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Health behaviors including alcohol use, smoking, and physical activity (PA) are known to impact the progression of dementia and modifying these risk factors at a younger age may help to delay or prevent the onset of cognitive impairment. Prospective memory (PM) is an understudied aspect of cognition that heavily influences a person's day-to-day life. Alcohol use and smoking have both been demonstrated to negatively impact a person's PM ability; meanwhile, there is reason to believe that PA could help to enhance PM ability through shared pathways. In the present study, the interaction between these health behaviors and self-reported PM ability is explored in a cross-sectional survey of young adults. An online survey asking about substance use behaviors, PA behaviors, and PM ability was completed by 96 individuals in an undergraduate Kinesiology course. Analyses of variance and multiple regression were used to analyze the impact of these health behaviors on PM ability and their interactions with one another. No significant differences in PM ability were observed between heavy, low, and non-substance users nor between high, moderate, and low active young adults. The interaction of binge drinking with PA was able to explain some variance in PM scores such that non-binge drinkers had stronger PM ability and binge drinkers had weaker PM ability with increasing levels of PA. The present study provides evidence that the relationship between PA and PM ability in young adults may be moderated by binge drinking behaviors.

# THE EFFECTS OF SUBSTANCE USE AND PHYSICAL ACTIVITY ON PROSPECTIVE MEMORY IN YOUNG ADULTS

by

Samuel W. Kibildis

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Dr. Jennifer Etnier

Committee Chair

APPROVAL PAGE

This thesis written by Samuel W. Kibildis has been approved by the following committee of the Faculty of The Graduate School at The University of North Carolina at Greensboro.

Committee Chair Dr. Jennifer Etnier

Committee Members Dr. Eric Drollette

Dr. Alexis Ganesh

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Date of Final Oral Examination

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# CHAPTER I: INTRODUCTION

According to the 2020 Report of the Lancet Commission, 40% of dementias worldwide are due to 12 modifiable behavioral risk factors. Three of these risk factors are excessive alcohol consumption, smoking, and physical inactivity. In 2018, more than half of the United States' (US) adult population drank alcohol in the past 30 days, as revealed by the Behavioral Risk Factor Surveillance System [BRFSS] survey. About 7% of the population engaged in heavy drinking, defined by the US Centers for Disease Control and Prevention (CDC; 2020) as drinking more than 14 or 7 drinks per week for men and women, respectively. It is estimated that excessive alcohol consumption cost the United States $249 billion in 2010 (CDC, 2020) and alcohol is perhaps the most commonly used recreational drug in Western society (Heffernan, 2012). Long-term alcohol consumption has been linked to many negative health consequences including increased risk for cancer, high blood pressure, heart and liver disease, stroke, immune system disorders, and mental health problems (World Health Organization [WHO], 2019). Chronic alcohol consumption is also known to cause learning and memory problems, acting as a risk factor for dementia and cognitive decline (Anstey et al., 2009).

According to the CDC (2020), smoking is the leading cause of preventable death and costs the US billions of dollars every year. In 2018, 13.7% of all adults (34.2 million people) were currently smokers (CDC, 2020). The negative health consequences of smoking are well-established, including increased risk for cancer, heart disease, stroke, lung diseases, diabetes, chronic obstructive pulmonary disease (COPD), tuberculosis, eye diseases, immune system disorders, and reproductive issues (US Department of Health and Human Services [HHS], 2014). Jha and colleagues (2013) established that smokers die 10 years earlier than nonsmokers, on average. Like alcohol use, smoking is known to serve as a risk factor for dementia and cognitive decline (Anstey et al., 2007).

The HHS President's Council on Sports, Fitness, and Nutrition (2017) reported that fewer than 5% of American adults participate in at least 30 minutes of physical activity (PA) every day. The CDC's Healthy People 2020 report stated that only one-fourth of US adults and one-fifth of US adolescents meet PA guidelines as established by the HHS (2018).

The cognitive reserve hypothesis (Stern, 2002, 2009) posits that every individual has a cognitive reserve which describes individual differences in brain structure and cognitive processes. This cognitive reserve decreases as an individual ages or experiences brain damage such as dementia pathology. An individual with higher levels of cognitive reserve could experience greater cognitive decline before showing symptomology of memory decline or dementia. There is evidence that health behaviors including PA, smoking, and drinking can impact the neuronal networks of the brain in such a way that could influence cognitive reserve. Specifically, excess alcohol use and cigarette smoking can result in brain atrophy, or shrinkage, and cigarette smoking is associated with abnormalities of the biology and structure of the brain (Kril & Halliday, 2004; Durazzo et al., 2010). Researchers in neuroimaging studies have shown that the activation of the frontal lobe and the activation and size of the medial temporal lobe (MTL) are negatively associated with heavy alcohol use (Agartz et al., 1999; Wendt & Risberg, 2001), and nicotine use (Levin et al., 2005). Chronic PA can preserve brain size as an individual grows older and stimulates neurogenesis in the MTL (Benedict et al., 2013; Brown et al., 2003). Further, PA preserves brain volume and neuronal structural integrity (Cheng, 2016). Together, the literature supports the idea that PA could mediate the effects of alcohol and smoking on cognitive decline that ultimately leads to dementia.

While dementia is likely not on the forefront of young adults' attention, it is interesting to consider how these negative health behaviors that are common in young adults could influence their cognition as they age. Young adults are at a critical juncture in development, and negative impacts on the brain during this period of life, such as the neurotoxic effects of alcohol and nicotine, could disproportionately impact development (Crews & Boettiger, 2009; Jacobus & Tapert, 2013). In young adulthood, an individual's behaviors heavily impact their cognitive reserve; the healthy and unhealthy behaviors an individual performs during young adulthood could influence cognitive reserve more than the same behaviors performed in another part of life. Despite this, individuals in their early 20s report the highest levels of excessive alcohol use (Patrick et al., 2016) and the prevalence of smoking still sits above 10% for adults age 18-24 (Levy et al., 2019).

The specific effects of excessive substance use during young adulthood on cognitive reserve may not be fully elucidated until significant research is performed; there is evidence, though, that substance use may have particular deficits for aspects of memory that are critical for everyday function. Specifically, prospective memory (PM) is described as the formation, retention, and retrieval of intentions and their associated actions that cannot be realized at the time of encoding (Ellis, 1996). Common examples include remembering to stop for gas the next time you leave the house or remembering to attend a meeting at a certain time. Better PM can improve quality of life and increase an individual's years of independent living (Schmitter-Edgecombe et al., 2009). Failures of PM can detrimentally impact a person's health, well-being, social status, and career (Cuttler et al., 2017). When asked subjectively about memory failures experienced in everyday life, PM failures are the most common, and when asked to report their most recent memory failure, over half of individuals responded with a PM failure (Crovitz & Daniel, 1984; Einstein & McDaniel, 1996; Kliegel & Martin, 2003).

There is evidence to demonstrate impaired PM ability in heavy drinkers (Heffernan et al., 2002; Ling et al., 2003; Heffernan et al., 2004; Heffernan, 2008; Ling et al., 2010; Heffernan & O'Neill, 2012) and in smokers (Heffernan et al., 2005; Heffernan et al., 2010; Dawkins et al., 2013). Notably, these groups with impaired PM have been shown to not use strategies to compensate for their memory, likely due to lack of awareness or concern of their impairment (Heffernan et al., 2002; Heffernan, 2008; Heffernan et al., 2010; Heffernan & O'Neill, 2012). Considering this, it may prove essential to determine other ways to preserve or otherwise enhance PM in heavy substance users.

Executive functioning (EF) is the aspect of the brain related to many higher order functions such as organizing, prioritizing, regulating emotions, understanding different points of view, and self-monitoring (Understood Team, 2021). EF's three main areas are working memory, cognitive flexibility, and inhibitory control (including self-control; Understood Team, 2021). Working memory is the ability of the brain to hold on to new information and use it in some way. Cognitive flexibility refers to an individual's ability to think about multiple concepts at the same time and to switch between two different concepts (Magnusson & Brim, 2014). EF, and working memory in particular, have been demonstrated to share resources with PM (Dobbs & Reeves, 1996; Marsh & Hicks, 1998; Kliegel et al., 2002; West et al., 2006; see also, Heffernan & O'Neill, 2012) and have shown impairments with heavy alcohol use and with smoking (Mendrek et al., 2006; Glass et al., 2008).

There is reason to believe that chronic PA could help to alleviate impaired PM ability in heavy drinkers and smokers. It is well established that chronic PA can impact brain structures in the frontal lobe (Guiney & Machado, 2012) and the MTL, (Erickson et al., 2011; Bugg & Head, 2011; Griffin et al., 2011). In a review, Loprinzi and colleagues (2018) make the argument that regular PA could also affect PM through emotional states. Both PM ability and regular PA are associated with mood state and emotional memory. Given the shared salience of emotion, Loprinzi and colleagues argue that there is plausibility to the idea of a relationship between regular PA and PM.

While there has been a paucity of research related to PA effects on PM in particular, there is research demonstrating a positive relationship between chronic PA and cognitive performance in young adults (for review see Guiney & Macahado, 2012). Padilla et al. (2014) and Pérez et al. (2014) have provided evidence that chronic PA in young adults has positive effects on EF, specifically inhibition and working memory. In a recent meta-analytic review, Haverkamp and colleagues (2020) found a small effect (Hedge's g=0.36; 95% CI=[0.25, 0.47]) of chronic PA on cognitive outcomes in individuals aged 12-20 years old. In this review, EF (Hedge's g=0.354; 95% CI =[0.207, 0.501]) and working memory specifically (Hedge's g=0.587; 95% CI=[0.274, 0.9]) demonstrated small-to-large effects for chronic PA interventions. Since these two measures have been shown to share resources with PM (Dobbs & Reeves, 1996; Marsh & Hicks, 1998; Kliegel et al., 2002; West et al., 2006; see also, Heffernan & O'Neill, 2012), the effect sizes of chronic PA on these measures lend further support for the idea that chronic PA could affect PM ability.

Emerging research has begun to investigate the potential of a relationship between PA and PM, albeit with acute PA. Cuttler and colleagues (2017) demonstrated that performance decreases on objective measures of PM performed during a bout of aerobic PA but can be enhanced following an acute bout of resistance PA. Other studies of PM were unable to find a relationship between objective measures of PM and acute PA (Frith et al., 2017; Green & Loprinzi, 2018). Frith and colleagues (2017) found no difference between control participants or participants who performed PA at different times in PM task performance as assessed by a delayed phone call from the subject to the researcher. Green and Loprinzi (2018) found no difference in PM task performance as assessed by the Royal Prince Alfred PM Test (RPA-ProMem Test; Radford et al., 2011) between groups who performed 15 minutes of treadmill walking or 15 minutes of sitting. To date, no study has been conducted examining the effects of chronic PA behaviors on PM, nor has any study examined self-reported PM and a potential relationship to PA.

Thus, the purpose of the present experiment was: (1) to replicate findings of decreased self-reported PM in young adults with a history of excessive drinking or smoking, (2) to explore the relationship between chronic PA and self-reported PM in young adults, and (3) to investigate chronic PA as a potential moderator of the relationship between self-reported substance use and PM. It was hypothesized that young adults with any history of drinking or smoking would have impaired PM ability compared to those who have never drunk or smoked. Also, it was hypothesized that young adults who report excessive drinking or smoking will report lower levels of PM as compared to non-substance users and low-intensity users, that young adults' PM ability would correlate positively with the age that substance use began, that young adults with higher levels of PA would self-report stronger PM ability compared to young adults with lower levels of PA, and that levels of PA and substance use would interact to predict PM ability in young adult substance users such that substance users with higher levels of PA will display stronger PM ability than substance users with lower levels of PA.

# CHAPTER II: REVIEW OF THE LITERATURE

## Overview

PM can be defined as remembering to do something at a particular moment in the future or executing a previously formed intention (Ellis et al., 1996). Common examples include remembering to stop at the store on the way home from work or remembering to take medication in the morning. PM is related to quality of life and independent living (Schmitter-Edgecombe et al., 2009), and failures of PM can detrimentally impact a person's social, financial, and occupational status as well as their health and general well-being (Cuttler et al., 2017). Despite its importance, failures of PM are the most common memory failures experienced in everyday life (Crovitz & Daniel, 1984; Kliegel & Martin, 2003).

PM is often referenced as having two categories: event-based and time-based. Event-based PM requires an individual to remember to perform an action when stimulated by an external cue in the environment, while time-based PM requires an individual to remember to perform an action at a particular time or after a certain amount of time has passed (Einstein & McDaniel, 1996). Event-based PM is inherently reliant on an external cue as successful remembering can only occur in the presence of the external event; on the other hand, if no external mnemonic is used as a strategy in aiding a time-based PM task, there is no external event that prompts action and an individual must instead rely on self-initiated retrieval to successfully perform the task (Einstein et al., 1995).

In line with Craik's (1986) theory that self-initiated retrieval is impaired with increasing age, Einstein et al. (1995) provided evidence that performance on time-based PM tasks relying on self-initiated retrieval decreases more dramatically with increasing age than performance on event-based PM tasks. Following this, McDaniel and Einstein (2000) proposed the multiprocess framework of PM which theorizes that people depend on both attention-demanding monitoring and automatic spontaneous retrieval for successful PM. At the time, monitoring theories believed that an executive attention system is committed to tracking the PM task and interrupting ongoing processes when the PM action is to be performed. Theories of spontaneous retrieval stated that no executive resources are spent on monitoring the PM task and the intention is successfully retrieved spontaneously, or cued by an external event, when the PM action is to be performed. In an experiment seeking to provide evidence for the theory, subjects were asked to perform PM tasks while performing various ongoing cognitive tasks. In theory, the monitoring view of PM would assume a cost to ongoing tasks as some of the executive is attending to the PM task; on the other hand, the spontaneous retrieval viewpoint would expect no cost to ongoing tasks. Results demonstrated that PM tasks could be successfully completed with no cost to ongoing tasks (i.e., spontaneous retrieval) or with different amounts of cost to the ongoing task (i.e., monitoring), dependent upon a number of factors including the difficulty of the ongoing task, the level of focus devoted to the PM task, and other individual differences. Thus, Einstein and colleagues (2005) concluded that PM tasks can be successfully completed with monitoring, spontaneous retrieval, or a combination of the two.

A large body of research exists for PM and aging, through which the field has been able to advance significantly. Schnitzspahn and colleagues (2011) demonstrated that older adults display significantly lower PM performance than younger adults in a laboratory setting, but significantly higher prospective memory performance in naturalistic settings. These findings replicated evidence from Rendell and Craik (2000) that there is an age-PM paradox regularly observed in that older adults perform better on PM in the real-world despite performing worse in highly controlled laboratory scenarios. Schnitzspahn and colleagues found that the age benefit for older adults in naturalistic settings was most strongly associated with the level of absorption in everyday tasks. In other words, older adults' day-to-day lives are filled with less demanding activities than younger adults, allowing older adults to devote more time to setting up strategies to aid PM and to carry out PM tasks when compared to younger adults. However, the improved PM ability of older adults in natural settings was also associated with higher motivation, improved metacognition, and self-awareness of an individual's PM abilities.

Older adults are not the only population to display decreased PM ability in a laboratory setting relative to healthy young adults, though, and it is important to consider how an individual experiences PM changes throughout the life span. Young adults specifically are at a critical juncture in terms of brain development, and negative impacts on the brain during this period of life such as negative health behaviors including alcohol consumption and smoking are likely to influence the aging process. This could be viewed in terms of the cognitive reserve hypothesis (Stern, 2002, 2009) which theorizes that, throughout the lifespan, an individual builds up a reserve based on individual differences in cognitive processes and their underlying neural networks. Both healthy and unhealthy behaviors performed by young adults, being at a critical point of brain development, could disproportionately impact the amount of cognitive reserve that an individual creates. When the aging process occurs, or in the event of brain damage, an individual with greater cognitive reserve would have to experience greater decline than an individual with less cognitive reserve before displaying symptomology of cognitive dysfunction.

Heffernan, O'Neill, Zamroziewicz, and other researchers have demonstrated that PM ability is impaired in chronic alcohol users and smokers in laboratory settings, and that the individuals in these populations, contrary to older adults, are not aware of their PM deficits (Heffernan et al., 2010; Heffernan & O'Neill, 2012; Zamroziewicz et al, 2017). Since individuals performing these unhealthy behaviors display cognitive deficits and a likely decrease in cognitive reserve, there is justification to explore the extent of the deficits in this group, and to consider lifestyle factors, strategies, and other health behaviors that could help to offset this decline, such as PA.

### Chronic Alcohol Use, Smoking, and Prospective Memory

In a line of systematic research, researchers have provided ample evidence to demonstrate impaired PM in samples of heavy substance users, both clinical and non-clinical. Specifically, researchers have observed subjective and objective PM failures in chronic heavy alcohol users (Heffernan et al., 2002; Ling et al., 2003; Heffernan et al., 2004; Heffernan, 2008; Ling et al., 2010; Heffernan & O'Neill, 2012) and chronic smokers (Heffernan et al., 2005; Heffernan et al., 2010; Dawkins et al., 2013). Notably, these groups with impaired PM have been shown to not use strategies to compensate for their memory, likely due to lack of awareness or concern of their impairment (Heffernan et al., 2002; Heffernan, 2008; Heffernan et al., 2010; Heffernan & O'Neill, 2012). Considering this, it may prove essential to determine other ways to preserve or otherwise enhance PM in heavy substance users. In particular, Heffernan (2008) has called for future research to investigate the impact of protective factors, including PA, on cognitive impairments associated with heavy substance use.

## Alcohol Use and Prospective Memory

The line of research into alcohol use and PM began in 2002 with Heffernan and colleagues' study comparing thirty heavy-alcohol drinkers and thirty low-alcohol drinkers on self-reported PM. At the time, it was known that chronic heavy alcohol users displayed impairment on a range of cognitive tasks including learning word lists, short- and long-term logical memory, general working memory, and EF (Grant et al., 1987; Bechara et al., 2001; Selby et al., 1998; Ambrose et al., 2001; Wendt et al., 2001). While the chronic heavy alcohol use literature had previously focused on retrospective memory (RM), this study sought to extend the knowledge of memory deficits in heavy drinkers by comparing their PM ability to that of low-dose or non-drinkers using the PM Questionnaire (PMQ; Hannon et al., 1995). This scale is a self-report measure that consists of four subscales: (1) short-term habitual PM (PMQ-ST), (2) long-term episodic PM (PMQ-LT), (3) internally-cued PM (PMQ-IC), and (4) the techniques to remember scale (PMQ-STRAT). For the purposes of this study, a heavy-alcohol drinker was defined as drinking more than the maximum weekly recommended amount by the United Kingdom (UK) government for the past five years, while a low-alcohol drinker had less than the maximum weekly recommended amount (28 and 21 units of alcohol per week for men and women, respectively; a unit of alcohol is defined as 10 mL or 8g of pure alcohol – equivalent to approximately one 1 oz. shot of spirits, a 5 oz. glass of wine or a 12 oz. can of beer [Drinkaware, 2020]). The results of the study were as hypothesized -- that is, a greater impairment was evident on the three PM subscales of the PMQ for heavy-alcohol drinkers when compared to low-alcohol drinkers. Additionally, it was noted that there was no difference in the number of memory strategies used between groups as evidenced by the PMQ-STRAT, despite heavy-alcohol users having an obvious impairment.

It is also important to note that Heffernan et al. (2002) used 'other drug use' as a covariate in their analysis of covariance (ANCOVA), reporting that this was a common procedure in the substance use and cognition literature. However, as the field progressed, it was found that other drugs, including nicotine, cannabis, and ecstasy, have associations with PM (Heffernan, Jarvis, et al., 2001; Heffernan, Ling et al., 2001; Bartholomew et al., 2010; for meta-analysis, see Platt et al., 2019). Some researchers continue to use these as covariates, while others exclude participants for using these drugs, and still others study 'multi-drug use' as a separate category.

The use of other drugs as a covariate should statistically control for the influence of these other drugs and isolate the findings to alcohol use, but considering potential interactions between alcohol and other drugs, it is important to note inclusion or exclusion of other drugs and how they are controlled for and assessed.

Heffernan et al. (2002) proposed various mechanisms through which they believed chronic heavy alcohol use could inhibit PM abilities. Firstly, they noted brain shrinkage that occurs with heavy alcohol use that could be permanent (Kril & Halliday, 1998). In addition, alcohol can reduce the number of cholinergic neurons in the basal forebrain, impairing hippocampal function (Garcia-Moreno et al., 2001). Inhibition of the function of the prefrontal lobe caused by alcohol could prove to be a promising mechanism as well, considering PM's relationship with the frontal and prefrontal regions of the brain (Okuda et al., 1998; McDaniel et al., 1999, Wendt & Risberg, 2001). Lastly, they discussed the putative depletion of neurotransmitters caused by alcohol (Hunter, 2000).

Heffernan et al. (2002) also discussed the weaknesses and limitations of their study, especially exploring the issue of self-report. They discussed a 'memory paradox;' the PMQ and other self-report measures of memory are asking subjects to remember how frequently they forget. It is likely someone with high levels of forgetting could forget how often they forget. This would lead to under-reporting. They argued, though, that the under-reporting would be more likely to occur for the heavy-alcohol drinkers, which would add to the strength of their findings, if anything.

Following Heffernan and colleagues' paper, the literature on alcohol use and PM began to evolve. While the literature base is too large to cover in its entirety, the work led by Heffernan, Ling, and colleagues is especially important. Ling and colleagues (2003) were able to replicate Heffernan's findings, to some degree. The major differences between this publication and that of Heffernan et al. (2002) were the questionnaire format, the sample size, and the addition of the Everyday Memory Questionnaire (EMQ; Sunderland et al., 1983) in addition to the PMQ. Thanks to a web-based format, Ling and colleagues were able to recruit 763 participants. The results of the demographic questionnaire revealed that the majority of the sample was female (60.9%), 21-25 years old (32%), European (71%), had some university education (31%), and drank at least some alcohol during a typical week (79.4%). This means that 20.6% drank no alcohol (no-alcohol). The subjects who reported drinking were further categorized into three groups -- 41.7% of the sample consumed 1-9 units of alcohol per week (light-alcohol), 29.8% of the sample consumed 10-25 units of alcohol per week (moderate-alcohol), and 8% of the sample consumed more than 25 units of alcohol per week (heavy-alcohol). In addition, it is important to note that the data was screened to allow only one submission per IP address, so that each household could presumably only submit one response with the assumption that this would help to avoid duplicate responses. Furthermore, any participant who had reported being under the influence of alcohol or drugs as they completed the questionnaire was excluded.

The results of this paper were interesting in a unique way. The authors of the study made a point to examine the psychometric properties of the PMQ and the EMQ in their study and noted that PMQ-ST and PMQ-IC subscales lacked reliability. As such, Ling et al. drew no conclusions from the data provided by these subscales. This meant that the remaining scales were the PMQ-LT, the PMQ-STRAT, and the EMQ. Results show that the heavy-alcohol group experienced more memory problems on both the PMQ-LT and the EMQ than the no-alcohol and light-alcohol groups and began to elucidate a dose-response relationship between alcohol consumption and everyday memory and PM. The effect sizes between the heavy-alcohol group and the no-alcohol and light-alcohol groups were moderate-to-large (Cohen's d=0.62 and 0.50, respectively). Per these findings, the magnitude of difference between PM in the heavy-alcohol group and the no-alcohol and light-alcohol groups is large enough that the difference should be noticeable to the casual observer. Ling et al. also noted that the online nature of their study conferred many advantages: a larger sample with more statistical power, participants being more willing to admit to drug use on an anonymous online site (Joinson et al., 1999), and participants being willing to disclose more while experiencing less influence from social desirability bias (Joinson et al., 1999).

While Ling and colleagues (2003) were able to replicate many of Heffernan and colleagues' findings (2002), there was no new understanding of the mechanisms involved in alcohol's effect on PM at this time. Ling et al. also noted that without a longitudinal study, there is no way to say that the alcohol use is the reason for the PM and everyday memory deficits. It was also noted that a young sample was used, and PM impairment may be more noticeable in an older sample.

In 2004, Heffernan and colleagues compared 80 adults aged 18-35 years old who reported no drug use other than alcohol and cigarettes. Half of the sample was made up of heavy drinkers who consumed between 21 and 46 units of alcohol per week, and the other half of the sample was made up of light drinkers who consumed between 0 and 10 units of alcohol per week. Of the 40 light drinkers, 9 were non-drinkers. The subjects completed the PMQ and the dysexecutive questionnaire (DEX; Wilson et al., 1996), which Burgess and colleagues (1998) demonstrated to measure five factors: (1) inhibition, (2) intention, (3) executive memory, (4) positive affect, and (5) negative affect. Results showed a significant difference in all measures on the PMQ and DEX between the heavy and light drinking groups except for the PMQ-STRAT subscale. In other words, heavy drinkers reported greater impairments in PM as measured by the PMQ and greater impairments in central EF as measured by the DEX. Heavy drinkers did not report using more strategies to compensate for their memory impairments when compared to light drinkers.

In 2008, Heffernan published a review of the alcohol and PM literature. In this review, Heffernan made the argument that excess alcohol use leads to impaired PM, that impaired PM could have implications for treating substance use in young adults and teenagers, and that there are many directions for future research in this field. Areas for future research included exploring the use of objective measures of PM, clarifying the specific PM deficits in young adults and teenagers caused by binge-drinking, exploring the effects of a pregnant woman drinking on the child's PM, exploring the potential of a benefit to PM when alcohol is consumed in moderation, differentiating the effects of acute as compared to chronic alcohol misuse, exploring the comorbidity and potential interactions of alcohol misuse and other drug use, clarifying the link between PM deficits and other areas of cognition, and exploring the impact of protective factors like PA on PM in chronic heavy alcohol users.

Ling and colleagues (2010) made further advancements in the alcohol use and PM literature. They sought to collect interval as opposed to categorical data for alcohol consumption by asking subjects to report units of alcohol consumed per week rather than asking them to self-categorize into groups based on ranges of units consumed. They also sought to introduce a clinical sample to the literature, specifically individuals in a hospital-based alcohol counseling service. This allowed for a comparison between current, nonclinical heavy alcohol drinkers (current heavy drinkers) and those who had previously consumed significant and potentially harmful amounts of alcohol but had undergone a short period of abstinence (former heavy drinkers). In this study, Ling et al. demonstrated that current heavy drinkers consistently reported the worst PM ability, followed by former heavy drinkers, then the moderate alcohol user group, then the light alcohol user group, then the never used alcohol group. Notably, though, the relationship between alcohol use and scores on the various PMQ subscales did not present linearly. The additional major finding was that the former heavy drinkers displayed some level of cognitive recovery following their period of abstinence. This finding is in line with other research demonstrating that there is a rapid cognitive recovery in alcoholics who abstain from alcohol (Leber et al., 1981; Bartsch et al., 2007).

Most recently, Heffernan and O'Neill (2012) demonstrated that binge drinkers aged 18-35 years experience time-based PM detriments when compared to non-binge drinkers in the same age group. Specifically, binge drinkers were defined as males who drink more than 8 units of alcohol or females who drink more than 6 units of alcohol in one session at least once per week. Like the chronic drinking literature, Heffernan and O'Neill demonstrated that those with PM impairments due to alcohol use lack perception of their detriment. Additionally, this study was the first in the alcohol use literature to use the Prospective-Retrospective Memory Questionnaire (PRMQ; Smith, 2000) as opposed to the PMQ. After Buchanan et al. (2005) brought to light psychometric concerns of the PMQ, specifically that the PMQ-ST and PMQ-IC subscales do not cluster in such a way to measure any latent variable when administered in a web-based format, researchers have largely shifted to the PRMQ. The PRMQ is a 16 item self-report questionnaire with two questions for each type of memory. The type of memory is defined by three domains: prospective or retrospective, self-cued or externally cued, and short-term or long-term delay. In other words, there are two questions assessing prospective, self-cued, short-term delay memory, two questions assessing retrospective, externally cued, long-term delay memory, two questions assessing prospective, externally cued, short-term delay memory, and so on. The PRMQ has reported good reliability for three scales, with Chronbach's alpha coefficients of 0.89, 0.84, and 0.80 for a total memory scale, a PM subscale, and a RM subscale, respectively (Crawford et al., 2003). Four other studies were able to replicate the factorial structure found by Crawford et al. (Crawford et al., 2005; Rönnlund et al., 2008; Piauilino et al., 2010; Hsu & Hua, 2011) but the cue and delay domains have not been found to create any factors that help to explain the data (Crawford et al., 2003; Blondelle et al., 2020).

Interestingly, Heffernan and O'Neill (2012) found no differences between groups on the PRMQ. The time-based PM impairments came to light instead with a standardized, objective measure of PM known as the Cambridge PM Test (CAMPROMPT; Wilson et al., 2005). This test challenges subjects to complete three time-based and three event-based PM tasks in the laboratory setting. While individuals are not allowed to use their own external cues or strategies, each task has multiple cues beyond the first. Scores on each individual task range from 6 (completed correctly with no extra cues) to 0 (failure to complete the task) and the score is calculated separately for the event-based tasks and the time-based tasks. As such, total scores on the CAMPROMPT range from 0-36, with a maximum score of 18 for each subscale. The difference in the time-based subscale of the CAMPROMPT between binge drinkers and non-binge drinkers was significant, as was the difference in the total CAMPROMPT score between groups. Event-based PM revealed no significant difference based on this study's results.

Other important studies in this area include the work by Zamroziewicz and colleagues (2017) and the meta-analysis by Platt and colleagues (2019). Zamroziewicz et al. surveyed 123 third and fourth-year college students on their alcohol use as part of the large-scale study Brain and Alcohol Research in College Students (BARCS). Researchers embedded objective time- and event-based PM tasks in the larger testing session, modelled after tasks in the Memory for Intentions Test (MIST; Raskin, 2004). While these tasks were not formally validated, heavy drinkers performed significantly worse on the time-based PM task than nondrinkers. Results also revealed a significant correlation between the number of reported blackouts from alcohol in the previous month and performance on the event-based PM task.

In 2019, Platt and colleagues conducted a meta-analytic review of the effects of licit and illicit drug use on PM. The researchers only considered objective measures of PM, and ultimately included 7 studies in their analysis, with a grand total of N=348 subjects. Analysis showed a significant impairment of event-based PM in heavy alcohol drinkers compared to control groups, with an effect size in the moderate to large range (SMD=-0.69, 95% CI=[-1.09, -0.30]). Heterogeneity was moderate ($I^2$=62%) with no single study contributing more significantly than the others. Only five of these studies assessed time-based PM, and results indicated a large range in effect size (SMD=-0.814, 95% CI=[-1.70, 0.02]). However, Platt et al. reported a high level of heterogeneity that was completely eliminated (i.e., $I^2$=0%) after the removal of one study. The effect size without this study was significant and in the small to moderate range (SMD=-0.43, 95% CI=[-0.72, -0.13]).

Ultimately, researchers have demonstrated impaired PM ability in heavy drinkers and binge drinkers. Based on self-reported strategies, heavy alcohol users do not attempt to compensate despite displaying a PM deficit. As such, other strategies to mitigate PM deficits in heavy alcohol users may be needed.

### Smoking and Prospective Memory

Compared to alcohol use, less exploration has occurred with regards to the impacts of tobacco and nicotine use on PM. To my knowledge, only two published studies to date have examined chronic tobacco and nicotine use relative to PM. Previous reports on cognition and smoking showed mixed results, although it was thought that the improved cognition displayed in some acute smoking studies was potentially just the reversal of abstinence or withdrawal symptoms (Parrott and Garnham, 1998; Williams, 1980). Considering the short-lived effect of nicotine in the blood, and the way that blood nicotine levels vary with inhalation patterns, it is crucial to consider nicotine abstinence when studying smoking (for review, see Parrott, 1998).

With the same sample as Ling et al. (2003), Heffernan et al. (2005) examined 763 individuals' smoking habits and self-reported memory ability with the web-based PMQ and EMQ. Unfortunately, while the study did ask subjects to report if they were currently under the influence of any drugs, it was not clarified if these participants were excluded or statistically controlled for, leaving current nicotine levels in smokers as a potential confounding variable. The 763 subjects were broken into four categories based on smoking habits: nonsmokers (61.3%), light smokers at 1-4 cigarettes per day (10.8%), moderate smokers at 5-14 cigarettes per day (16.5%), or heavy smokers at 15+ cigarettes per day (11.5%). The results of the study showed that heavy smokers reported more lapses in long-term PM than moderate smokers and nonsmokers, and a positive linear dose-response relationship was noted between reported lapses in PM and levels of smoking. An effect size analysis demonstrated that a heavy smoker could be expected to experience 21.59% and 16.46% more PM problems than nonsmokers and moderate smokers, respectively. It was suggested that future research attempt objective measures of PM and include ratings of depression, given that there is a relationship between smoking and clinical depression (Breslau et al., 1992; Hall et al., 1993) as well as a relationship between depression and a person's subjective opinion of their memory abilities (Hendricks et al., 2002).

Heffernan and colleagues (2010) conducted another study on chronic smoking and PM. Since the 2005 study, the psychometric properties of the PMQ had been called into question (Buchanan et al., 2005) and there had been no replication of the PM deficit in smokers using a different questionnaire. As such, Heffernan et al. planned to use the newer, more reliable PRMQ and an objective measure of PM, namely the CAMPROMPT. Heffernan et al. recruited 18 smokers and 22 non-smokers. Results demonstrated that subjects did not report differential lapses on the PRMQ based on smoking status. The smokers performed significantly worse on both subtests within the CAMPROMPT -- event-based and time-based PM -- as well as on CAMPROMPT total scores. This was the case despite participants in the smoking group being asked to smoke directly before involvement in the test to avoid any potential for nicotine withdrawal. Results also showed a negative correlation between the length of smoking in years and scores on the CAMPROMPT. Lastly, Heffernan et al. found no difference in the reported number of strategies used by smokers as measured by the PMQ-STRAT. This, combined with the lack of self-reported lapses, provides some insight that smokers may be unaware of their PM failures, or otherwise not compensating for these deficits.

Ultimately, similar to drinkers, smokers show deficits in PM ability, though these groups do not always report a perceived deficit and do not report using more or fewer strategies than control comparisons. The prevalence of smoking, while continuing to decrease, still sits above 10% for adults aged 18-24 (Levy et al., 2019), and individuals in their early 20s report the highest levels of binge and high-intensity drinking (Patrick et al., 2016). As such, it could prove important to identify other strategies for improving PM ability in these groups. There is potential for regular PA to improve PM ability as chronic PA has been shown to improve other measures of cognition.

Chronic Physical Activity and Cognition

Young adults are at a critical juncture in development, and negative impacts on the brain during this period of life, such as the neurotoxic effects of alcohol and nicotine, could disproportionately impact development and levels of cognitive reserve (Crews & Boettiger, 2009; Jacobus & Tapert, 2013). The potential for regular long-term PA to affect PM in young adults who drink and smoke is based on the pathways shared by the variables (Loprinzi et al., 2018). Specifically, it is well established that chronic PA can positively impact brain structures in the frontal lobe (Guiney & Machado, 2012) and the MTL (Erickson et al., 2010; Bugg & Head, 2011; Griffin et al., 2011). Neuroimaging studies have also implicated activation of the frontal lobe (Burgess et al., 2001; Simons et al., 2006; Kliegel et al., 2008) and the MTL (Gordon et al., 2011) in PM processes. Lastly, heavy alcohol and nicotine use are known to negatively impact the frontal lobe (Wendt & Risberg, 2001; Levin et al., 2005) and heavy alcohol use causes deficits in the MTL (Agartz et al., 1999).

In addition, PM is demonstrated to share similar resources with EF, and working memory in particular (Dobbs & Reeves, 1996; Marsh & Hicks, 1998; Kliegel et al., 2002; West et al., 2006; see also, Heffernan & O'Neill, 2012). Researchers have demonstrated that EF and working memory are impaired in individuals with a history of heavy alcohol use and in individuals with a history of smoking (Mendrek et al., 2006; Glass et al., 2008). Specifically, smokers demonstrated similar working memory ability as nonsmokers when they were tested within an hour of smoking but demonstrated significantly decreased working memory ability when tested after at least 13 hours of abstinence. This observed impairment with abstinence could serve as an obstacle for individuals looking to quit smoking (Mendrek et al., 2006). PA has demonstrated a positive impact on working memory, EF, and other cognitive variables, which could help to moderate the impacts of drinking and smoking on PM ability.

With regards to young adults, an early review reported that higher levels of PA have been associated with better task switching (Guiney & Macahado, 2012). In addition, young adults display an association between fitness level and top-down modulation of attention and control, and similarly to older adults, regular aerobic PA has also been shown to improve young adults' working memory updating (Guiney & Machado, 2012). Further, evidence has demonstrated that chronic PA in young adults is positively associated with EF, specifically inhibition and working memory (Padilla et al., 2014; Pérez et al., 2014).

The impacts of chronic PA on cognitive function in young adults have been reported meta-analytically by multiple groups, including Etnier, Salazar, and colleagues (1997), Etnier, Nowell, and colleagues (2006), Verburgh and colleagues (2013), Roig and colleagues (2013), and Haverkamp and colleagues (2020). In 1997, Etnier and colleagues reported a small effect of chronic PA on cognitive functioning (Hedge's g=0.33, SD=0.58) which consistently decreased with greater experimental rigor. In young adults specifically, chronic PA revealed a moderate effect size (Hedge's g=0.64 for participants aged 18-30 years old). The type of cognitive task was not assessed as a moderator for chronic PA effects in this meta-analysis.

Using meta-regression, Etnier and colleagues (2006) found a small, positive association between PA and cognitive performance across 37 studies (ES=0.34). However, this study also found no support for the hypothesis that cardiovascular fitness can predict cognitive performance. In fact, in young adults, fitness level in cross sectional studies demonstrated a negative relationship with cognitive performance, and fitness was not predictive of cognitive performance in pre- and post-test comparisons.

More recently, Verburgh et al. (2013) found no effect of chronic PA on EF when 5 studies of individuals aged 6-35 years old were analyzed meta-analytically (Cohen's d=0.14, 95% CI=[-0.04, 0.32]). Of these 5 studies, only one used a young adult sample, assessing inhibition and interference in 27 individuals. Stroth et al. (2009) reported a small-to-moderate effect (Cohen's d=0.39; 95% CI=[-0.07, 1.45]). The lack of evidence available for this meta-analysis demonstrates the lack of previous research on the impacts of chronic PA on EF.

Roig and colleagues (2013) reviewed the effects of 19 long-term PA studies on memory meta-analytically. Their results revealed a small but significant effect on memory (SMD=0.15, 95% CI=[0.04, 0.25]). When broken down by memory type, this effect was observed for short-term (SMD=0.15, 95% CI=[0.02, 0.27]) but not long-term (SMD=0.07, 95% CI = [-0.13, 0.26]) RM. There was no study included concerning PM. In this meta-analysis young adults revealed the largest improvement in short-term memory after long-term PA when compared to other age groups, but Roig et al. note that only four long-term PA studies used young adults, with only one assessing long-term memory.

Most recently, Haverkamp and colleagues (2020) meta-analytically reviewed the effects of PA interventions on cognitive outcomes and academic performance in individuals aged 12-30 years. Ultimately, 27 chronic intervention studies were included in the review, with 52 effect sizes reported on cognitive outcomes. The results demonstrated a small-to-moderate effect (Hedge's g=0.36; 95% CI=[0.25, 0.47]) on cognitive outcomes. Considering the specific impacts of EF and working memory on PM ability, it is important to consider these outcomes as well. Thirty-four effect sizes reported for EF and 14 effect sizes reported for working memory culminated in moderate, statistically significant effect sizes (Hedge's g=0.354 and 0.587, respectively). These subcategories reported the two largest effect sizes for chronic PA interventions, lending further credence to the idea that chronic PA could affect PM ability.

Ultimately, researchers have demonstrated that chronic PA is associated with improved cognition, specifically improving EF and working memory. These two variables have demonstrated specific relationships to PM ability, and as such, there is reason to believe that chronic PA could positively impact PM ability.

### Physical Activity and Prospective Memory

While there has been little research on the relationship between PA and PM in particular, emerging research has begun to investigate the potential of a relationship. At present, there are three studies examining the relationship between acute PA and PM and one review article to suggest a potential link between regular PA and PM (Frith et al., 2017; Cuttler et al., 2017; Loprinzi et al., 2018; Green & Loprinzi, 2018). At the present time, it has been demonstrated that performance decreases on PM tasks performed during a bout of aerobic PA but can be enhanced following an acute bout of resistance PA (Cuttler et al., 2017). The other studies of PM in the field were unable to find a relationship between PM and acute PA, though, notably, each suffered from methodological shortcomings that will be discussed in more detail later (Frith et al., 2017; Green & Loprinzi, 2018). To date, no study has been conducted examining the effects of chronic PA behaviors on PM.

In a review, Loprinzi and colleagues (2018) make the argument that regular PA could affect PM through mood state and emotional memory. Unfortunately, no study has assessed the relationship between chronic PA and PM ability; thus far, researchers have only assessed acute PA in relation to PM ability.

The first study to examine this potential relationship was a randomized controlled trial (Frith et al., 2017). Frith and colleagues examined 88 young adults who were randomized into four groups: a control group and groups that performed PA before, during, or after learning. This experiment was conducted to examine the effects of the timing of acute PA on memory in young adults and PM was only a small portion of the study. The task used to examine PM was a time-based task where the participant was supposed to call the researcher 24 hours after the experiment. The scoring of this task was a simple success/failure determined by whether or not the participant called the researcher within 5 minutes of the agreed-upon time. This task reflects a real-world task as opposed to a lab-based task and allows subjects to use strategies to aid performance (e.g., prompts, alarms, notes). It does not consider event-based PM, and it has no assessment of validity or reliability. Frith and colleagues found no difference between groups in PM task success.

Cuttler and colleagues (2017) attempted to expand the PA and PM literature by examining the effects of acute aerobic and resistance PA on PM in 120 young adults. The PM tasks used in this study were the Reminder PM Test and the Red Pen PM Test, both of which assess event-based PM. The Reminder PM Test is considered a test of episodic PM because it only requires execution once. Specifically, participants are told to remind the researcher to send an email to their supervisor after they complete a later cognitive test. Alternatively, the Red Pen PM Test is considered a test of habitual PM because it requires execution multiple times throughout the testing session. Whenever a subsequent cognitive task requires the test subject to write or draw, they are supposed to request a red pen that is hidden in a drawer in between use. The instructions for these tasks were given to the subject early in the testing session, before any PA occurred.

Another PM task was performed during PA, known as the Viral Video PM Test (Cuttler et al., 2017). This task involved watching a viral video during the PA phase (or during seated rest for the control group) and saying the word “animal” whenever an animal appeared on screen. This is also a test of event-based habitual PM, similar to the Red Pen PM Test, but assessed PM during PA.

It is important to take note of the PA bout used in this study (Cuttler et al., 2017). The goal of the bout was to elevate a participant's heart rate to 50-70% of their age-predicted maximum heart rate ($HR_{max}$; as determined by 220-age). If an individual's heart rate went above 70%, they were asked to slow down or rest until heart rate dropped again. While this was reported as a standard indication of moderate-intensity PA, this level of PA would likely be considered closer to light PA for many individuals in this sample. With an average age of 20 years old, the age-predicted $HR_{max}$ would be 200 beats per minute (bpm). Fifty to seventy percent of this would be 100-140 bpm. The Center for Disease Control (CDC) now recommends 64-76% $HR_{max}$ for moderate intensity PA, which would range from 128-152 bpm for a 20-year old (CDC, 2020). The researchers reported an average heart rate of 132.93 bpm in the aerobic group, falling into the CDC's suggested moderate range, but only a heart rate of 121.72 bpm in the resistance group, which is below the moderate range.

Results of the study demonstrated a detrimental effect of aerobic PA on the PM task performed during PA (i.e. the Viral Video PM Test) compared to the control group ($p=0.02$), but a similar effect was not found for resistance PA. The resistance PA group also displayed better performance on the episodic PM task (i.e. the Reminder PM Test) than either the control ($p=0.04$) or aerobic PA ($p<0.01$) group. No significant differences were found between groups on the habitual PM test performed after PA (i.e. the Red Pen PM Test).

Lastly, Green and Loprinzi (2018) explored the effects of 15 minutes of treadmill walking compared to 15 minutes of sitting on PM using the Royal Prince Alfred PM Test (RPA-ProMem test). This test assesses short- and long-term event- and time-based PM and has been found to be valid and reliable (Blondelle et al., 2020). The short-term tasks include the participant telling the researcher about their most recent meal 20 minutes after exercising (time-based) and the participant asking for a personal item back when an alarm goes off in the test room (event-based). The long-term tasks are performed outside of the lab and allow for the use of external cues and strategies (e.g. alarms, notifications, notes; Blondelle et al., 2020). These tasks include the participant calling the researcher when they arrive at home (event-based) and the participant returning an envelope to the researcher's mailbox one week after the testing session (time-based). The scoring of the RPA-ProMem ranges from 0-12 as each task can be scored from 0-3 based on how correct and timely the task was completed. The results of this study demonstrated no effect of acute low-intensity PA on PM in 51 college students.

In summary, while a review from Loprinzi and colleagues (2018) was able to provide reasonable justification for a relationship between regular PA and PM, only one study has found any relationship between acute PA and PM, noting decreased PM performance during an acute bout of aerobic PA and increased PM performance following an acute bout of resistance PA (Cuttler et al., 2017). Two studies found no relationship between acute PA and PM ability. Frith and colleagues (2017) failed to find a relationship using a non-validated PM task scored in a binary fashion that likely lacked sensitivity. Green and Loprinzi (2018) used a 15-minute, low intensity PA bout that may have been insufficient to produce any changes. No study has explored self-reported PM in relation to acute or chronic PA, nor has any study explored objective PM ability in relation to chronic PA.

# CHAPTER III: METHODS

## Participants

Young adults aged 18-35 years old were recruited for this study. Participants were recruited from an undergraduate course at University of North Carolina at Greensboro (UNCG, i.e., KIN 388). Students were required to complete the survey for class but had to give consent for their answers to be used for research. Participants were not compensated for participation in this experiment. Ultimately, 104 students completed the study, and 96 gave permission for their data to be included in the study.

## Design

The study design was a cross-sectional survey. Upon beginning the survey, participants were presented with an informed consent form detailing their involvement in the study and clarifying that participation in the study was on a voluntary basis and could be stopped at any time. Participants were then presented a questionnaire assessing demographic information (i.e., age, gender identity, ethnicity, race, year in school, major, sport participation status) before proceeding into the survey.

The survey used in the present study was created using Qualtrics software. The survey was presented online, which can provide a larger sample with more statistical power, more anonymity in responses leading to an increased willingness to admit to drug use, and increased disclosure with less influence from social desirability bias (Joinson et al., 1999).

## Questionnaires

### International Physical Activity Questionnaire

Participants were asked to report their PA behavior using the International Physical Activity Questionnaire (IPAQ), a questionnaire created by an international group to assess the PA behaviors of adults aged 18-65 which has demonstrated strong reliability and validity in a 12-

country assessment (Craig et al., 2003). Specifically, the English short form was used, which includes 7 questions covering 4 domains: the time spent performing (1) vigorous and (2) moderate activity, (3) walking, and (4) sitting over the past 7 days. Data from the IPAQ was cleaned, assessed for outliers, and truncated according to standard protocol (Ara, 2005). Total scores were calculated continuously as MET*minutes per week (MET*min./wk.) and were divided categorically into Low (not meeting either of the other categories' criteria), Moderate (3 or more days of vigorous PA for at least 20 minutes per day, 5 or more days of moderate PA and/or walking for at least 30 minutes per day, or 5 or more days of PA combining to at least 600 MET-minutes per week), and High (vigorous PA at least 3 days per week and a total of at least 1500 MET-minutes per week or 7 days per week of any intensity PA with a total of at least 3000 MET-minutes per week) active categories for descriptive purposes based on the same standard protocol.

### SUBSTANCE USE QUESTIONNAIRE

Alcohol and smoking behavior were assessed using modified questions from the 2021 Youth Risk Behavior Surveillance (YRBS) System (CDC, 2020). This questionnaire was created to assess health behaviors in US high-school students, is updated yearly by experts in the field, and suggested edits are only made if a majority of YRBS sites approve (CDC, 2020). The YRBS has demonstrated moderate to strong reliability in years past (Brener et al., 2002). For the current study, questions were taken from the following subsections of the survey: cigarette smoking, electronic vapor products (EVPs), other tobacco products, and drinking alcohol. Modifications were made to the questions such that they were appropriate for a young adult sample. Specifically, the answer choices for questions asking about the age at which a behavior was first performed were extended beyond '17 years old or older' to '21 years old or older.' In addition, questions pertaining to the means through which tobacco products and alcohol were obtained were omitted from the questionnaire. Lastly, a question was added that drew from the other drug questions of the YRBS System to assess other drug use. Questions pertaining to marijuana, synthetic marijuana, prescription medication misuse, cocaine, inhalants, heroin, methamphetamines, ecstasy, and illegal injectable drugs were combined into a single question with answer choices including 'yes,' 'no,' and 'prefer not to answer.'

Additional questions assessing the dose level of EVP use were asked that did not stem from the YRBS System. These included questions used to assess nicotine levels in EVPs (Hyland et al., 2017) and questions used to assess the frequency of EVP use on a given day (Weaver et al., 2017).

Participants were informed that none of their survey answers would be disclosed for any reason, that their names would not be matched to their survey responses, and that any question could be skipped if the participant felt uncomfortable providing an answer.

### Beck Depression Inventory

Young adults with Major Depressive Disorder (MDD) display cognitive impairments when compared to young adults without MDD, particularly in the domain of EF (Castaneda, 2008). Further, depressive symptoms are a known risk factor for Mild Cognitive Impairment (MCI) and general cognitive decline (Barnes et al., 2006; Ganguli et al., 2006). As such, participants' depressive symptom severity was assessed using the Beck Depression Inventory (BDI). The BDI is a 21-item, self-report rating of depression (Beck et al., 1961). Internal consistency for the BDI is high, with alpha coefficients of 0.86 and 0.81 for psychiatric and non-psychiatric populations respectively (Beck et al., 1988). Each item is scored on a scale of 0-3 for a potential total of 63. BDI scores were categorized as Minimal (0-9), Mild (10-18), Moderate (19-29), and Severe (30-63) for descriptive purposes. Resources including the school psychology clinic were provided in case students wanted to speak with a professional regarding substance use or depression.

### Prospective-Retrospective Memory Questionnaire

Participants were asked to report PM and RM ability using the Prospective-Retrospective Memory Questionnaire (PRMQ; Smith et al., 2000). The PRMQ is a 16 item self-report questionnaire with eight questions each assessing PM and RM ability. The PRMQ has demonstrated strong reliability for three subscales, with Chronbach's alpha coefficients of 0.89, 0.84, and 0.80 for a total memory scale, a PM subscale, and a RM subscale, respectively (Crawford et al., 2003). The PM and RM subscale both consist of 8 items scored 1-5 on a Likert scale, with higher scores representing stronger memory ability and less frequent memory errors.

Statistical Analysis

Statistical analyses were conducted using IBM SPSS Statistics Version 27. Independent variables included history of alcohol use (yes/no); days of alcohol consumption and days of binge drinking over the past 30 days; age at which alcohol consumption began; history of cigarette smoking (yes/no); age at which smoking began; history of EVP use (yes/no); days of EVP use, occasions per day of EVP use, and puffs per occasion of EVP use, all over the past 30 days; and self-reported PA levels. Dependent variables include subjective reports of PM ability and RM ability. Demographic variables including age, gender, ethnicity, race, year and major in school, body mass index (BMI), and depression levels were examined and, where necessary, were included as covariates. Other variables that were explored include other tobacco product use, other drug use, and sedentary time. While analyses were planned for days smoked and cigarettes per day over the past 30 days, only 4 participants reported having used a cigarette in the past 30 days, and thus these analyses were dropped.

Researchers confirmed that groups did not differ on any demographic information prior to conducting statistical analyses. Researchers conducted regression analyses to examine the impacts of alcohol use, EVP use, and PA on PRMQ scores. Models included PRMQ scores as the dependent variable and substance use (alcohol consumption, binge drinking, and EVP use), PA, and the interactions of PA and substance use variables as independent variables. It was expected that PA would interact with substance use behaviors such that greater variance would be explained by the models including PA than by those without PA. Unless otherwise noted, all results are considered with a significance level of $\alpha=0.05$.

# CHAPTER IV: RESULTS

Ninety-six individuals gave consent to be included in the analysis. Demographic characteristics of the sample are detailed in Table 1. The sample was made up of 43.8% males (n=42) and 56.3% females (n=54). No other gender identity was reported in the sample, though options included 'transman,' 'transwoman,' and 'other.' As such, it is probably safe to assume that gender identity is equivalent to biological sex in this sample. The sample was mostly junior and senior undergraduate students (35.4% and 49%; n=34 and 47, respectively). White and black racial categories were the most common (38.5% and 47.9%; n=37 and 46, respectively). Over 90% of the sample consisted of Kinesiology majors (n=91) and 71.9% of the sample was not participating in organized sport of any kind (n=69). Tests of demographic information and PRMQ scores were conducted and a significant correlation was observed for both PRMQ subscales with BDI total score. An independent samples t-test found a difference in PM subscale score based on gender identity ($t(94)=2.155$, $p<0.05$), but the same difference was not observed for RM subscale score ($t(94)=0.937$, $p>0.05$). No other demographic variables influenced scores on the PRMQ. As such, gender and BDI total score were included as covariates on further analyses of the PM subscale and BDI total score was included as a covariate on further analyses of the RM subscale where applicable.

Table 1. Demographic Information

| | | N | % | | | N | % |
|---|---|---|---|---|---|---|---|
| **Gender Identity** | Man | 42 | 43.8% | **Year in School** | Freshman | 4 | 4.2% |
| | Woman | 54 | 56.3% | | Sophomore | 11 | 11.5% |
| **Spanish, Hispanic, or Latino Origin** | Yes | 8 | 8.3% | | Junior | 34 | 35.4% |
| | No | 88 | 91.7% | | Senior | 47 | 49% |
| **Race** | White | 37 | 38.5% | **Major** | Kinesiology | 91 | 94.8% |
| | Black or African American | 46 | 47.9% | | Other | 5 | 5.2% |
| | American Indian or Alaska Native | 1 | 1% | **Sport Participation** | Varsity athlete | 10 | 10.4% |
| | Asian | 4 | 4.2% | | Recreational athlete | 17 | 17.7% |

| | | N | % | | | N | % |
|---|---|---|---|---|---|---|---|
| **Race (cont.)** | Other | 3 | 3.1% | **Sport Participation (cont.)** | No organized sports | 69 | 71.9 |
| | Missing | 5 | 5.2% | **BDI Category** | Minimal | 73 | 76% |
| | | | | | Mild | 15 | 15.6% |
| | | | | | Moderate | 6 | 6.3% |
| | | | | | Severe | 2 | 2.1% |

Body Mass Index

Participants reported height in inches and weight in pounds. Height in inches was converted to height in meters (m) and weight in pounds was converted to weight in kilograms (kg). BMI was calculated as kg/m$^2$. The sample was categorized by BMI as underweight (less than 18.5 kg/m$^2$), healthy weight (between 18.5 and 24.9 kg/m$^2$), overweight (between 25 and 29.9 kg/m$^2$), or obese (30 kg/m$^2$ or greater). Of the 92 participants who provided height and weight, 12.5% were classified as obese (n=12), 37.5% were overweight (n=36), and 44.8% were normal or healthy weight (n=43). BMI statistics can be found in Table 2.

Table 2. Body Mass Index Categories

| | N | % |
|---|---|---|
| **Underweight (<18.5 kg/m$^2$)** | 1 | 1% |
| **Healthy Weight (18.5-24.9 kg/m$^2$)** | 43 | 44.8% |
| **Overweight (25.0-29.9 kg/m$^2$)** | 36 | 37.5% |
| **Obese (≥30.0 kg/m$^2$)** | 12 | 12.5% |
| **Missing** | 4 | 4.2% |

Physical Activity

In this sample, 76% of subjects were considered highly active by categories as determined by the IPAQ (n=73). Only 5.2% of participants were considered low active (n=5), with the moderate activity group making up the rest of the sample (18.8%; n=18). This means that the PA data had a low level of variance ($\sigma^2$=0.314).

Table 3. IPAQ Categories

| | N | % |
|---|---|---|
| **Low** | 5 | 5.2% |
| **Moderate** | 18 | 18.8% |
| **High** | 73 | 76% |

<u>Substance Use</u>

Substance use results are detailed in Appendix A. Independent samples T-tests confirmed that there was no difference in scores between those who had used other drugs and those who had not on either the PM subscale ($t(94)=-0.629$, $p=0.531$) or the RM subscale ($t(94)=-0.7$, $p=0.486$). As such, the use of other drugs was not included as a covariate on any further analyses.

For the purposes of this study, categorical variables of substance use were created (see Table 4) with a goal of creating categories that were meaningful (top priority) and had cell sizes that were as equal as possible. For alcohol consumption, the 'no alcohol' group consisted of those who had not consumed an alcoholic drink in the past 30 days, the 'light alcohol' group consisted of those who had consumed alcohol on 1 to 5 days of the past 30, and the 'regular alcohol' group consisted of those who had consumed alcohol on 6 or more days of the past 30. For binge drinking (defined as consuming 4 or more drinks or 5 or more drinks in a short period of time for women and men, respectively), the 'no binge' group included those who had not binge drunk in the past 30 days, the 'infrequent' group included those who had binge drunk just 1 or 2 days of the past 30, and the 'frequent' group included those who had binge drunk on 3 or more days of the past 30.

Behaviors involving the use of an electronic vapor product (EVP) were separated into 3 categories: no EVP, light EVP, and regular EVP. The number of EVP 'puffs' in the past 30 days was calculated by multiplying the number of days an EVP was used in the last 30, the number of occasions an EVP was used per day, and the number of puffs taken from the EVP per occasion. The number of puffs in the past 30 days was analyzed and broken into 3 groups, no EVP for those who had not used an EVP in the past 30 days (n=78), light EVP for those with a composite score below the median value of the remaining subjects (n=9), and regular EVP for those with a composite score above the median value (n=9).

Table 4. Substance Use Categorization

| | | N | % |
|---|---|---|---|
| **Alcohol Category** | No alcohol | 36 | 37.5% |
| | Light alcohol | 41 | 42.7% |
| | Regular alcohol | 19 | 19.8% |
| **Binge Drinking Category** | No binge | 61 | 63.5% |
| | Infrequent | 22 | 22.9% |
| | Frequent | 13 | 13.5% |
| **Smoked a cigarette in the past 30 days** | No | 92 | 95.8% |
| | Yes | 4 | 4.2% |
| **EVP Category** | No EVP | 78 | 81.3% |
| | Light EVP | 9 | 9.4% |
| | Regular EVP | 9 | 9.4% |

Hypothesis 1

The first hypothesis was that young adults with any history of drinking or smoking would have lower levels of PM than those who had never drunk or smoked. To assess the first hypothesis, a multivariate analysis of covariance (MANCOVA) was performed comparing scores on the two PRMQ subscales based on whether a subject had ever drunk alcohol, smoked a cigarette, or used an EVP. There was no significant difference in PRMQ-PM scores based on whether a participant had drunk ($F(1, 87)=0.018$, $p=0.895$), smoked ($F(1,87)=0.172$, $p=0.679$), or used an EVP ($F(1, 87)=0.061$, $p=0.805$). Similarly, no difference was found for PRMQ-RM scores based on whether a participant had drunk ($F(1, 87)=0.607$, $p=0.438$), smoked ($F(1, 87)=0.507$, $p=0.478$), or used an EVP ($F(1, 87)=0.347$, $p=0.558$).

Hypothesis 2

The second hypothesis was that young adults who report excessive drinking or smoking would report lower levels of PM as compared to non-substance users and low-intensity users. To assess the second hypothesis, a MANCOVA was performed to assess differences in PRMQ scores for each substance use variable.

The PRMQ-PM scores were not different based on a participant's group for alcohol use ($F(2,78)=0.694$, $p=0.503$), binge drinking ($F(2,78)=0.931$, $p=0.398$), or EVP use ($F(2, 78)=0.407$, $p=0.667$). Similarly, no difference was found between groups for PRMQ-RM scores based on alcohol use ($F(2, 78)=0.10$, $p=0.990$), binge drinking ($F(2,78)=0.2785$, $p=0.068$), or EVP use ($F(2, 78)=1.614$, $p=0.206$).

Hypothesis 3

The third hypothesis was that young adults' PM ability would correlate positively with the age that substance use began. To assess the third hypothesis, correlations were assessed between both PRMQ subscales, the age of first drink, and the age of first cigarette, including only those participants who had reported having drunk or smoked in the past. The correlations can be seen in Table 3. Age of first drink (n=77) did not correlate significantly with the score on the PM subscale ($r=0.026$, $p=0.824$) or the score on the RM subscale ($r=0.014$, $p=0.903$). Age of first cigarette (n=28) did not correlate significantly, but showed a trend toward significance, with the score on the PM subscale ($r=0.335$, $p=0.081$; Figure 1) and the score on the RM subscale ($r=0.361$, $p=0.059$; Figure 2). The age of first cigarette demonstrated a weak positive relationship with scores on both the PM and RM subscale; as the age of first cigarette increased (onset occurred at an older age), so did scores on the PM and RM subscales.

Table 5. Age Correlations

| | | **PRMQ-PM** | **PRMQ-RM** |
|---|---|---|---|
| **Age of first drink** | Pearson Correlation | 0.026 | 0.014 |
| | Sig. (2-tailed) | 0.824 | 0.903 |
| | N | 77 | 77 |
| **Age of first cigarette** | Pearson Correlation | 0.335 | 0.361 |
| | Sig. (2-tailed) | 0.081 | 0.059 |
| | N | 28 | 28 |

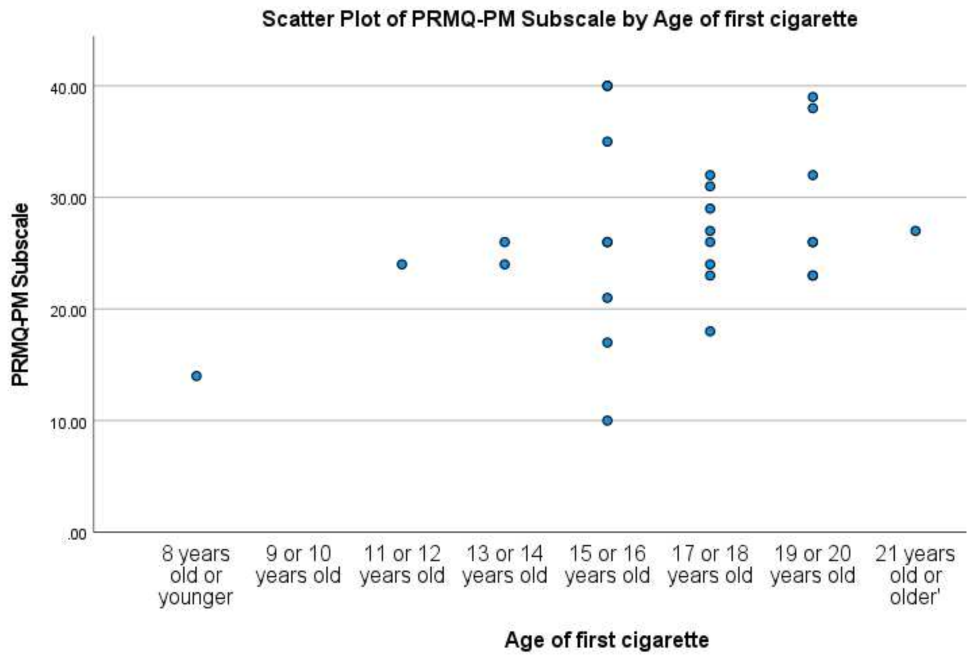


Figure 1. PM-Cigarette Age Correlation

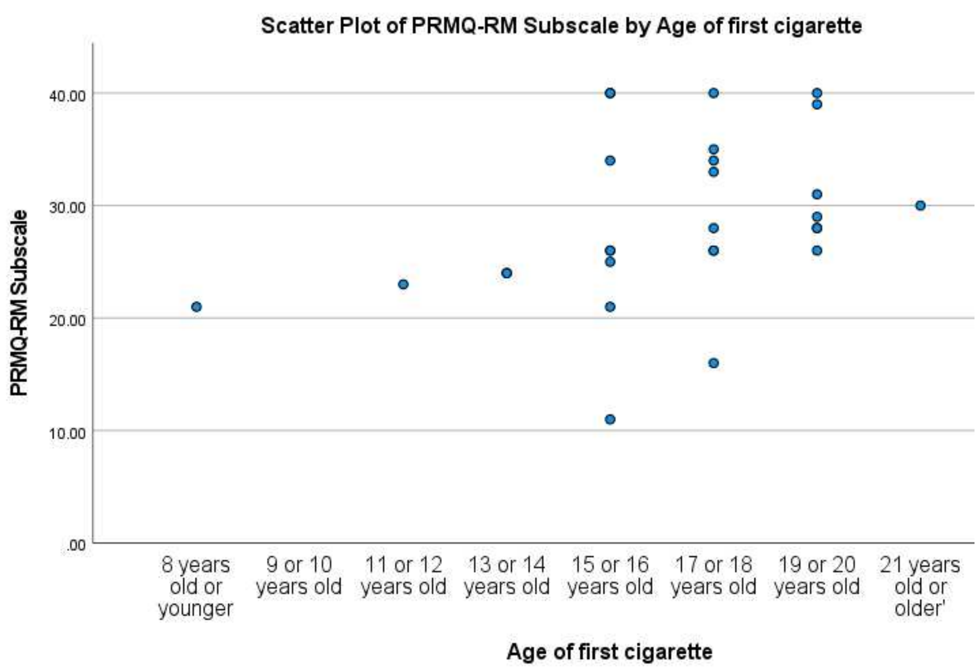


Figure 2. RM-Cigarette Age Correlation

Hypothesis 4

The fourth hypothesis was that young adults with higher levels of PA would self-report better PM ability compared to young adults with lower levels of PA. A correlation was performed for each of the PRMQ scales and the continuous variable of PA measured as MET-minutes per week. As can be seen in Table 4, no significant correlations were found. Total PA (n=96) was not correlated with the PM subscale (r=-0.003, p=0.976) or the RM subscale (r=0.034, p=0.743).

Table 6. Physical Activity Correlations

| | | **PRMQ-PM** | **PRMQ-RM** |
|---|---|---|---|
| **Total PA (MET-minutes per week)** | Pearson Correlation | -0.003 | 0.034 |
| | Sig. (2-tailed) | 0.976 | 0.743 |
| | N | 96 | 96 |

Hypothesis 5

The fifth hypothesis was that levels of PA and substance use would interact to predict PM such that substance users with higher levels of PA would display better PM ability than substance users with lower levels of PA. To assess the fifth hypothesis, hierarchical regression analyses were performed for each of the three substance use variables (alcohol group, binge drinking category, and EVP category) with dependent variables including the scores of both PRMQ subscales. Models included:

1. BDI total score, gender identity (PM only)
2. Model 1 plus total PA (MET-minutes per week)
3. Model 2 plus substance use group
4. Model 3 plus total PA*substance use group

PROSPECTIVE-RETROSPECTIVE MEMORY QUESTIONNAIRE-PROSPECTIVE MEMORY SUBSCALE

The model summaries for all regressions using the dependent variable PRMQ-PM subscale are available in Table 5.

Models 1 and 2

In all substance use categories, Models 1 and 2 were the same. Model 1 ($F(2, 93)=6.119$, $p<0.01$) was significant, while Model 2 was not. Model 1 accounted for 11.6% of the variance in PM subscale scores, and BDI total score was the only significant predictor ($\beta=-0.265$, $p<0.01$). Model 1 can be seen in Figure 3. This relationship indicates that PM ability decreased as depressive symptom severity increased. Model 2's lack of significance shows no significant main effect of total PA on PRMQ-PM subscale scores.

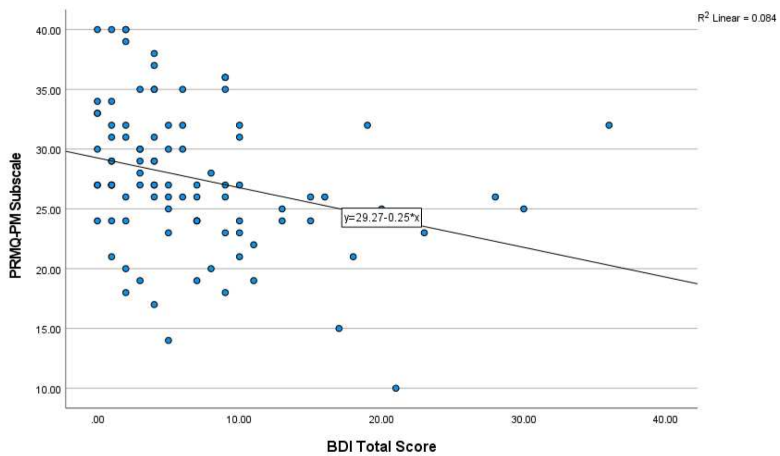


Figure 3. BDI-PM Subscale Regression

Model 3

In each regression, substance use was entered in Model 3 to test for main effects. No substance use category had a significant $R^2$ change for Model 3.

Model 4

In each regression, the total PA*substance use group interaction was entered in Model 4. The results of the interaction varied depending on the type of substance.

*Alcohol Group*

Model 4 did not significantly change the $R^2$ of the regression when examining the total PA*alcohol group interaction.

*Binge Drinking Category*

When examining binge drinking, Model 4 ($F(5, 90)=3.254$, $p=0.01$), including BDI total score, gender identity, total PA (MET*min./wk.), binge drinking category, and the total PA*binge drinking interaction, revealed a trend towards significance ($R^2_{change}=0.034$, $F_{change}(1, 90)=3.644$, $p=0.059$). In this model, BDI total score was a significant predictor ($\beta=-0.236$, $p<0.05$) and the total PA*binge drinking interaction approached significance ($\beta=-0.529$, $p=0.059$). The interaction can be seen in Figure 4. This relationship indicates that non-binge drinkers experienced an increase in PM ability with greater levels of PA while both frequent and infrequent binge drinkers experienced a decrease in PM ability with greater levels of PA.

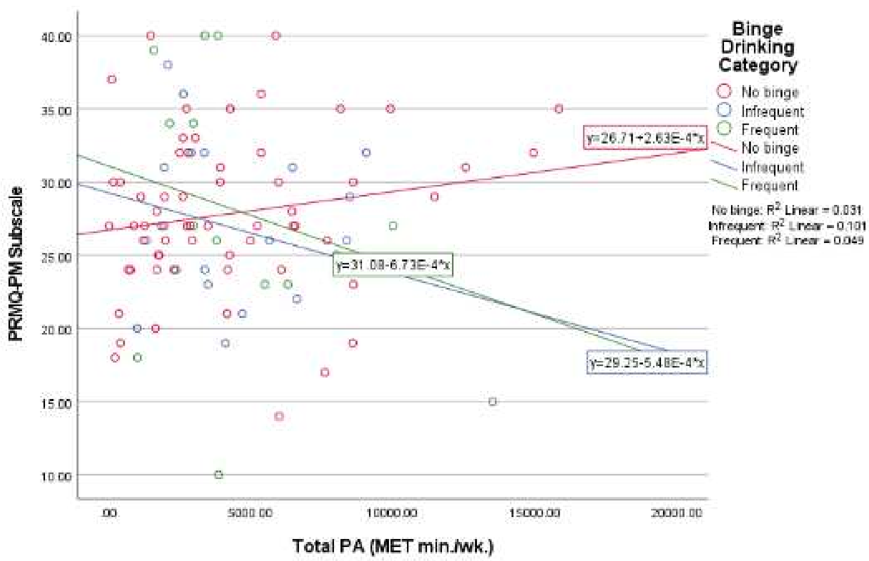


Figure 4. Total PA*Binge Drinking Interaction

*EVP Category*

Model 4 did not significantly change the $R^2$ of the regression when examining the total PA*EVP category interaction.

Table 7. PRMQ-PM Subscale Regression Model Summaries

| **Model** | **R** | **$R^2$** | **Adj. $R^2$** | **Std. Error of the Estimate** | **Change Statistics** | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | **$R^2$ change** | **F change** | ***df*1** | ***df*2** | **Sig. F change** |
| **1** | 0.341 | 0.116 | 0.097 | 5.714 | 0.116 | 6.119 | 2 | 93 | 0.003 |
| **2** | 0.343 | 0.118 | 0.089 | 5.740 | 0.001 | 0.148 | 1 | 92 | 0.701 |
| **3-alc** | 0.359 | 0.129 | 0.091 | 5.734 | 0.011 | 1.191 | 1 | 91 | 0.278 |
| **4-alc** | 0.359 | 0.129 | 0.081 | 5.766 | 0 | 0.014 | 1 | 90 | 0.907 |
| **3-binge** | 0.345 | 0.119 | 0.080 | 5.768 | 0.001 | 0.113 | 1 | 91 | 0.738 |
| **4-binge** | 0.391 | 0.153 | 0.106 | 5.686 | 0.034 | 3.644 | 1 | 90 | 0.059 |
| **3-EVP** | 0.345 | 0.119 | 0.080 | 5.768 | 0.001 | 0.119 | 1 | 91 | 0.731 |
| **4-EVP** | 0.348 | 0.121 | 0.072 | 5.792 | 0.002 | 0.222 | 1 | 90 | 0.639 |

PROSPECTIVE-RETROSPECTIVE MEMORY QUESTIONNAIRE-RETROSPECTIVE MEMORY SUBSCALE

The model summaries for all regressions using the dependent variable PRMQ-RM subscale are available in Table 6.

Models 1 and 2

In all substance use categories, Models 1 and 2 were the same. Model 1 ($F(2, 93)=5.494$, $p<0.01$) was significant, while Model 2 was not. Model 1 accounted for 10.3% of the variance in RM subscale scores, and BDI total score was a significant predictor ($\beta=-0.321$, $p<0.01$; see Figure 5). This relationship indicates that RM ability decreased as depressive symptom severity increased. Model 2's lack of significance shows no significant main effect of total PA on PRMQ-RM subscale scores.

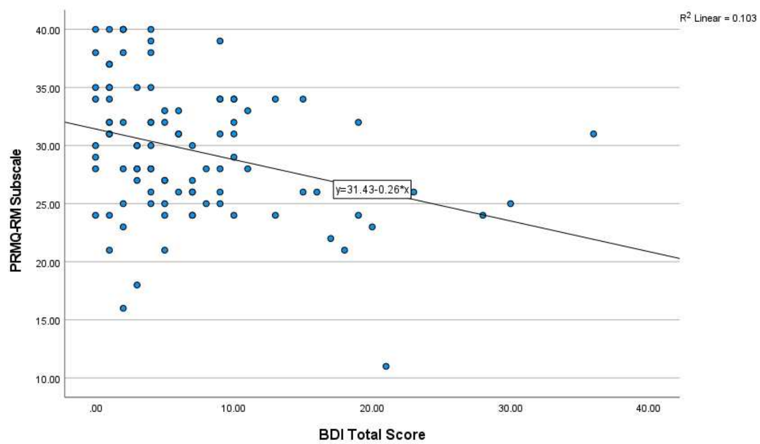


Figure 5. BDI-RM Subscale Regression

Models 3 and 4

In each regression, substance use was entered in Model 3 to test for main effects. No substance use variable's main effect resulted in a significant change in $R^2$. In each regression, the total PA*substance use group interaction was entered in Model 4. The results of the interaction were not significant for any of the substance use variables.

Table 8. PRMQ-RM Subscale Regression Model Summaries

| **Model** | **R** | **$R^2$** | **Adj. $R^2$** | **Std. Error of the Estimate** | **Change Statistics** | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | **$R^2$ change** | **F change** | ***df* 1** | ***df* 2** | **Sig. F change** |
| **1** | 0.321 | 0.103 | 0.093 | 5.474 | 0.103 | 10.762 | 1 | 94 | 0.001 |
| **2** | 0.325 | 0.106 | 0.086 | 5.494 | 0.003 | 0.307 | 1 | 93 | 0.581 |
| **3-alc** | 0.331 | 0.109 | 0.080 | 5.512 | 0.004 | 0.382 | 1 | 92 | 0.538 |
| **4-alc** | 0.348 | 0.121 | 0.083 | 5.505 | 0.012 | 1.245 | 1 | 91 | 0.267 |
| **3-binge** | 0.335 | 0.113 | 0.084 | 5.503 | 0.007 | 0.710 | 1 | 92 | 0.402 |
| **4-binge** | 0.337 | 0.114 | 0.075 | 5.528 | 0.001 | 0.140 | 1 | 91 | 0.709 |
| **3-EVP** | 0.328 | 0.107 | 0.078 | 5.518 | 0.002 | 0.179 | 1 | 92 | 0.673 |
| **4-EVP** | 0.337 | 0.114 | 0.075 | 5.529 | 0.006 | 0.629 | 1 | 91 | 0.430 |

# CHAPTER V: DISCUSSION

The purpose of this study was to explore the relationships of PA and substance use to PM ability. There is evidence to demonstrate impaired PM ability in heavy substance users (Heffernan et al., 2002; Heffernan et al., 2004; Heffernan et al., 2005; Heffernan, 2008; Heffernan, Clark, et al., 2010; Heffernan, Moss, and O'Neill, 2010; Heffernan & O'Neill, 2012; Ling et al., 2003; Ling et al., 2010). Notably, these groups with impaired PM do not use strategies to compensate for their faltering memory. Considering this, it may prove essential to determine other ways to preserve or otherwise enhance PM in heavy substance users. There is reason to believe that chronic PA could help to alleviate impaired PM ability in heavy substance users (for review, see Loprinzi et al., 2018).

The present study employed online questionnaires to assess PA levels, substance use behaviors, and subjective PM ability. Ninety-six undergraduate students provided sufficient data for analysis. Statistical methods including MANCOVA and hierarchical regression were used to compare self-reported PM ability between substance use and PA groups and to assess the interactions of PA and substance use behaviors on PM ability.

In the sample of 96 undergraduate students, only 5 were majors other than Kinesiology. This means that 94.8% of the sample was studying Kinesiology. Further, 12.5% of the sample was obese, compared to normal rates of about 40% in US adults aged 20 to 39 years (CDC, 2021). Variance in reported substance use behavior was low, meaning that substance use had to be broken into larger, broader categories. A surprisingly small number of participants had smoked cigarettes in the past 30 days, most of the participants that reported drinking drank infrequently, and while EVP use was more common (almost 20% of participants reported using an EVP in the past 30 days), most participants who reported EVP use selected that they did so only on occasion. PA variances were similarly low; the sample was, by majority, highly active (76%). This proportion is higher than, but may not be far off from, the population average. Bauman and colleagues (2009) found that 62% of about 4,500 US adults aged 18-65 reported being highly active by IPAQ standards.

No difference was found for PRMQ scores based on alcohol use, binge drinking, or EVP use. The reported age of a participant's first drink did not correlate with self-reported PM ability. In addition, no relationship was found between PRMQ scores and total PA. There was an observed trend toward significance, however, for the correlation of the reported age of a participant's first cigarette and self-reported PM ability. Results demonstrate that PM ability increases as the age of first cigarette increases. The brain is more plastic in adolescence (Fuhrmann et al., 2015), and thus it stands to reason that negative lifestyle choices earlier in life would influence the brain more dramatically. There is evidence to demonstrate that the adolescent brain is impacted differently by nicotine than adults, and that aberrant activation of nicotinic acetylcholine receptors (nAChRs) in adolescence may cause lasting changes in neuronal signaling that could impact cognition (Yuan et al., 2015). As such, the brain development of an individual who smokes a cigarette at a younger age could be more impacted than an individual who smokes at an older age. Additionally, an individual who starts smoking at an earlier age could have become more reliant on nicotine when compared to an individual who started smoking at a later age. This would mean that the effects of nicotine abstinence would be more noticeable for an individual who started smoking at an earlier age. Nicotine abstinence is known to cause impaired EF, and considering the relationship between EF and PM, the effects of abstinence would likely cause decreased PM performance. The results provide further evidence of the benefits of delaying age of onset for negative health behaviors as much as possible.

The hierarchical regression revealed that BDI score was a significant predictor of scores on the PRMQ, such that higher scores on the BDI were related to lower scores on the PRMQ; interestingly, lower scores on the PRMQ represent weaker memory ability and more frequent memory errors. This means that stronger depressive symptomology as reported on the BDI was related to impaired memory ability. This is in line with previous research in young adults, which has demonstrated impaired cognitive ability in those with depression (Castaneda et al., 2008).

On the PM subscale, no main effects from PA or from any substance use variable were observed. Previous findings on the relationship between self-reported PM ability and substance use demonstrate a consistent detriment in PM ability for alcohol and cigarette users. This contradiction could likely be explained by the low power of this study (due to low variance in PA and substance use behavior variables) to detect changes in self-reported PM ability.

Alternatively, PA's interaction with binge drinking helped to predict scores on the PM subscale. While the interaction was not significant, it showed a trend toward significance such that binge drinkers with higher levels of PA reported more frequent PM errors than binge drinkers with lower levels of PA. The same trend was not observed for non-substance users. The significant interaction of PA and binge drinking on the PM subscale demonstrates that higher levels of PA are associated with higher self-reported PM ability for non-binge drinkers; alternatively, higher levels of PA are associated with lower self-report PM ability in binge drinkers. The interaction provides evidence that the positive relationship between PA and PM ability may not be observed if an individual also performs binge drinking behaviors. More physically active binge drinkers had worse PM ability than less physically active binge drinkers. Speculatively, this could relate to the nature of PA and binge drinking behaviors. Einstein and colleagues (2005) demonstrated that PM ability can be improved or impaired depending on the nature of other ongoing tasks and the focal status of the PM task. Both binge drinking and PA are behaviors that take time to perform; the time spent on these ongoing behaviors could be replacing intended actions that are thusly not performed. There could also be a relation to the focal status of the PM task. Individuals who perform binge drinking behaviors and PA may be devoting cognitive resources to these behaviors and may not have cognitive resources available to focus on the PM task. The interaction effect was nonsignificant for alcohol consumption in the past 30 days and for EVP use in the past 30 days. This could also be due to low levels of variability in substance use and PA behaviors. Alternatively, PA may not influence the relationship between PM subscale scores and alcohol drinking or EVP behavior in any noteworthy way.

On the other hand, no substance use variable was significantly related to scores on the RM subscale. This may be due to the specific effect of substance use on EF. PM is more reliant on EF than RM is, and substance use behaviors are known to specifically relate to EF in young adults (Mendrek et al., 2006; Glass et al., 2008).

The results largely contradict what would be expected based on the cognitive reserve (CR) hypothesis. The CR hypothesis (Stern, 2002, 2009) states that every individual has a cognitive reserve fueled by lifestyle factors such as substance use and PA. Based on the CR hypothesis, substance use would be expected to decrease an individual's reserve; evidence demonstrates that excess alcohol use can cause brain shrinkage (Kril & Halliday, 2004) and cigarette smoking can result in brain atrophy and biological and structural abnormalities in the brain (Durazzo et al., 2010). PA would be expected to increase reserve as it can help to preserve brain size (Benedict et al., 2013), stimulate hippocampal neurogenesis (Brown et al., 2003), and preserve neuronal structural integrity (Cheng, 2016). As such, based on the CR hypothesis, it was expected that the decreased reserve related to substance use could be compensated by the increased reserve of PA. If this were the case, low active substance users would have the least reserve and, in turn, the worst cognitive ability (i.e., memory). This would be followed by high active substance users and low active non-substance users, who would have moderate reserve and ability, and high active non-substance users would have the most reserve and, in turn, the strongest cognitive ability. The results of the study did not match this expectation; however, the observed interaction between PA and binge drinking could be explained in part by the CR hypothesis. It is possible that the expected increase in reserve from PA behaviors is overshadowed by the decrease in reserve associated with binge drinking. Alternatively, binge drinking could serve as a blocking mechanism for the increased reserve benefit associated with PA.

Based on the findings of the present study, PA may have some potential to interact with substance use to influence an individual's memory ability. When an individual reported binge drinking, they did not experience the positive relationship between PA and PM ability that was observed in non-binge drinkers. From a practical perspective, these results provide evidence that binge drinking behaviors can limit the positive impacts of PA on PM ability. Educating binge drinkers on this impact could help to encourage positive behavior change through cessation of binge drinking. On the other hand, the results could help explain why some people choose not to perform PA. An individual who sees no benefit from PA (such as a binge drinker) may see no reason to continue the behavior. From the other perspective, the results of the study could be used to educate those who are currently physically active to help prevent the onset of negative health behaviors such as binge drinking.

## Limitations

The present study was not without limitations. Notably, the sample was largely homogenous. Substance use and PA behaviors all had low levels of variability; this may be attributed to the large majority (94.8%) of the sample consisting of Kinesiology majors who may be committed to more healthy lifestyles than students in other majors. In fact, evidence suggests that Kinesiology majors are more likely to engage in healthy behaviors such as PA (Many et al., 2016). In addition, self-report questionnaires were used to assess memory ability; the memory paradox represents the idea that an individual with a poor memory is more likely to forget the frequency of their memory errors. This would lead to an under-reporting effect for memory errors; however, if memory errors are under-reported, this would be more likely to take away from potential significance, rather than adding to it. The study also relied on self-report questionnaires for substance use behaviors. Considering the health science nature of the class, the small number of individuals who would not be legally allowed to engage in the behaviors (i.e., younger than 21 years old), and the peer pressure of taking the survey for a class, substance use behaviors could be biased in any number of ways (peer pressure, trying to say what the researcher is expecting, etc.). In order to mitigate any potential effect, participants were reminded that the research was confidential, results would be de-identified, that researchers were not required to report illegal behavior, and that their survey responses would have no impact on their standing. Lastly, self-report of PA, especially in a class discussing the benefits of PA, could result in inaccurate answers. However, Joinson and colleagues (1999) noted that online questionnaires, like those employed in the present study, result in more open answers and more disclosure with less influence from social desirability bias when compared to paper-and-pencil questionnaires.

## Recommendations for Future Research

Given the low levels of variability and the homogenous nature of the sample, the next step for research would be to expand upon the sample. Including undergraduates from other majors that are less focused on health and the effects of lifestyle could be a potential first step, as this may result in higher levels of variability and greater power to detect differences in PM ability. Further, examining young adults from other universities, non-students in other professions, different cultures, different socioeconomic statuses, and with various diseases and conditions would help to replicate the findings of the current study and improve the generalizability of the results and the practical recommendations that stem from them. In addition, future research could include objective tasks of PM to compare to self-report scores. Ultimately, longitudinal examination of lifestyle behaviors including PA and substance use and their effects on PM could provide strong evidence for PA's protective effect against substance use.

## Conclusion

In conclusion, this study provides the first evidence for a potential interaction between PA and substance use behaviors on the PM ability of substance users. Despite a largely homogenous sample and low levels of variability on assessed behavioral variables, PA interacted with cigarette smoking and binge drinking to help explain scores on the PM subscale of the PRMQ. A main effect was also observed as cigarette smoking helped to explain variance in scores on the RM subscale of the PRMQ.

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APPENDIX A: SUBSTANCE USE DETAILS

Table A1. Ever Used Alcohol

| | | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|---|
| Valid | Yes | 77 | 80.2 | 80.2 | 80.2 |
| | No | 19 | 19.8 | 19.8 | 100.0 |
| | Total | 96 | 100.0 | 100.0 | |

Table A2. Age of First Drink

| | | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|---|
| Valid | 9 or 10 years old | 1 | 1.0 | 1.3 | 1.3 |
| | 11 or 12 years old | 2 | 2.1 | 2.6 | 3.9 |
| | 13 or 14 years old | 6 | 6.3 | 7.8 | 11.7 |
| | 15 or 16 years old | 12 | 12.5 | 15.6 | 27.3 |
| | 17 or 18 years old | 30 | 31.3 | 39.0 | 66.2 |
| | 19 or 20 years old | 17 | 17.7 | 22.1 | 88.3 |
| | 21 years old or older | 9 | 9.4 | 11.7 | 100.0 |
| | Total | 77 | 80.2 | 100.0 | |
| Missing | System | 19 | 19.8 | | |
| Total | | 96 | 100.0 | | |

Table A3. Days of Alcohol in the Past 30

| | | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|---|
| Valid | 0 days | 17 | 17.7 | 22.1 | 22.1 |
| | 1 or 2 days | 29 | 30.2 | 37.7 | 59.7 |
| | 3 to 5 days | 12 | 12.5 | 15.6 | 75.3 |
| | 6 to 9 days | 13 | 13.5 | 16.9 | 92.2 |
| | 10 to 19 days | 5 | 5.2 | 6.5 | 98.7 |

| | | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|---|
| | 20 to 29 days | 1 | 1.0 | 1.3 | 100.0 |
| | Total | 77 | 80.2 | 100.0 | |
| Missing | System | 19 | 19.8 | | |
| Total | | 96 | 100.0 | | |

Table A4. Days of Binge Drinking

| | | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|---|
| Valid | 0 days | 25 | 26.0 | 41.7 | 41.7 |
| | 1 day | 15 | 15.6 | 25.0 | 66.7 |
| | 2 days | 7 | 7.3 | 11.7 | 78.3 |
| | 3 to 5 days | 11 | 11.5 | 18.3 | 96.7 |
| | 6 to 9 days | 2 | 2.1 | 3.3 | 100.0 |
| | Total | 60 | 62.5 | 100.0 | |
| Missing | System | 36 | 37.5 | | |
| Total | | 96 | 100.0 | | |

Table A5. Most Drinks in A Sitting

| | | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|---|
| Valid | 1 or 2 drinks | 25 | 26.0 | 41.7 | 41.7 |
| | 3 drinks | 8 | 8.3 | 13.3 | 55.0 |
| | 4 drinks | 5 | 5.2 | 8.3 | 63.3 |
| | 5 drinks | 10 | 10.4 | 16.7 | 80.0 |
| | 6 or 7 drinks | 7 | 7.3 | 11.7 | 91.7 |
| | 8 or 9 drinks | 3 | 3.1 | 5.0 | 96.7 |
| | 10 or more drinks | 2 | 2.1 | 3.3 | 100.0 |
| | Total | 60 | 62.5 | 100.0 | |
| Missing | System | 36 | 37.5 | | |
| Total | | 96 | 100.0 | | |

Table A6. Ever Smoked

| | | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|---|
| Valid | Yes | 28 | 29.2 | 29.2 | 29.2 |
| | No | 68 | 70.8 | 70.8 | 100.0 |
| | Total | 96 | 100.0 | 100.0 | |

Table A7. Age of First Smoke

| | | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|---|
| Valid | 8 years old or younger | 1 | 1.0 | 3.6 | 3.6 |
| | 11 or 12 years old | 1 | 1.0 | 3.6 | 7.1 |
| | 13 or 14 years old | 2 | 2.1 | 7.1 | 14.3 |
| | 15 or 16 years old | 8 | 8.3 | 28.6 | 42.9 |
| | 17 or 18 years old | 8 | 8.3 | 28.6 | 71.4 |
| | 19 or 20 years old | 7 | 7.3 | 25.0 | 96.4 |
| | 21 years old or older | 1 | 1.0 | 3.6 | 100.0 |
| | Total | 28 | 29.2 | 100.0 | |
| Missing | System | 68 | 70.8 | | |
| Total | | 96 | 100.0 | | |

Table A8. Days of Cigarettes

| | | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|---|
| Valid | 0 days | 24 | 25.0 | 85.7 | 85.7 |
| | 1 or 2 days | 2 | 2.1 | 7.1 | 92.9 |
| | 3 to 5 days | 1 | 1.0 | 3.6 | 96.4 |
| | All 30 days | 1 | 1.0 | 3.6 | 100.0 |
| | Total | 28 | 29.2 | 100.0 | |
| Missing | System | 68 | 70.8 | | |
| Total | | 96 | 100.0 | | |

Table A9. Cigarettes/Day

| | | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|---|
| Valid | Less than 1 | 24 | 25.0 | 85.7 | 85.7 |
| | 1 | 3 | 3.1 | 10.7 | 96.4 |
| | 11 to 20 | 1 | 1.0 | 3.6 | 100.0 |
| | Total | 28 | 29.2 | 100.0 | |
| Missing | System | 68 | 70.8 | | |
| Total | | 96 | 100.0 | | |

Table A10. Ever Used EVP

| | | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|---|
| Valid | Yes | 44 | 45.8 | 45.8 | 45.8 |
| | No | 52 | 54.2 | 54.2 | 100.0 |
| | Total | 96 | 100.0 | 100.0 | |

Table A11. EVP with Nicotine

| | | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|---|
| Valid | Yes | 31 | 32.3 | 70.5 | 70.5 |
| | No | 13 | 13.5 | 29.5 | 100.0 |
| | Total | 44 | 45.8 | 100.0 | |
| Missing | System | 52 | 54.2 | | |
| Total | | 96 | 100.0 | | |

Table A12. Nicotine Concentration

| | | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|---|
| Valid | Don't know | 16 | 16.7 | 51.6 | 51.6 |
| | 1-12mg or 0.1-1.2% | 1 | 1.0 | 3.2 | 54.8 |
| | 13-17mg or 1.3-1.7% | 1 | 1.0 | 3.2 | 58.1 |

| | | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|---|
| | 18-24mg or 1.8-2.4% | 4 | 4.2 | 12.9 | 71.0 |
| | 25+mg or 2.5+% | 9 | 9.4 | 29.0 | 100.0 |
| | Total | 31 | 32.3 | 100.0 | |
| Missing | System | 65 | 67.7 | | |
| Total | | 96 | 100.0 | | |

Table A13. Days of EVP Use

| | | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|---|
| Valid | 0 days | 26 | 27.1 | 59.1 | 59.1 |
| | 1 or 2 days | 7 | 7.3 | 15.9 | 75.0 |
| | 6 to 9 days | 4 | 4.2 | 9.1 | 84.1 |
| | 10 to 19 days | 2 | 2.1 | 4.5 | 88.6 |
| | 20 to 29 days | 1 | 1.0 | 2.3 | 90.9 |
| | All 30 days | 4 | 4.2 | 9.1 | 100.0 |
| | Total | 44 | 45.8 | 100.0 | |
| Missing | System | 52 | 54.2 | | |
| Total | | 96 | 100.0 | | |

Table A14. Occasions of EVP Use per Day

| | | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|---|
| Valid | Less than 1 | 5 | 5.2 | 27.8 | 27.8 |
| | 1 | 1 | 1.0 | 5.6 | 33.3 |
| | 2 to 5 | 5 | 5.2 | 27.8 | 61.1 |
| | 6 to 10 | 3 | 3.1 | 16.7 | 77.8 |
| | 11 to 20 | 2 | 2.1 | 11.1 | 88.9 |
| | More than 20 | 2 | 2.1 | 11.1 | 100.0 |
| | Total | 18 | 18.8 | 100.0 | |
| Missing | System | 78 | 81.3 | | |
| Total | | 96 | 100.0 | | |

Table A15. Puffs of EVP per Occasion

| | | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|---|
| Valid | 1 | 1 | 1.0 | 5.6 | 5.6 |
| | 2 to 3 | 12 | 12.5 | 66.7 | 72.2 |
| | 4 to 5 | 2 | 2.1 | 11.1 | 83.3 |
| | 6 to 10 | 2 | 2.1 | 11.1 | 94.4 |
| | More than 10 | 1 | 1.0 | 5.6 | 100.0 |
| | Total | 18 | 18.8 | 100.0 | |
| Missing | System | 78 | 81.3 | | |
| Total | | 96 | 100.0 | | |

Table A16. Use of Chew, Snuff, Dip, etc. in the Past 30 Days

| | | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|---|
| Valid | 0 days | 95 | 99.0 | 99.0 | 99.0 |
| | 3 to 5 days | 1 | 1.0 | 1.0 | 100.0 |
| | Total | 96 | 100.0 | 100.0 | |

Table A17. Use of Cigars, Cigarillos, etc. in the Past 30 Days

| | | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|---|
| Valid | 0 days | 92 | 95.8 | 95.8 | 95.8 |
| | 3 to 5 days | 1 | 1.0 | 1.0 | 96.9 |
| | 6 to 9 days | 1 | 1.0 | 1.0 | 97.9 |
| | 10 to 19 days | 1 | 1.0 | 1.0 | 99.0 |
| | All 30 days | 1 | 1.0 | 1.0 | 100.0 |
| | Total | 96 | 100.0 | 100.0 | |

Table A18. Use of Other Drugs

| | | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|---|
| Valid | Yes | 34 | 35.4 | 35.4 | 35.4 |
| | No | 62 | 64.6 | 64.6 | 100.0 |
| | Total | 96 | 100.0 | 100.0 | |