in the context of peer pressure.

For the purposes of this study, we selected measures aimed to measure multiple components of impulsivity based on evidence of construct validity. This study adds to the literature on the construct validity of specific neurocognitive measures and specific components of trait impulsivity. Overall, discrete aspects of trait impulsivity (i.e., BIS-11 total score) were moderately associated with performance on select neurocognitive measures. As hypothesized, the IGT, a measure of impulsive decision making, was specifically related to non-planning impulsivity. The construct validity of the ZMT, taken from the BADS, has not been well studied. Our findings suggest that several components of the ZMT (i.e., profile score, trials one and two total scores), were also moderately correlated with non-planning impulsivity. ZMT trial one plan time was most strongly correlated with motor impulsivity (e.g., "I do things without thinking"). Furthermore, Trails A, a measure of processing speed and attention showed no significant association with trait attentional impulsivity, but was most strongly correlated with non-planning impulsivity (e.g., “I am self controlled”). However, contrary to our hypotheses we did not find any relationship between maze trace or solve time and trait impulsivity. This level of analysis increases our understanding of what these neurocognitive tests are measuring. This is particularly important given that Trails A, Trails B, and the ZMT are neuropsychological measures used to measure cognitive strengths and weaknesses and to assess for impairments in clinical practice.

Limitations

First, this study was limited in the comprehensiveness of neurocognitive measures sampled in this study. In order to administer the questionnaires and neurocognitive measures within a manageable time frame (approximately 1 hour) we were required to limit the number of measures we could administer. However, executive function and impulsivity are multi-faceted domains with numerous neurocognitive measures to assess executive function and impulsivity. Given the preliminary nature of this study, we chose a representative sampling of measures that have previously been found to be associated with trait impulsivity.

Finally, this study was also limited by the low frequency of MTs in the young adult population. For this reason, we compared ETs to a combined group of morning- and ITs. While previous research suggests that MTs and ITs are similar when it comes to personality characteristics. However, it is not clear whether these groups might differ in performance on neurocognitive measures.

Future Directions

Future research should 1.) Investigate neurocognitive performance between chronotypes in a clinical sample of extreme circadian preference such as delayed and advanced sleep phase disorder. 2.) Future research should investigate this relationship in sample of community-dwelling adults. College students tend to have unique social rhythms and school/work schedules. This may result in a unique relationship between chronotype and cognitive function as compared to what would typically be see in the working adult population. 3.) Study this relationship within the context of a more comprehensive assessment of neurocognitive measures of impulsivity, with a particular emphasis in attentional impulsivity (the component that differed most between chronotype groups). This should include a comparison of chronotypes on measures of sustained, divided, and selective attention with consideration for errors of omission, commission, and reaction time. 4.) As predicted, we were unable to recruit an adequate sample of MTs to allow for enough power to investigate each chronotype as independent groups. The current literature suggests that MTs and ITs tend to be most alike on measures of impulsivity and irregular, impulsive behavioral patterns. However, given that construct has yet to be studied in the context of neurocognitive function, future research would benefit from comparing neurocognitive performance between chronotypes.

Conclusions

Young adults have a higher probability for engaging in risky behaviors due to immature development of neuroanatomical behavioral control systems. Past research suggests that variability in impulsivity amongst young adults may contribute to the types of impulsive decisions that lead to risky behavior. The results of this study indicate greater attentional impulsivity in evening-type young adults. Greater trait attentional impulsivity in ETs may explain the tendency for more dysfunctional behavioral patterns in ETs. This study found no significant difference in performance on neurocognitive measures between chronotypes. These results should be interpreted with caution given the abovementioned limitations. Future research should investigate whether these trait differences between chronotypes may manifest in behavioral and neurocognitive differences in other domains of cognitive functioning. If ETs report greater impulsivity as measured by the BIS-11 and other measures, but do not appear to show measurable difference in cognitive function, alternative explanations must be explored.

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