UENO, AIKO, M.S. The Effect of Cognitive Fatigue on Physical Activity Intention and Behavior among Physically Active and Inactive Individuals. (2021)

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The American College of Sports Medicine recommends young adults engage in physical activity (PA) regularly for the purpose of psychological and physical health. However, the majority of young adults in the United States fail to meet the PA guidelines. Past literature has shown that cognitive fatigue (CF) negatively influences subsequent cognitive activities and physical performance, yet only several studies investigated the effects of CF on motivation, intention, and planning to participate in PA when they are cognitively fatigued. These studies are limited to either physically active or inactive populations, and it is unclear if there is difference in the effects of CF on PA intention between physically active and inactive individuals. Thus, the purpose of this study was to examine the effects of CF on PA intention and behavior among physically active (HPA) and low physically active (LPA) college students. It was hypothesized that HPA would report higher intentions to participate in PA and actual PA behaviors compared to LPA, but when individuals were cognitively fatigued, they would report lower intentions and actual behaviors compared to when they were not cognitively fatigued. Undergraduate male and female students who were enrolled in KIN 388 in Spring 2021 at the University of North Carolina at Greensboro participated in this research study as a part of their lab assignment. The results showed that the CF task failed to produce a measurable change in self-reported fatigue. However, HPA intended to participate in PA significantly more than LPA within the 24 hours after the experiment. Furthermore, HPA actually performed significantly higher PA than LPA within the 24 to 48 hours after the experiment. Lastly, although there was no difference in intentions to participate in PA between cognitively fatigued and non-cognitively fatigued individuals, actual behavior showed that cognitively fatigued individuals performed PA significantly less than non-cognitively fatigued individuals. It is concluded that there was an effect of CF on PA behaviors when comparing between HPA and LPA individuals.

THE EFFECT OF COGNITIVE FATIGUE ON PHYSICAL ACTIVITY INTENTION AND BEHAVIOR AMONG PHYSICALLY ACTIVE AND INACTIVE INDIVIDUALS

by

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CHAPTER I: INTRODUCTION

Currently, the American College of Sports Medicine and the American Heart Association recommend that adults perform at least 150 minutes of moderate to vigorous intensity physical activity (PA) to maintain or enhance their psychological and physical health (Haskell et al., 2007). However, the majority of young adults (between 18-24 years old) in America do not meet these guidelines, which raises both psychological and physical concerns (Clarke, 2016). Thus, it is important to identify the reasons why young adults are not physically active.

The barriers to participating in PA that college students tend to face include time constraints, tiredness, lack of energy, low motivation, and much more (Ebben & Brudzynski, 2008). Past studies have shown that when individuals are cognitively fatigued or tired, their subsequent cognitive performances are influenced. For example, individuals experience declines in attentional and executive controls, reduced abilities to suppress irrelevant information, require longer time to plan, and are less prepared for future actions (Faber et al., 2012; Lorist et al., 2000; van der Linden et al., 2003). In regards to physical activity, cognitive fatigue's effect on preparation for future actions may influence exercise planning and adherence, change exercise intentions, decision-making, and evaluation of the costs of engaging in exercise (Brown & Bray, 2019; Ginis & Bray, 2010; Harris & Bray, 2019). Furthermore, individuals who engage in exercise when being cognitively fatigued require more effort to complete the exercise, experience higher exertion, and declines in their actual physical performance compared to when they are not cognitively fatigued (Ginis & Bray, 2010; Head et al., 2016; MacMahon et al., 2014; Marcora et al., 2009). For the young adults who are required to complete schoolwork at college during semesters, they may be more cognitively tired and less motivated to engage in exercise, and therefore choose unhealthy behaviors instead of participating in physical activity regularly.

Resource theory and resource allocation theory potentially explain how cognitive fatigue occurs. These theories propose that processing resources are limited, so when several processes occur simultaneously they compete against each other for resources, and performance eventually decreases (Norman & Bobrow, 1975). Specifically, compared to learned and automated tasks, complex tasks that require more attention, especially under limited time availability, use cognitive resources more intensively (Barrouillet et al., 2004; Kanfer & Ackerman, 1989). Once cognitive resources are depleted, cognitive fatigue occurs. Furthermore, individuals with less cognitive resources and working memory capacity tend to mind-wander because of less regulation of their attention away from irrelevant information (Randall et al., 2014). Thus, self-regulation is an important factor to sustain task performance as well as to achieve a desired goal or outcome (Hagger et al., 2009). Along with resource theory, the limited strength model also explains that self-regulation is dependent upon limited resources, so that depletion of these resources consequently decreases the ability to self-regulate at a later time (Vohs & Heatherton, 2000). To summarize, cognitively demanding tasks (i.e., schoolwork) that require a number of cognitive resources may decrease the same resources that are necessary to engage in PA.

Although cognitive fatigue is reasonable to explain why college students may not engage in physical activity, there are some college students who do participate in physical activity. According to past literature, regularly engaging in PA has a positive effect on cognitive performance including perceptual speed, short-term memory, working memory, and episodic memory (Bielak et al., 2014; Etnier et al., 1997) as well as psychological aspects like self-regulation (Oaten & Cheng, 2006). Also, individuals who regularly participate in PA tend to evaluate the PA as having more benefits than costs (Marshall & Biddle, 2001). Thus, individuals who evaluate PA as beneficial tend to participate in PA more regularly, which then increases cognitive performance and self-regulation.

Studies that consider motivation, intention, and planning to participate in a single bout of exercise after being cognitively fatigued are limited. Physically inactive college students who performed high cognitive demanding tasks reduced their intended physical effort, decreased their physical performance, and altered their exercise plans (Brown & Bray, 2019; Ginis & Bray, 2010). Another study that investigated the effects of cognitive fatigue on intention to participate in PA among healthy physically active college students found that some participants, regardless of the conditions, chose to participate in PA. However, those who completed the high cognitive demand task evaluated the exercise differently, suggesting that the perceived benefits and costs of exercise changed, and there was a decreased intention to choose to participate in exercise (Harris & Bray, 2019). However, these studies only looked at one group of participants who were either regularly physically active or who were regularly inactive, and it is unclear to what degree there would be different intentions to participate in a single bout of exercise after being cognitively fatigued between physically active and inactive individuals. Thus, the purpose of this study was to investigate the effects of cognitive fatigue on the PA intention and behavior among physically active and inactive individuals in a young adult population. Furthermore, this study added a subjective assessment of perception of workload toward cognitive task after completion of the cognitive task to assess how differently physically active and inactive university students perceived the cognitive task.

CHAPTER II: REVIEW OF LITERATURE

What is Cognitive Fatigue?

Fatigue has been divided into peripheral fatigue and central fatigue. While peripheral fatigue refers to the inability to sustain a workload or force and is associated with physical or neuromuscular fatigue, central fatigue is defined as difficulty in the initiation and maintenance of mental and physical performance that requires self-motivation. An external cue or stimulation in advance could help individuals with central fatigue to perform physical or mental performance even though extra perceived effort could be required. However, individuals with central fatigue may experience difficulty initiating and executing serial or incremental activities because episodes of self-limiting activities such as stress, loss of sleep, or cognitively demanding tasks reduce their self-motivation. Thus, the major characteristic of central fatigue is a "failure of focused attention that normally provides the unconscious ('automatic') link between the self-guided voluntary effort, performance of sequential motor or cognitive tasks and sensory input" (p.35) (Chaudhuri & Behan, 2000). More specifically, mental fatigue, also described as cognitive fatigue (CF), is a subjective and psychological feelings that individuals may experience due to a prolonged period of and/or challenging performance that requires cognitive functions such as memory, judgment, reasoning, and other intellectual activities (Ackerman, 2011; Boksem & Tops, 2008).

When individuals are cognitively fatigued, numerous physical and psychological consequences are observed. First, CF is found in various cognitive domains such as attentional and executive function and causes individuals to experience difficulty suppressing irrelevant information during selective attention. Also, planning and preparation of upcoming activities are influenced by CF. Individuals with CF had less accuracy and more errors during preparation processes under the circumstance where participants knew what would be coming to next (Lorist et al., 2000). Furthermore, when the effects of CF on executive function were examined, the abilities of flexibility (or rather inflexibility defined as the tendency to "perseverate or hold on to an ineffective strategy"; p.49) and planning (the ability to initiate actions strategically, with an effective plan, and with efficient preparation time) in the CF group were lowered compared to the non-CF group (van der Linden et al., 2003). Thus, individuals tend to display different cognitive processing when they have been cognitively fatigued. Not only the cognitive functions are influenced, but CF also influences exercise effort, planning, and adherence (Ginis & Bray, 2010), alters exercise intentions and behavior (Brown & Bray, 2019), and affects exercise decision-making and the evaluation of the costs of engaging in exercise (Harris & Bray, 2019). Although individuals may decide to participate in PA, CF eventually decreases PA performance both aerobically and anaerobically (Head et al., 2016; MacMahon et al., 2014; Marcora et al., 2009).

Theories and Models of Cognitive Fatigue

First, it is reasonable to introduce the theories that account for CF. Resource theory explains the relationship between cognitive abilities and performance in a domain. Generally, processing resources are limited, so that when several processes require the same portion of the resources, deterioration of performance can be observed due to the allocation of the resources on the several processes (Norman & Bobrow, 1975). This is called "The principle of graceful degradation," in which smooth degradation of task performance could happen instead of calamitous failure (p.45). Furthermore, Norman and Bobrow (1975) explain two types of processes through the performance-resource function: resource-limited processes and data-limited processes. First, resource-limited processes show that the success of performance is dependent on the amount of resources that are applied to the task. They consider that the performance is reflected in the devotion of resources up to the limit. So that, when large amounts of resources are given to the task, the better task performance should be observed. On the other hand, when the amount of the resources is reduced on the task due to other processes competing for the resources, the performance would be negatively influenced. On the other hand, data-limited processes are independent of processing resources. Thus, the allocation of resources does not influence task performance, and the success of performance is dependent on task characteristics. For example, detecting a sound in a noisy environment requires the recognition mechanisms initially. However, once the possible processing (i.e., recognition) is completed, the performance depends on quality of data. Another example includes that the performance (or task) is data-limited when individuals need to rely on their stored memory after all processes to encode information are completed. Therefore, according to Norman and Bobrow (1975), generally, in most tasks, the portion of resource-limited region would smoothly rise first up to a point until the amount of resource does not affect performance. From there on, performance would completely be an independent of resources and data-limited because allocating the resources does not influence performance further than that. However, resource allocations differ depending on task characteristics such as complexity and difficulties. For example, information processing that requires attentional effort uses the larger cognitive resources of limited availability. When the task is learned and automated or simple, the attention required is less than when the task is more complex or just learned because less demands on attention are needed to perform the task. In addition to resource theory and resource allocation theory, Kanfer and Ackerman (1989) proposed an allocation policy, in which the available resources are distributed into three areas: task effort, off-task, and self-regulation.

In addition to the association between attention allocation and task characteristics (i.e., complexity and difficulties), motivation also influences the individual's attentional effort (Kanfer & Ackerman, 1989). Motivation refers to the direction, attention, and maintenance of attentional effort. Thus, when individuals are interested in executing a difficult task, they tend to focus more on the task compared to something they do not like. Specifically, among the three distributions, self-regulation is necessary to sustain attention on a complex task or during early stages of task acquisition (Kanfer & Ackerman, 1989). Self-regulation is defined as "a broad construct representing the cognitive, motivational-affective, social and physiological processes that modulate attention, emotion and behavior to a given situation/stimulus, for the purpose of pursuing a goal" (Bassett et al., 2012). In daily life, there are numerous barriers, impulses, temptation, and habits to overcome. Individuals are required to control over self and inhibit those short-term gratification to sustain their long-term goal (Hagger et al., 2009). When individuals fail to self-regulate their immediate gratifications, they tend to start mind-wandering or being distracted (i.e., off-task thought) and are not able to achieve their goal (Randall et al., 2014).

The meta-analysis of attention regulation conducted by Randall and colleagues (2014), suggests that the combination of cognitive resources, attention allocation, and task characteristics affects individuals' mind-wandering. According to this meta-analysis, individuals with less cognitive resources tend to mind-wander more, which is associated with decrements in performance. On the other hand, individuals with greater cognitive resources have greater attention allocation on a task, which is related to improvements in performance. Furthermore, one of their results displayed that there is a negative association between working memory capacity and mind-wandering. Thus, individuals who have less working memory capacity tend to mind-wander more. This implies that those with less working memory capacity are less likely to regulate their attention from irrelevant information with the result being that they mind-wander.

Although it is briefly explained as a definition of CF that the prolonged and challenging cognitive activity (or cognitive load) triggers CF, how cognitive demands are conceptualized is more complex. Barrouillet and colleagues (2004) proposed the time-based resource sharing (TBRS) model in addition to the resource sharing process. According to the resource sharing process, during working memory span, components of processing and storage share the same resource. Like a bottle neck, these components compete against each other for attention to process tasks or constantly refresh memory traces through a retrieval process. However, when individuals are provided enough time to process tasks, the detriments of performance are less affected because it is possible to deal with the cognitive demands in an appropriate manner. However, the TBRS model suggests that when the time to process the ongoing cognitive activity is limited, the performance is negatively affected since it requires an individual to switch rapidly between processing and maintenance. They concluded that cognitive demand is a "function of the amount of work to be done divided by the time allowed to do it (Barrouillet et al., 2004, p.96)." When the effects of a high cognitive demanding task that is applied by TBRS model on CF is investigated, the CF is more induced under environmental constraints where the complexity of task (i.e., high cognitive demanding task) is continuously performed with a time pressure. This suggests that CF is not triggered by the complexity of task itself but also by the available time to process it (Borragán et al., 2017).

To summarize, the CF occurs depend on the task characteristics, individuals' motivation toward tasks, self-regulation and working memory capacity that control individuals mind-wandering.

Theories related to Self-regulation

As briefly described above, self-regulation is a key factor for sustaining task performance over time. The distinction between self-regulatory and self-control is that self-control is the ability to inhibit immediate impulses or habitual responses while self-regulation refers to the ability to control the self to achieve desire goals (Hagger et al., 2009). A limited strength model of self-control proposes that self-control is a limited resource. So that, when the resources are used or competed for with other self-regulatory activities, it leads to impairments in subsequent performance because self-control is a necessary factor to self-regulate (Baumeister et al., 2007; Hagger et al., 2009; Muraven & Baumeister, 2000). According to this model, a task that requires self-regulation decreases the ability to self-regulate at a later time (Vohs & Heatherton, 2000). This may explain why individuals make a decision that they refrain from exercising after cognitively fatiguing tasks because exercising also needs self-regulation abilities. Furthermore, negative moods also affect self-regulation abilities (Heatherton & Wagner, 2011). If the consequence of executing a cognitively demanding task brings individuals negative emotions, then they may prefer to engage in a pleasuring behavior at the moment (i.e., resting instead of exercising, alcohol consumption, intake of unhealthy foods) rather than maintaining their long-term goal. Lastly, the limited strength model explains that when the self-regulation resource is limited, this depletion may reduce feelings of self-efficacy (Hagger et al., 2009; Muraven & Baumeister, 2000). This is an important point because according to social cognitive theory, self-efficacy is a key determinant of health-related behaviors although this theory posits a reciprocal relationship between the individuals, their environment, and behavior (Ebben & Brudzynski, 2008; Bandura, 1991).

Effects of Exercise on Cognitive Performance

It is well established that both regular engagement in PA and a single bout of exercise influences cognitive performance. A past meta-analysis showed small but positive effects of a single session of PA on cognitive performance (Chang et al., 2012; Etnier et al., 1997; Lambourne & Tomporowski, 2010; Roig et al., 2013).

The longitudinal data to look at the association between PA and cognitive performance showed that individuals who participate in PA regularly had a higher starting point in cognitive ability regardless of age (Bielak et al., 2014). In a randomized control study, young and healthy adults were randomly assigned into either control group or running group (30 minutes, three times per week, for six weeks). Only the runner group showed improvements in aerobic fitness and increased visuospatial memory (Stroth et al., 2009).

More specifically looking at the limited strength of self-control, Oaten and Chang (2006) brought a concern about the effects of academic stress on self-control among university students because the stress period such as examinations or school-work in general may use the self-regulatory resources, resulting in reduced resources to self-regulate to initiate and maintain healthy behaviors including PA and instead resulting in unhealthy behaviors (i.e., smoking cigarette, not participating in PA, and consuming unhealthy foods). Thus, this study examined the effects of a 2-month exercise program on the self-control behaviors. Their results showed that relative to control (non-exercise) group, the individuals who participated in the exercise program improved their laboratory-based self-control behaviors (visual tracking task following a thought-suppression task) Also, they did not show the increases in stress during exam period, improved study habits, decreased unhealthy behaviors (i.e., smoking, alcohol, and coffee consumption), and increased healthy behaviors (i.e., taking dietary habits, emotional control, self-care habits). Their conclusion suggested that regular engagement in PA has a positive impact on self-control in many domains.

Additionally, the amount of sleep individuals gets each night also affects cognitive performance. Even 1~3 days of sleep restrictions can have a negative influence on various cognitive functions, including lapses of attention, slowed working memory, underestimating the impact of sleep restriction on cognitive readiness (Banks & Dinges, 2007). Considering the sleep and exercise, both sleep and exercise influence each other through reciprocal interactions (Chennaoui et al., 2015). Kato and colleagues (2018) examined the relationship of daily PA and total sleep time (TST) on cognitive performance in young adults and found that both PA and TST were significantly correlated with working memory. Thus, it is important to consider sleep duration and quality when discussing CF because sleep deprivation and CF are correlated to each other.

The Effects of Cognitive Fatigue on Exercise Intention

CF due to sustained cognitive demands influences various domains. However, the number of studies that have specifically investigated the effects of CF on the intention and motivation to engage in physical activity is limited. Ginis and Bray (2010) examined the effects of self-regulatory depletion on aerobic exercise planning and behaviors as well as how the depletion of self-regulation could predict adherence to exercise plans over the next eight weeks. The participants for this study were university students (M=20.0 years old; SD=2.4) who were physically inactive (less than 2 bouts of exercise per week, for 30 minutes or more at a moderate or strenuous intensity over the past 6 months). First, participants performed aerobic exercise on a stationary bicycle for 15-minutes at a perceived intensity of 5 of the Borg's CR-RPE. Then, the participants were asked to construct a 30 minutes (six 5minutes bout of aerobic exercise circuit) exercise plan by choosing 10 exercise equipment with the different level of intensity (1: easy to 10: hard). The average level of six equipment (participants could repeatedly choose same equipment) was calculated. After planning, the participants were randomly assigned into either the self-regulatory depletion group or the control group using manipulation of Stroop task (high cognitive load vs. low cognitive load). The participants in both groups performed the Stroop task for 3 minutes and 40 seconds. The participants were asked to construct exercise circuit plans from 10 different intensities of exercise equipment again as they did before the manipulation task. In reality, participants only planned the circuit, but not perform the exercise circuit. Participants then performed the 15-minutes of aerobic exercise again at the end of the experiment. For the self-regulatory depletion group, a follow-up study was conducted. The participants were asked to fill out a questionnaire regarding an exercise plan which assessed how many days per week they plan to exercise next 8 weeks and how many minutes they would engage in an exercise each day. They were asked to record their exercise on a log-sheet. Their manipulation check in the main study did only find the difference in mental effort, but not in tiredness, frustration, mood, or arousal. The results showed that the intensity of exercise circuit plan did not change among those who performed the low cognitive load task while those who performed the high cognitive load task reduced the intensity on their planned exercise circuit plan. Furthermore, the participants exposed to self-regulatory depletion generated lower levels of work on the bicycling task compared to pre-exercise session. Also, there was an effect of self-depletion on the exercise adherence over the next 8 weeks. The participants who reported the greater decrease in intensity of exercise at the post-depletion task did not adhere the immediate exercise plans that they created after the experiment for the 8 weeks.

The second study conducted by Brown and Bray (2019) investigated the effect of cognitive control exertion on mental fatigue and exercise-related perceptions and total work of 50-minutes of aerobic exercise at their own selected-pace. The rationale for this study was that the earlier study (Martin Ginis & Bray, 2010) did not produce the mental fatigue from the cognitive control task, so that this study examined whether the effects of fatigue on intentions lead to corresponding changes in behavior. They recruited university students (M=20.16 years; SD= 1.48) who currently did not engage in moderate to vigorous physical activity for the past six months. At the first visit, participants completed a graded cardiovascular exercise test to gain familiarity of ratings of perceived exertion (RPE) and to determine participants' RPE which was correlated with specific workload. At visits 2 and 3, participants were told to exercise for 30 minutes at their RPE of 12-17. Then, participants rated their intended RPE for the exercise session on Borg's RPE scale ranging from 6 to 20 before 52-minutes of experimental manipulation (high vs. low cognitive control exertion). After the completion of the cognitive manipulation task, participants were asked again about their intended RPE for the exercise session as well as task motivation. Finally, participants started performing aerobic exercise on an ergometer cycle for 30 minutes at an adjusted workload depending on their intended RPE during a graded cardiovascular exercise test to provide the participants an initial resistance level. As the exercise continued, the participants were notified that the workload could be adjusted throughout the exercise. Heart rate and total work performed while exercising was recorded. Motivation to exercise showed no difference between conditions. Their primary outcomes showed that compared to low cognitive control exertion, participants who completed the high cognitive control exertion exhibited significantly greater mental fatigue, greater reductions in intended RPE, and less total work performed during the exercise session. They mentioned that 50-minutes of a cognitive demanding task is similar to a lecture for university students. Thus, they concluded that 50 minutes of mental fatigue (i.e., lecture) alters the intention of how much exertion they would put in exercise as well as total work performed.

Despite literature showing the effects of mental fatigue on exercise performance or people's intentions to exert effort while exercising, there are few studies to determine the mechanisms underlying these effects. Thus, Harris and Bray (2019) examined if the cognitive demanding task altered individuals' decision-making to participate in physical activity and if the perceived mental fatigue and subjective benefit-cost evaluations toward physical activity mediated the decision-making. Furthermore, they also investigated the effect of CF on the subjective perceived exertion and exercise. Regularly physically active college students were recruited for this study. All participants first performed a modified graded exercise test at the moderate-vigorous intensities until their rating of perceived exertion exceeded a certain point. After the exercise session, participants were randomly assigned into either high or low mental fatigue condition. Before, during, and after performing the cognitive task, participants were asked to rate their perceived mental exertion and subjective mental fatigue. After the cognitive manipulation, participants were provided a choice of either performing 22-minutes of moderate to vigorous physical activity on a stationary bike or taking 22-minutes of free time (non-exercise, leisure time). Although their mental fatigue task manipulation produced the mental fatigue in high mental fatigue group, there was no direct group difference regarding the decision-making to participate in physical activity. However, their serial mediation analysis found that individuals who were in high cognitive demanding group rated higher mental fatigue and lower subjective evaluations of the benefits and costs of exercise, and in turn they indirectly chose leisure time instead of performing exercise. To summarize, the CF did not directly influence decision-making to participate in physical activity but affects decision-making indirectly through a process of feeling higher mental fatigue and evaluating lower subjective benefits and costs of exercise.

Future Study

CF leads to various psychological and physiological consequences such as declines in performance across numerous cognitive domains, PA performance, and motivational aspects

(Brown & Bray, 2019; Faber et al., 2012; Ginis & Bray, 2010; Harris & Bray, 2019; Head et al., 2016; Lorist et al., 2000; MacMahon et al., 2014; Marcora et al., 2009; van der Linden et al., 2003). Past studies, in contrast, have made it clear that engagement in regular PA has a positive effect on cognitive performance including perceptual speed, short-term memory, working memory, episodic memory, as well as self-regulatory performance (Bielak et al., 2014; Etnier et al., 1997; Oaten & Cheng, 2006). With consideration of decision-making and motivation to participate in PA, individuals who regularly participate in PA tend to perceive greater pros (or benefits) than cons (or costs) of exercise while those who do not engage in PA have greater cons than pros (Marshall & Biddle, 2001). Although Marshall and Biddle (2001) demonstrated a relation between individuals' positive and negative evaluations of exercising, their evaluations are based on their general and habitual patterns of behavior, not the acute decisions individuals make regarding whether or not to participate in exercise under a certain circumstance.

Although Bray and colleagues (Brown & Bray, 2019; Ginis & Bray, 2010; Harris & Bray, 2019) established the effects of CF on subsequent psychological elements including planning, motivation, and decision-making to participate in an acute bout of exercise, their participants are homogeneous; either non-PA or regular PA individuals. Thus, it is unknown if there would be differences on CF and intention to participate in exercise after being cognitively fatigued between regular PA individuals and non-PA individuals. Furthermore, the two studies (Ginis & Bray, 2010; Harris & Bray, 2019) performed both exercise test and cognitive manipulation task on the same day. This may bring the extra fatigue that is accumulated from both physical and cognitive performance. Therefore, it is unclear if the CF task itself brings different perceptions toward task and intention to participate in physical activity. The purpose of this study was to examine the effects of CF itself on exercise intentions and behavior among regularly PA and non-regularly PA individuals. It was hypothesized that there would be an interaction between PA and CF. It was predicted that individuals who participate in PA regularly would report a higher intention to be active and engage in more PA behavior after being cognitively fatigued compared to non-regularly PA individuals because of greater amounts of cognitive resources. However, it was also predicted that participants in the HCF task group would report a lower intention to participate in PA and actual behavior compared to those in the

LCF task. Lastly, the perception of the CF manipulation task would be assessed to see how differently regularly PA and non-regularly PA individuals perceive the cognitive task.

CHAPTER III: METHODS

Participants

Undergraduate male and female students who were enrolled in KIN 388 in Spring 2021 at the University of North Carolina at Greensboro participated in this research study as a part of their lab assignments in the course. Although every student was given the opportunity to complete the study for their class credit, only those who signed the informed consent for their data to be used in a research study were included in this thesis. Also, the inclusion criteria for their data to be included was that they were 18-30 years of age, currently taking no medication that influences cognitive performance, not currently diagnosed as attention-deficit/hyperactivity disorder (ADHD), and not color-blind.

Design

A quantitative between-subjects experimental design was used. The participants were randomly assigned into either high or low cognitive fatigue conditions: half of the high PA (HPA) and low PA (LPA) status was assigned into the high cognitive fatigue condition (HPA-HCF and LPA-HCF) while the other half was assigned into the low cognitive fatigue condition (HPA-LCF and LPA-LCF). The independent variables in the present study were CF task (HCF and LCF) through completion of the modified Stroop task (congruent or non-congruent) and PA status (HPA and LPA). Before and after the cognitive performance, participants were asked if they had intentions to perform PA immediately after, within the 24 hours after, and within the 48 hours after completion of the cognitive task and the degree of CF. Also, their perception of task workload was assessed after the CF task. Thus, the dependent variables were the PA intention, the degree of CF, and the perception of workload.

Participants were instructed not to exercise on the day that they participated in this experiment to exclude the possibility to affect their CF level and intention to participate in PA. Also, participants were given an instruction to participate in this experiment on a day that was typical of their normal daily life. For example, participants were advised not to take this experiment after an exam, after a lack of sleep, or when they felt sick or tired.

Materials

DEMOGRAPHIC INFORMATION

The participants' age, ethnicity/race, level of education, and biological sex were asked to determine their demographics. In addition to the demographic information, participants were asked whether they are currently diagnosed with ADHD or taking any medication that influence cognitive performance as well as if they were color-blind or not.

PHYSICAL ACTIVITY LEVEL

The International Physical Activity Questionnaire (IPAQ) short-form was used to assess PA status among participants. This questionnaire assessed three intensities (light, moderate, and vigorous intensity) of PA and sitting time that individuals do in their normal lifestyle.

Total PA scores were calculated based on the Guidelines for Data Processing and Analysis of the IPAQ. The middle 20 percent of participants were removed from analysis to make a distinct division between HPA and LPA. Those who were in top 40 percent of IPAQ scores were considered as HPA individuals while the bottom 40 percent were categorized as LPA individuals.

COGNITIVE FATIGUE TASK

The cognitive fatigue task was performed on "*Presentation Mobile"* App on each participant's own mobile phone. The participants were asked to download the free "*Presentation Mobile*" App from Google Play Store or App Store on their phone prior to the experiment day.

The Stroop task was used to manipulate the level of CF (Stroop, 1935). Participants were required to respond to the color of the ink, not the word itself (i.e., respond "green" if the color of word is green although the word says “red”). Participants in high CF condition performed the randomly mixed trials of congruent (word and color are same) and incongruent (word and color are different) condition. On the other hand, participants in the low CF group performed only congruent trials.

Before the task started, participants were instructed that they would see words written in color on the screen and were required to respond to the name of ink’s color as quickly and accurately as possible. Participants were notified at the beginning of the trial that their scores were recorded. Also, participants had two practice sessions to make sure that they understood the task.

Participants were required to complete five of 2-minutes blocks as used in the study conducted by Harris and Bray (2019). Each trial was 900 ms, which consisted of 800 ms of the color-word stimuli and 100 ms of inter-trial interval. Also, each time, participants were provided feedback indicating that they either correctly or incorrectly responded or missed the opportunity to respond.

SUBJECTIVE COGNITIVE FATIGUE

A Visual Analogue Scale-fatigue (VAS-F) was used to assess CF (Wewers & Lowe, 1990). The VSA-F has been shown to be a valid and reliable measure of fatigue and energy level (Lee et al., 1991). Participants were given an instruction to place a mark (X) on the line of 100 mm length, representing how they felt currently, along a visual analogue line that extends between being “not at all tired” to being “extremely tired”. This measure was used before and after the CF task

RATINGS OF PERCEIVED EXERTION - MENTAL (RPE-M)

Participants were asked to rate their perceived mental exertion (RPE-M) before and after the CF task The Borg’s CR-10 scale were used from 0 (no exertion at all) to 10 (maximal exertion) (Borg, 1998). The Borg's CR-10 scale has been shown a high reliable and valid tool to measure perceived exertion (Shariat et al., 2018). Although this scale was originally designed to measure general exertion such as physical fatigue, past studies used the Borg's CR-10 scale to assess mental fatigue (Brown & Bray, 2019; Ginis & Bray, 2010).

PERCEPTION OF WORKLOAD

The NASA Task Load Index (NASA-TLX) was used to assess workload. Using this scale, participants rated their subjective mental demand, physical demand, temporal demand, performance, effort, and frustration (NASA, 1986). Each scale was presented on a 100-point range with 5-point steps anchored by bipolar descriptions (Low/High). The NASA-TLX has good reliability and validity to measure mental workload (Ym et al., 2005). The NASA-TLX was asked only after the completion of the cognitively demanding task. Each component of this scale was calculated by computing differences between conditions.

MOOD SCALE

Feeling Scale (FS) and Felt Arousal Scale (FAS) were measured before and after the CF task. In FS, participants were asked to rate their feeling state from -5 (very bad) to 0 (neutral) to +5 (very good). FAS asked participants to rate their arousal level from 1 as low arousal (i.e., calm, relax, tired, bored) to 5 as high arousal (i.e., energy, excitement, anxiety, tension). These measurements have a reliability, convergent validity, and discriminant validity (Russell et al., 1989).

INTENTION OF PHYSICAL ACTIVITY

The intention to participate in PA was asked before and after the cognitive task. First, they were asked if they had intention to participate in PA immediately after, within the 24 hours after, and within the 48 hours after the cognitive task. If they answered yes, then they were asked what intensity (light, moderate, or vigorous) and how many minutes they intended to participate in PA.

PHYSICAL ACTIVITY BAHAVIOR

Participants were asked to recall their PA behavior immediately after, within the 24 hours after, and 48 hours after the experiment. Similar to intention of PA, they were asked if they participated in any PA immediately after, within the 24 hours after, and within the 48 hours after the experiment. If they answered yes, they were asked what intensity and how many minutes they participated in PA.

Potential Covariates

CHRONIC COGNITIVE FATIGUE

The current level of CF was assessed before the experiment and considered as a covariate between PA and chronic CF. The Fatigue Sensitivity Scale (FSS) was used to measure their current CF level. This scale is designed to differentiate fatigue from clinical depression and asks participants to rate their own fatigue level (Krupp et al., 1989). The participants were asked to circle a number that applies to them. In total, 9 questions (i.e., "Fatigue causes frequent problems for me" or "I am easily fatigued") had participants rate their responses from 1 (Strongly Disagree) to 7 (Strongly Agree). The higher scores indicated higher sensitivity and functional impairment as a result of fatigue. The scoring was done by calculating the average response to the questions. This scale has sufficient internal consistency, test-retest validity, and concurrent validity (Krupp et al., 1989).

SLEEP QUALITY INDEX

The Pittsburgh Sleep Quality Index (PSQI) was used to assess participants' sleep quality and disturbance over a one-month period (Buysse et al., 1989). This assessment has high test-retest reliability and good validity to distinguish between healthy control and individuals with primary insomnia (Backhaus et al., 2002). The scoring for each of the 19-self-rated questions were calculated based on the instructions, indicating from 0 =”no difficulty in sleeping” to 3 = “severe difficulty in sleeping.” The global score was added from seven components, again scoring from 0 (no difficulty) to 21 (severe difficulty).

Procedures

Day 1: All students received the questionnaires of demographics, IPAQ, PSQI, and FSS to complete. After the completions of these materials, the IPAQ score was calculated, and the participants were classified into either “HPA” or “LPA” groups. Half of the HPA and half of the LPA were randomly assigned into high cognitive fatigue condition (HPA-HCF and LPA-HCF) while the other half was assigned into low cognitive fatigue condition (HPA-LCF and LPA-LCF).

Day 2: The participants were asked to answer the hours and quality of sleep before starting the experiment. Also, they were asked if they had worked or taken classes prior to participating in the experiment as well as if so, how long they worked and how many classes they had on the day. Then the participants were asked to complete five sets of 2-minutes of the cognitive manipulation tasks (high cognitive task vs. low cognitive task). Before and after the cognitive demanding task, they were asked to rate their CF level, mental exertion level, intention to participate in PA, and arousal and feeling level. In addition to these materials, after the cognitive demanding task, NASA-TLX was assessed.

Day 3: 48 hours after the experiment, participants received another questionnaire and were asked to recall their PA behavior immediately after, within the 24 hours after, and within the 48 hours after the experiment.

Data Analysis

SPSS Version 27 was used for the data analysis. Alpha was set at 0.05 for all analyses. Descriptive statistics, including means and standard deviations, were reported in order to understand the distribution of VSA-F, RPE-M, NASA-TLX, FS, FAS, PA-intention, and PA-behavior. A 2 (HPA x LPA) x 2 (HCF x LCF) factorial Analysis of Variance (ANOVA) was conducted to measure main effects and interactions between groups in NASA-TLX and PA behavior. In addition, a 2 (HPA x LPA) x 2 (HCF x LCF) x 2 (Pre x Post) mixed ANOVA was conducted to assess groups differences in VAS-F, RPE-M, FS, FAS, and PA intentions. Significant interactions were followed up.

CHAPTER IV: RESULTS

Demographics and Baseline Data

Ninety-seven students agreed to participate in this study. Based on the IPAQ score, the middle 20% (n=20) of students were removed from the study. An additional 18 students were excluded from the data for the following reasons: currently diagnosed with ADHD or taking medication that affects cognitive performance (n=6), age (n=1), inadequate score on IPAQ (n=1), incomplete survey (n=4) or failure to properly complete the CF task (n=2), and following the wrong procedures (n=4). Thus, a total of 59 students were included for further analysis. Three of the HPA students who were supposed to complete the HCF task accidentally performed the LCF task. Therefore, the allocation of the sample between groups became unequal and sample size for each group was as follows: HPA-HCF: n=11, HPA-LCF: n=18, LPA-HCF: n=15, and LPA-LCF: n=15. The mean age for the entire sample was 21.15 years (SD=1.86). The demographic information of participants and baseline measurements (years of education, IPAQ, FSS, and PSQI) in each group are described in Table 1.

A 2 (PA) x 2 (CF) ANOVA showed that there were no significant interactions between PA x CF for age ($F(1,55)=0.94, p>0.05$), years of education ($F(1,55)=1.82, p>0.05$), FSS ($F(1,53)=0.50, p>0.05$), or PSQI ($F(1,44)=0.09$, $p>0.05$). However, there was a significant main effect of PA ($F(1,55)=5.27, p<0.05$) and CF ($F(1,55)=7.33, p<0.01$), such that the students in HPA groups (M=21.59, SD=2.24) were significantly older than those in LPA groups (M=20.73, SD=1.31), and the students in HCF groups (M=21.77, SD=2.30) were older than those in LCF groups (M=20.67, SD=1.27). Furthermore, there was no significant PA x CF interaction ($F(1,55)=1.15, p>0.05$) in terms of total scores of IPAQ. However, there was an expected main effect of PA ($F(1,55)=85.72, p<0.001$), such that the students in HPA groups (M=10414.64, SD=4967.68) had significantly higher scores in IPAQ than those in LPA groups (M=1524.78, SD=857.39).

Table 1: Demographics and baseline information.

	HPA		**LPA**	
	HCF (n=11)	LCF (n=18)	HCF (n=15)	LCF (n=15)
Age	*M*=22.64 (*SD*=3.00)	*M*=20.94 (*SD*=1.35)	*M*=21.13 (*SD*=1.41)	*M*=20.33 (*SD*=1.11)
Ethnicity/Race [a]	W: n=5 (45.5%) B: n=4 (36.4%) AI: n=1 (9.1%) O: n=1 (9.1%)	W: n=10 (55.6%) B: n=7 (38.9%) L: n=1 (5.6%)	W: n=2 (13.3%) B: n=11 (73.3%) L: n=1 (6.7%) O: n=1 (6.7%)	W: n=7 (46.7%) B: n=7 (46.7%) L: n=1 (6.7%)
Education	*M*=14.09 (*SD*=0.83)	*M*=14.33 (*SD*=0.91)	*M*=14.40 (*SD*=0.83)	*M*=14.00 (*SD*=1.00)
Gender [b]	M: n=7 (63.6%) F: n=4 (36.4%)	M: n=10 (55.6%) F: n=8 (44.4%)	M: n=6 (40%) F: n=9 (60%)	M: n=2 (13.3%) F: n=13 (86.7%)
IPAQ	*M*=9345.23 (*SD*=5634.00)	*M*=11068.17 (*SD*=4558.71)	*M*=1670.27 (*SD*=802.97)	*M*=1379.30 (*SD*=912.49)
FSS	*M*=32.36 (*SD*=14.21)	[n=17] *M*=29.12 (*SD*=10.54)	*M*=23.33 (*SD*=9.45)	[n=14] *M*=24.21 (*SD*=9.74)
PSQI	[n=8] *M*=5.88 (*SD*=4.09)	[n=16] *M*=5.56 (*SD*=2.78)	[n=12] *M*=6.58 (*SD*=3.85)	[n=12] *M*=5.67 (*SD*=3.20)

Note. [a] W = White/Caucasian, B = Black/African American, AI = American Indian, L = Latin/Spanish/Hispanic, O= Others
[b] M = male, F = female

Pre-experiment Conditions

Table 2 presents the means and standard deviations for sleep-hours and sleep-quality the night before the participants participated in the experiment as well as the pre-experimental conditions including attending classes and working. There were no significant main effects of PA ($F(1,55)=0.01$, $p>0.05$) and CF ($F(1,55)=0.91$, $p<0.05$) on sleep hours or significant PA x CF interaction between PA and CF ($F(1,55)=0.04$, $p>0.05$). Furthermore, in terms of sleep quality, there were no main effects of PA ($F(1,55)=0.97$, $p<0.05$) and CF ($F(1,55)=2.98$, $p>0,05$) or PA x CF interaction ($F(1,55)=2.12$, $p>0.05$) the night before the experimental day.

Also, 12 people participated in this research study in the morning (between 6:00 am and noon), 21 people in the afternoon (between noon to 6:00 pm), 15 people in the evening (between 6:00 pm and 9:00 pm), and 11 people in the night (between 9:00 pm and 6:00 am). Furthermore, 12 people took classes before participating in this research study. Seven people took one course, 1 person took two courses, and 4 people took three courses before the experiment. Also, 9 people worked before the experiment. The duration of work varied from 1 hour to 8 hours. Two people had mentally demanding jobs, 2 had physically demanding jobs, 2 had both mentally and physically demanding jobs, and 3 had neither mentally nor physically demanding jobs.

Table 2. Pre-experimental condition.

	HPA		**LPA**	
	HCF (n=11)	LCF (n=18)	HCF (n=15)	LCF (n=15)
Sleep hours	*M*=7.23 (*SD*=2.02)	*M*=7.58 (*SD*=1.27)	*M*=7.18 (*SD*=1.66)	*M*=7.72 (*SD*=2.11)
Sleep quality [a]	*M*=1.72 (*SD*=0.65)	*M*=1.78 (*SD*=0.65)	*M*=1.27 (*SD*=0.46)	*M*=1.87 (*SD*=1.66)
Time [b]	M: n =1 (9.1%) A: n =5 (45.5%) E: n =3 (27.3%) N: n=2 (18.2%)	M: n=6 A: n=6 E: n=2 N: n=4	M: n=3 A: n=4 E: n=3 N: n=5	M: n=2 A: n=6 E: n=7 N: n=0
Class attended before the experiment	Yes: n=4 (36.4%) No: n=7 (63.6%)	Yes: n=4 (22.2%) No: n=14 (77.8%)	Yes: n=2 (13.3%) No: n=13 (86.7%)	Yes: n=2 (13.3%) No: n=13 (86.7%)
# of class attended	One: n=2 Two: n=1 Three: n=1	One: n=1 Two: n=0 Three: n=3	One: n=2 Two: n=0 Three: n=0	One: n=2 Two: n=0 Three: n=0
Work before the experiment	Yes: n=0 No: n =11	Yes: n=4 No: n=14	Yes: n=2 No: n=13	Yes: n=3 No: n=12
Job types [c]		MD: n =0 PD: n=0 BO: n=2 NE: n=2	MD: n=0 PD: n=2 BO: n=0 NE: n=0	MD: n=2 PD: n=0 BO: n=0 NE: n=1
Work hours		*M*=4.94 (*SD*=0.43)	*M*=7.50 (*SD*=0.71)	*M*=2.00 (*SD*=1.00)

Note. [a] Sleep quality ranges from 1= very well to 4 = very poor.
[b] M=morning (6:00 am to noon), A=afternoon (noon to 6:00 pm), E=evening (6:00 pm to 9:00 pm), N=night (9:00pm to 6:00am)
[c] M=mentally demanding job, P=physically demanding job, B=both mentally and physically demanding job, N=neither mentally nor physically demanding job

Cognitive Fatigue Tasks

The means and standard deviations for total trials and percentage accuracy are presented in Table 3. A 2 (PA) x 2 (CF) ANOVA showed that there was no significant main effect of PA ($F(1,55)=0.06$, $p>0.01$) or interaction between PA and CF ($F(1,55)=2.41$, $p>0.05$) in the total trials of the task. However, there was a significant main effect of CF in the total trials of the CF task ($F(1,55)=43.36$, $p<0.05$). The students in HCF groups (*M*=408.31, *SD*=12.37) performed significantly more trials than those in LCF groups (*M*=390.45, *SD*=8.28). For percentage accuracy, there was a significant main effect of CF ($F(1,55)=6.94$, $p<0.05$). As expected, the students in LCF groups (*M*=97.97, *SD*=1.73) had significantly higher percentage of accuracy compared to those in HCF groups (*M*=96.60, *SD*=2.39). Yet, PA did not have a main effect ($F(1,55)=1.09$, $p>0.05$) and there was no significant interaction between PA and CF ($F(1,55)=6.94$, $p>0.05$) in the percentage of accuracy.

Table 3. CF conditions between the groups.

	HPA		**LPA**	
	HCF (n=11)	LCF (n=18)	HCF (n=15)	LCF (n=15)
Total trial	*M*=406.27 (*SD*=12.27)	*M*=392.67 (*SD*=9.67)	*M*=409.80 (*SD*=12.65)	*M*=387.80 (*SD*=5.41)
% of accuracy	*M*=96.28 (*SD*=2.96)	*M*=97.71 (*SD*=1.44)	*M*=96.84 (*SD*=2.03)	*M*=97.37 (*SD*=2.14)

Feeling and Tiredness

NASA-TLX

Table 4 shows the means, standard deviations, and effect sizes for HPA (HCF vs LCF) and LPA (HCF vs LCF) for the six components of NASA-TLX. A 2 (CF) x 2 (PA) ANOVA was performed to assess the difference between groups in the six components of the NASA-TLX.

When examining the main effect for NASA-TLX, there was no significant main effect of PA or CF on the Mental (PA: F(1,55)=0.56, p>0.05, CF: F(1,55)=1.92, p>0.05), Physical (PA: F(1,55)=2.76, p>0.05, CF: F(1,55)=0.04, p>0.05), Temporal (PA: F(1,55)=0.91, p>0.05, CF: F(1,55)=1.20, p>0.05), Performance (PA: F(1,55)=0.26, p>0.05, CF: F(1,55)=0.09, p>0.05), Effort (PA: F(1,55)=0.04, p>0.05, CF: F(1,55)=0.40, p>0.05), or Frustration components (PA: F(1,55)=0.10, p>0.05, CF: F(1,55)=0.83, p>0.05).

None of the components demonstrated a significant interaction between PA and CF (Mental: F(1,55)=0.31, p>0.05, Physical: F(1,55)=0.45, p>0.05, Temporal: F(1,55)=1.89, p>0.05, Performance: F(1,55)=1.16, p>0.05, Effort: F(1,55)=0.66, p>0.05, and Frustration: F(1,55)=0.31, p>0.05).

Table 4. Means, Standard Deviations, and Effect sizes for the six components of NASA-TLX.

	HPA			**LPA**		
	HCF (n=11)	LCF (n=18)	Effect size for HPA (HCF vs LCF)	HCF (n=15)	LCF (n=15)	Effect size for LPA (HCF vs LCF)
Mental	*M*=46.73 (*SD*=21.31)	*M*=39.94 (*SD*=25.17)	d = 0.29	*M*=55.55 (*SD*=31.64)	*M*=42.07 (*SD*=30.07)	d = 0.44
Physical	*M*=6.64 (*SD*=6.33)	*M*=11.72 (*SD*=13.34)	d =-0.45	*M*=20.47 (*SD*=27.57)	*M*=17.60 (*SD*=31.21)	d = 0.10
Temporal	*M*=53.64 (*SD*=30.50)	*M*=33.50 (*SD*=33.50)	d = 0.62	*M*=50.20 (*SD*=29.51)	*M*=52.47 (*SD*=34.31)	d = -0.07
Performance	*M*=85.64 (*SD*=11.40)	*M*=78.89 (*SD*=20.31)	d = 0.38	*M*=82.87 (*SD*=22.54)	*M*=86.73 (*SD*=16.32)	d = -0.20
Effort	*M*=41.27 (*SD*=24.32)	*M*=39.72 (*SD*=29.30)	d = 0.06	*M*=46.47 (*SD*=31.35)	*M*=37.87 (*SD*=33.77)	d = 0.26
Frustration	*M*=21.55 (*SD*=26.61)	*M*=23.83 (*SD*=24.92)	d = -0.09	*M*=19.93 (*SD*=17.53)	*M*=23.86 (*SD*=24.35)	d = -0.19

Note. A positive effect size means that the mean in HCF group was higher than LCF group while a negative effect size means that the mean in LCF group was higher than HCF group

Table 5. Effect size for the six components of NASA-TLC in comparison between HPA and LPA

	Effect size for HCF (HPA vs. LPA)	**Effect size for LCF (HPA vs. LPA)**
Mental	*d*=0.32	*d*=0.08
Physical	*d*=0.64	*d*=0.25
Temporal	*d*=-0.11	*d*=0.56
Performance	*d*=-0.18	*d*=0.06
Effort	*d*=0.18	*d*=-0.06
Frustration	*d*=-0.07	*d*=0.00

Note. A positive effect size means that LPA group was higher than HPA while a negative effect size means that HPA group was higher than LPA group.

VAS-F, RPE-M, FS, and FAS

In Table 6, the means and standard deviations as well as effect sizes are described for VAS-F, RPE-M, FS, and FAS. A mixed ANOVA was run to compare by time (pre/post), CF, and PA level for each variable. For VAS-F, there were no significant main effects of time ($F(1,55)=1.30, p>0.05$), PA ($F(1,55)=0.01, p>0.05$, or CF ($F(1,55)=0.25, p>0.05$). Furthermore, there were no significant two-way interactions for PA x CF ($F(1,55)=0.25, p>0.05$), time x PA ($F(1,55)=0.17, p>0.05$), or time x CF ($F(1,55)=2.39, p>0.05$). Lastly, there was no significant time x PA x CF interaction ($F(1,55)=1.14, p>0.05$).

For RPE-M, there were no significant main effects of time ($F(1,55)=3.29, p>0.05$), PA ($F(1,55)=0.75, p>0.05$), or CF ($F(1,55)=2.38, p>0.05$). Also, no significant two-way interactions were found for PA x CF ($F(1,55)=0.07, p>0.05$), time x PA ($F(1,55)=0.11, p>0.05$), and time x CF ($F(1,55)=0.01, p>0.05$). Lastly, there was no significant three-way interaction for time x PA x CF ($F(1,55)=0.61, p>0.05$).

When examining the main effect and interaction for FS, there were no significant main effects for time ($F(1,55)=2.29, p>0.05$), PA ($F(1,55)=0.62, p>0.05$), or CF ($F(1,55)=0.12, p>0.05$). Furthermore, no significant two-way interactions were found for time x PA

($F(1,55)=0.00$, $p>0.05$), time and CF ($F(1,55)=1.95$, $p>0.05$), and PA x CF ($F(1,55)=0.92$, $p>0.05$). Lastly, the three-way interaction for time x PA x CF ($F(1,55)=0.26$, $p>0.05$) did not reach significance ($F(1,55)=0.26$, $p>0.05$)

For FAS, there were no significant main effects of time ($F(1,55)=2.79$, $p>0.05$), PA ($F(1,55)=0.46$ $p>0.05$), or CF ($F(1,55)=3.84$, $p>0.05$). Moreover, there were no significant two-way interactions between time and PA ($F(1,55)=0.13$, $p>0.05$), time and CF ($F(1,55)=2.09$, $p>0.05$), and PA and CF ($F(1,55)=2.09$, $p>0.05$). The time x PA x CF interaction was not significant ($F(1,55)=0.02$, $p>0.05$).

Table 6. Means, Standard deviations, and Effect Sizes for VAS-F, RPE-M, FS, and FAS.

		HPA		**LPA**	
		HCF (n=11)	LCF (n=18)	HCF (n=15)	LCF (n=15)
VAS-F	PRE	*M*=32.73 (*SD*=21.88)	*M*=30.39 (*SD*=20.42)	*M*=28.13 (*SD*=17.85)	*M*=38.73 (*SD*=27.49)
	POST	*M*=39.27 (*SD*=26.05)	*M*=33.83 (*SD*=24.39)	*M*=38.93 (*SD*=31.31)	*M*=32.67 (*SD*=33.39)
	Effect Size	$d = 0.30$	$d = 0.17$	$d = 0.61$	$d = 0.22$
RPE-M	PRE	*M*=2.73 (*SD*=0.90)	*M*=2.50 (*SD*=1.25)	*M*=2.80 (*SD*=2.14)	*M*=2.07 (*SD*=1.22)
	POST	*M*=3.36 (*SD*=1.36)	*M*=2.83 (*SD*=1.38)	*M*=2.93 (*SD*=1.33)	*M*=2.60 (*SD*=1.24)
	Effect Size	$d = 0.70$	$d = 0.26$	$d = 0.06$	$d = 0.43$
FS	PRE	*M*=2.55 (*SD*=1.81)	*M*=2.67 (*SD*=1.94)	*M*=2.73 (*SD*=1.53)	*M*=1.73 (*SD*=2.31)
	POST	*M*=2.09 (*SD*=2.07)	*M*=2.56 (*SD*=1.62)	*M*=2.07 (*SD*=1.75)	*M*=1.80 (*SD*=2.54)
	Effect Size	$d = -0.25$	$d = -0.06$	$d = -0.43$	$d = 0.03$
FAS	PRE	*M*=2.27 (*SD*=1.10)	*M*=2.11 (*SD*=1.28)	*M*=1.60 (*SD*=0.83)	*M*=2.33 (*SD*=0.90)
	POST	*M*=2.27 (*SD*=1.01)	*M*=2.50 (*SD*=1.20)	*M*=1.67 (*SD*=0.98)	*M*=2.87 (*SD*=1.41)
	Effect Size	$d = 0.00$	$d = 0.30$	$d = 0.08$	$d = 0.60$

Note. A positive effect size means that post-task value was higher than pre-task value.

Physical activity intention and behavior

PHYSICAL ACTIVITY INTENTION

Based on the MET value calculated from the IPAQ (light intensity =3.3 MET, moderate intensity = 4.0 MET, and vigorous intensity = 8.0 MET), each time point of intensity and minutes was described as a MET value for the PA intention and behavior. The means and standard deviations for the MET value of PA intentions are shown in Table 7.

A 2 (CF) x 2 (PA) x 2 (pre/post) mixed ANOVA was run to see the difference in MET value of PA intentions. When examining the main effect and interaction for PA intention immediately after the experiment, there were no main effects of time ($F(1,55)=0.10, p>0.05$), PA ($F(1,55)=1.06, p>0.05$), or CF ($F(1,55)=1.35, p>0.05$). Furthermore, there were no significant time x PA interaction ($F(1,55)=0.30, p>0.05$), time x CF interaction ($F(1,55)=0.10, p>0.05$) or PA x CF interaction ($F(1,55)=1.35, p>0.05$). Also, the three-way interaction between time, PA, and CF did not reach significance ($F(1,55)=0.30, p>0.05$).

For PA intention within 24 hours after the experiment, a mixed ANOVA revealed that there were no significant main effects of time ($F(1,55)=0.21, p>0.05$) or CF ($F(1,55)=0.01, p>0.05$) but there was a significant main effect of PA ($F(1,55)=6.23, p<0.05$). The students in HPA groups ($M=431.16, SD=528.62$) had a higher MET value to perform PA compared to those in LPA ($M=96.05, SD=274.01$). Furthermore, there was a significant interaction between time and PA ($F(1,55)=4.67, p<0.05$) (see Figure 2), but no significant interactions between time and CF ($F(1,55)=0.10, p>0.05$) or PA and CF ($F(1,55)=0.13, p>0.05$). Lastly, no significant three-way interaction between time, PA, and CF was found ($F(1,55)=0.84, p>0.05$).

Finally, when testing the main effect and interaction for the PA intentions within the 48 hours after the experiment, there were no significant main effects of time ($F(1,55)=1.51, p>0.05$), PA ($F(1,55)=3.84, p=0.055$), or CF ($F(1,55)=1.37, p>0.05$). No significant interactions were found between time and PA ($F(1,55)=0.84, p>0.05$), time and CF ($F(1,55)=0.72, p>0.05$), or PA and CF ($F(1,55)=2.01, p>0.05$). Lastly, the three-way interaction for time x PA x CF was not significant ($F(1,55)=0.29, p>0.05$).

Table 7. Information about PA intentions.

		HPA			**LPA**		
		HCF (n=11)	LCF (n=18)	Effect size (HCF vs LCF)	HCF (n=15)	LCF (n=15)	Effect size (HCF vs LCF)
Immediate	PRE	*M*=0.00 (*SD*=0.00)	*M*=86.33 (*SD*=240.52)	*d=0.45*	*M*=4.40 (*SD*=17.04)	*M*=2.20 (*SD*=8.52)	*d=-0.16*
	POST	*M*=0.00 (*SD*=0.00)	*M*=69.83 (*SD*=232.89)	*d=0.38*	*M*=4.40 (*SD*=17.04)	*M*=6.60 (*SD*=25.56)	*d=0.12*
	Effect Size	*d=0.00*	*d=-0.07*		*d=0.00*	*d=0.52*	
24 hours	PRE	*M*=402.05 (*SD*=462.10)	*M*=448.94 (*SD*=577.71)	*d=0.09*	*M*=134.20 (*SD*=367.33)	*M*=57.90 (*SD*=132.19)	*d=-0.28*
	POST	*M*=355.55 (*SD*=374.22)	*M*=374.22 (*SD*=574.40)	*d=0.04*	*M*=145.20 (*SD*=415.97)	*M*=125.70 (*SD*=270.95)	*d=-0.06*
	Effect Size	*d=-0.10*	*d=-0.13*		*d=0.03*	*d=0.51*	
48 hours	PRE	*M*=162.59 (*SD*=244.93)	*M*=442.44 (*SD*=841.13)	*d=0.41*	*M*=107.93 (*SD*=195.19)	*M*=62.13 (*SD*=161.73)	*d=-0.26*
	POST	*M*=195.32 (*SD*=245.09)	*M*=594.61 (*SD*=932.36)	*d=0.53*	*M*=107.93 (*SD*=195.19)	*M*=89.13 (*SD*=195.33)	*d=-0.10*
	Effect Size	*d=0.13*	*d=0.18*		*d=0.00*	*d=0.17*	

Note. A positive effect size that compares pre- and post-task means that post-test value was higher than pre-test value while a negative effect size means that pre-test value was higher than post-test value. For effect size that compares between HCF and LCF, a positive value indicates that mean in LCF was higher than HCF while a negative value indicates that mean in HCF was higher than LCF.

Table 8. Effect size to compare the PA intention between HPA and LPA

		Effect Size for HCF (HPA vs LPA)	**Effect Size for LCF (HPA vs LPA)**
Immediate	PRE	*d*=0.34	*d*=-0.47
	POST	*d*=0.33	*d*=-0.36
24 hours	PRE	*d*=-0.65	*d*=-0.89
	POST	*d*=-0.53	*d*=-0.53
48 hours	PRE	*d*=-0.25	*d*=-0.60
	POST	*d*=-0.40	*d*=-0.72

Note. A negative effect size means that value in HPA was higher than LPA.

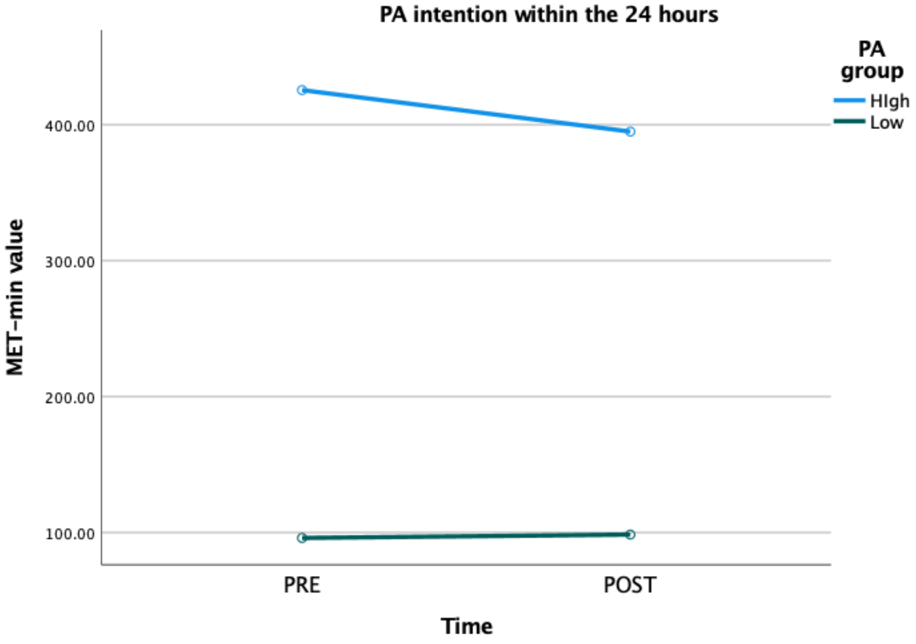

Figure 1. PA intention within the 24 hours

PHYSICAL ACTIVITY BEHAVIOR

A 2(CF) x 2(PA) ANOVA was run to see the difference in actual behavior. Means and standard deviations of actual PA behavior are described in Table 9. There was no significant main effect of PA ($F(1,55)=2.39$, $p>0.05$) or CF ($F(1,55)=0.69$, $p>0.05$) or PA x CF interaction ($F(1,55)=0.03$, $p>0.05$) immediately after the experiment.

When the group difference was examined for the behavior within the 24 hours after the experiment, there was a significant main effect of PA ($F(1,55)=6.05$, $p<0.05$) and CF ($F(1,55)=4.16$, $p<0.05$). Compared to LPA groups ($M=88.18$, $SD=156.43$), students in HPA groups had higher MET values within the 24 hours after the experiment ($M=309.78$, $SD=399.53$). Also, the students in LCF groups ($M=275.36$, $SD=358.28$) had a significantly higher MET value than those in HCF groups ($M=97.77$, $SD=231.25$). However, there was no interaction between PA and CF ($F(1,55)=1.81$, $p>0.05$).

Lastly, there was also a significant main effect of PA ($F(1,55)=4.97$, $p<0.05$) and CF ($F(1,55)=4.65$, $p<0.35$) on the PA behavior within the 48 hours after the experiment. The students in HPA groups ($M=479.09$, $SD=798.44$) had a significantly higher MET value than LPA groups ($M=90.73$, $SD=159.86$). In addition to PA, the students in LCF groups ($M=433.89$, $SD=761.19$) had higher MET value than those in HCF ($M=88.35$, $SD=146.68$). However, there was no significant interaction between PA and CF ($F(1,55)=2.41$, $p>0.05$).

Table 9. Information for PA behavior.

	HPA			LPA		
	HCF (n=11)	LCF (n=18)	Effect size	HCF (n=15)	LCF (n=15)	Effect size
Immediate	*M*=105.45 (*SD*=234.11)	*M*=79.50 (*SD*=167.93)	*d=-0.13*	*M*=51.30 (*SD*=106.29)	*M*=12.00 (*SD*=46.48)	*d=-0.48*
24 hours	*M*=147.41 (*SD*=344.06)	*M*=409.00 (*SD*=407.18)	*d=0.68*	*M*=61.37 (*SD*=87.09)	*M*=115.00 (*SD*=203.87)	*d=0.34*
48 hours	*M*=145.05 (*SD*=200.79)	*M*=683.22 (*SD*=953.93)	*d=0.70*	*M*=46.77 (*SD*=72.40)	*M*=134.70 (*SD*=208.70)	*d=0.56*

Note. A positive effect size means that value in LCF was higher than HCF group.

CHAPTER V: DISCUSSION

The purpose of this study was to investigate the effect of CF on exercise intention and behavior among HPA and LPA individuals. The manipulation check to assess changes in subjective fatigue, mental exertion, affect, or arousal in response to the CF task did not reach significance. However, when the effect size was calculated, there was a small-sized effect of time (pre-and post-cognitive task) on subjective fatigue in HPA-HCF and LPA-LCF and a medium-sized effect in LPA-HCF. This effect size indicates that both the HCF groups and LPA-HCF experienced higher fatigue after the cognitive task compared to the pre-cognitive task. This finding was consistent with past studies by Bray and his colleagues (Brown & Bray, 2019; Harris & Bray, 2019). Both studies showed that participants reported higher subjective fatigue after they completed the high cognitively demanding task. In addition, Bray and colleagues found that HCF groups showed a larger effect size in subjective fatigue compared to LCF groups. In this study, results showed a consistent finding, with HCF groups showing higher mental fatigue compared to LCF groups. On the other hand, the LPA-LCF decrease their subjective fatigue. This finding was something unexpected because, in contrast, the HPA-LCF group increased their subjective fatigue after the cognitive fatiguing task. Furthermore, HPA-HCF had a medium-sized effect of time on mental exertion while both LCF groups had a small-sized effect of time. These effects suggest that those groups indicated that their mental exertion was higher after the cognitive task compared to pre-cognitive task. On the other hand, the LPA-HCF group did not show a significant effect of time on mental exertion, such that only this group did not experience any change in mental exertion after the cognitive task relative to pre-cognitive task. The increase in mental fatigue after the completion of the cognitive task in the HPA-HCF and both LCF groups was also consistent with the studies by Bray and colleagues (Brown & Bray, 2019; Harris & Bray, 2019), but the lack of a difference between pre-cognitive task and post-cognitive task in LPA-HCF group in this study was a surprising finding. The decrease in subjective fatigue in the LPA-LCF group and no difference in mental exertion in the LPA-HCF were unexpected results in this study. This could be because the LCF groups may have struggled to distinguish between subjective fatigue and mental exertion. Future studies should distinguish more clearly between subjective fatigue and mental exertion especially when these measurements are assessed online.

In addition, both of the HCF groups showed a small-sized effect of time to decrease their feelings (i.e., pleasure) after the cognitive task while both of LCF groups had a small-to-medium sized effect to increase their arousal after the cognitive task. This means that after the cognitive task, HCF groups experienced a negative emotion while the LCF groups did not change their affect level. On the other hand, the LCF groups showed higher arousal such that the LCF groups may have experienced more energy or excitement after the cognitive task.

For PA intention and behavior, the results showed that there were no significant group differences in PA intentions and behavior immediately after participation in the experiment. However, when examining the effects of CF on PA intention within the 24 hours after participating in the experiment, the results revealed that there was a significant main effect of PA and a PA x time interaction. This interaction shows that compared to the time prior to the cognitive task, the HPA groups showed lower intentions in MET value after the cognitive task. On the other hand, the LPA groups showed higher intentions in MET value after the cognitive task. However, there was still significant differences in MET value between the HPA and LPA groups in both pre- and post-cognitive task. This difference shows that the HPA groups had higher PA intentions than the LPA groups at both time points relative to the cognitive task. Furthermore, when PA behavior was analyzed, there was a main effect of PA and CF on PA behavior within the 24 hours after participating in the experiment. These findings confirm that HPA individuals had higher intention and performed more PA than LPA individuals. In addition, although there was no difference in intention to participate in PA after the cognitive task between HCF and LCF, the actual behavior was influenced by the cognitively demanding task within 24 hours. Furthermore, for the intention and behavior within 48 hours after the experiment, there was no main effect of PA or CF or interaction on PA intention. However, there was a significant main effect of PA and CF on PA behavior. These findings indicate that there was no difference in intention to participate in PA within the 48 hours, but HPA actually participated in more PA compared to LPA. Furthermore, LCF engaged in PA significantly more than HCF regardless of intention.

These results confirm that HPA individuals expectedly engaged in PA significantly more than LPA individuals within the 24 to 48 hours after the experiment. A possible explanation could be that HPA individuals had a positive evaluation toward PA, resulted in participating in

PA (Marshall & Biddle, 2001). Moreover, although there was no group difference in PA intention within the 48 hours after the experiment, HPA individuals engaged in PA significantly more than LPA individuals. This finding indicates that HPA individuals participated in PA within the 48 hours after the experiment regardless of their intention. Because PA is a frequent behavior among HPA individuals, the automatic processes that initiate and control the behavior could occur despite the CF manipulation and in comparison to LPA individuals who required a conscious decision-making to engage in PA (Ouellette & Wood, 1998). It is important to note that the self-reported PA behavior at baseline was consistent with the behavior measured in this experiment. Yet, this experiment showed that the CF still had an impact on the PA behavior,

Regardless of PA status, both HCF groups participated in PA significantly less than LCF groups within the 24 hours to 48 hours after the experiment. It is possible that the cognitively demanding task could have reduced the resources for self-regulation that were necessary to execute their intention of PA into actual behavior (Hagger et al., 2009). Moreover, there was a negative small-sized effect of time on FS among the students who completed the HCF task. This result is consistent with the study by Heatherton and Wagner (2011) that negative emotions resulted from a cognitively demanding task may have changed individual's behavior to pleasuring behaviors (i.e., resting) instead of keeping the intention to participate in PA. Although this study did not examine the evaluation of subjective benefits of exercise, higher mental exertion may have lowered subjective evaluations of benefits of PA, in turn HCF groups decided not to participate in PA (Harris & Bray, 2019).

In addition to investigating the effects of CF on PA intention and behavior, this study assessed the perception of the CF manipulation task to see how differently HPA and LPA individuals perceived the cognitive task. The results showed that there was no significant group difference in the six components of the NASA-TLX. However, when effect sizes were calculated, there was a small-sized effect of the cognitive task on the mentally demanding components, such that the HCF groups showed higher perceptions of mental demands of the task than LCF groups. Furthermore, when the mental demand perception was compared between HPA and LPA who completed the HCF task, there was a small-sized effect of PA level on mental demanding perception, such that LPA individuals tended to feel the task was more mentally demanding than HPA individuals. In addition to the mental perception of the task, there was a small-to-medium-sized effect of PA on the physically demanding components, such that compared to HPA, LPA individuals reported a higher perception of the physical demands of the task. It is interesting to note that HPA and LPA showed different mentally demanding perceptions of the HCF task, which could explain why LPA showed medium-sized effect on subjective fatigue and decided not to participate in PA. Furthermore, LPA individuals perceived higher physical demands of the cognitive task. This could explain why individuals deteriorate PA performance when they are cognitively fatigued (Aitken & MacMahon, 2019).

When VAS-F, RPE-M, FS, FAS, PA intention, and PA behavior were analyzed using age as a covariate, the results were the same for VAS-F, RPE-M, FS, FAS, and PA intention. However, the main effect of CF on PA behavior within the 24 hours to 48 hours after the participants completed the experiment became non-significant. In future studies, it is suggested that age be matched when completing the random assignment if the researchers are not interested in age as a moderator. However, it could be interesting for future studies to investigate the effects of CF on PA intention and behavior with age as a moderator such as comparing young adults in their early 20s to and those in their late 20s.

There are limitations of this study. First, it is important to note that the HCF groups performed significantly more trials than the LCF groups even though the duration of the task and stimuli, intervals between stimuli, and duration of feedback were consistent between conditions. It is possible that HCF groups responded to the stimuli more quickly than LCF groups, so that they performed more trials. Thus, HCF may have shown the higher perception of the mental demands of the task and experienced higher fatigue and mental exertion because of the total number of trials in addition to the different task characteristics. Furthermore, it could be possible that the HCF showed higher subjective fatigue based upon the time-based resource sharing model (TBRS) which proposes that CF could be induced by the complex task and time-pressure (Barrouillet et al., 2004). This means that compared to LCF groups, HCF groups may have felt more pressured to respond to the stimuli quickly, and in turn this brought higher fatigue. Second, this study had a small sample size, which resulted in a large variance and inconsistent findings. Thus, future studies are needed with larger sample sizes. Lastly, this experiment failed to produce a manipulation check with respect to subjective fatigue, mental exertion, feelings, and arousal. Although the cognitive task resembled the one used in Harris and Bray's study that successfully produced mental fatigue in HCF group, their study had LCF group watch a video documentary while HCF group performed the same task. On the other hand, LCF groups in this study were performed in more real-life settings, so that the LCF groups also performed a task (albeit a less cognitively demanding task) to control for differences within the groups. Yet, having LCF groups perform less cognitively demanding task may still have led them to mental fatigue to some degree, in turn the difference between HCF and LCF groups became smaller.

However, there are strengths of this study as well. First, to my knowledge, it is the first study that examined the effects of CF itself on PA intention and behavior and compared between HPA and LPA individuals. Although the results showed an expected result that HPA individuals participated in PA more than LPA individuals, this study revealed different perceptions to the cognitive task between HPA and LPA, in which LPA showed higher mental and physical demanding perceptions to the cognitively demanding task. Although future studies are needed to assess the differences in perceptions toward CF task, this study showed an important point that the different perceptions would lead to unhealthy behaviors in addition to PA habits and evaluation. In addition, this study used a cognitive task performed on participants' mobile phones. This allowed for an examination of cognitive fatigue in a real-life setting. Past studies (Brown & Bray, 2019; Ginis & Bray, 2010; Harris & Bray, 2019) showed the impact of CF on mental fatigue, exercise planning, decision-making, and behavior, but these outcomes were examined in research-lab settings. In contrast, in this experiment, participants were able to participate in the study anywhere and anytime convenient for them. That could establish further knowledge that the CF has still an influence in PA behavior in real-life settings for college students. Using a cognitive task on mobile might make it possible for future research to examine the studies of cognitive function and fatigue in real-life settings. Lastly, as a future direction, using a classroom lecture as a CF manipulation would be interesting because that could measure the effects of CF in more real-life setting where university students spend their time in daily life. This might compare how their subjective fatigue, mental exertion, feelings, and intention to participate in PA may change before and after the lecture. In addition to these factors, it would be interesting to assess individuals' mind-wandering during the lecture. Past studies show that those with less cognitive resources tend to mind-wander, which is associated with decrements in performance (Randall et al., 2014). Thus, assessing if students mind-wander during the class could be related to CF and performance in class and using PA level as a moderator could be a great question to be followed up.

In conclusion, there was an effect of CF on PA intention and behavior. HPA individuals participated in PA significantly more than LPA individuals. However, when individuals were exposed to a cognitively fatiguing task, they engaged in PA significantly less than when they were not exposed. A possible reason why they decided not to participate in PA regardless of their intention may be their different perceptions of the cognitively demanding task.

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