BRAIN HEALTH AND ACTIVE LIVING: A SOCIAL ECOLOGICAL APPROACH

By

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DISSERTATION

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ABSTRACT

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Advocating active lifestyles and improving brain health across the lifespan is one of the universal and ultimate goals for Healthy People 2030. Unhealthy movement behaviors (physically inactive, excessive sedentary behavior, and insufficient sleep) and high prevalence of depression and cognitive impairment among young adults keep challenging higher education and public health systems. A comprehensive understanding of the determinants and mechanisms of movement behaviors and brain health is needed. Grounded in the social ecological model, this dissertation was to examine the behavioral and psychosocial mechanisms of brain health (depression and cognitive function) among young adults (18-45 years old).

Study 1 (Chapter 2) examined the effects of individual determinants (i.e., sociodemographic factors and weights status) and adherence to the 24-hour movement behavior guidelines on depression among 278 college students (187 females; M_{age} = 22.38). Participants completed the validated depression survey and wore the accelerometers (GT9X ActiGraph) assessing their 24-hour movement behaviors. Results revealed significant effects of individual determinants on the prevalence of depression, but not on adherence of the 24-hour movement behavior guidelines. No significant associations were found between adherence to the 24-hour movement behavior

guidelines and the likelihood of depression (odds ratios ranged from 0.56 to 1.85; $p > 0.05$). It is concluded that adherence to the 24-hour movement behavior guidelines was not a direct determinant of the prevalence of depression

Study 2 (Chapter 3) further investigated the associations and psychosocial mechanisms among all levels of social ecological factors, 24-hour movement behaviors, and brain health outcomes (i.e., depression and cognitive function). A total of 111 college students (81 females) were included in this study. They completed assessments on social ecological factors, 24-hour movement behaviors, and depression. A subgroup (n = 60) performed a computerized cognitive function test assessing their spatial working memory. Results indicated no significant group differences of perceived competence and perceived social and built environmental support between groups who met and who did not meet the 24-hour movement behavior guidelines. Perceived competence was the most influential factor of depression and served as a mediator in the relationships of perceived social support and home environment with depression. Sedentary behavior exhibited significant associations with spatial working memory after controlling for social ecological factors. These findings suggest that improving young adults' competence beliefs toward physical activity is an operational strategy to alleviate depressive symptoms among young adults. Sedentary behavior demonstrated to be beneficial for spatial working memory in this study while more evidence is warranted.

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DEDICATION

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CHAPTER ONE

Introduction

Promoting active lifestyles and improving brain health is one of the primary goals in Healthy People 2030 [1]. Brain health among young adults, especially college students, has gained increasing attention in education and public health systems. More than 20% of college students are depressed in the United States [2]. Meanwhile, 21.6% of American adults (16- to 65-year old) reported 12-month non-medical psychoactive substance use for cognitive enhancement [3]. Maintaining healthy movement behaviors, such as regularly participating in physical activity (PA), sitting less, and having a quality sleep, are suggested to improve and retain brain health [4–7]. In 2018, the United States released the second edition of Physical Activity Guideline for Americans and extended the significant benefits of an active lifestyle (e.g., engage in PA and reduce sedentary behavior) on brain health, such as increasing cognitive function and decreasing depression [8]. Some other countries, such as Canada and Australia, also developed comprehensive 24-hour Movement Behavior Guidelines (including PA, sedentary behavior, and sleep), in order to promote active lifestyles and enhance overall health. College students constitute a significant proportion of the young adult population, and young adulthood is a critical period for establishing healthy behaviors and stabilizing cognitive performance for the development of future life patterns [9,10]. Given the high prevalence of depression and the increasing rate of cognitive impairment among college students [2,3], it is urgent to employ a comprehensive approach to understand the influential factors associated with their daily behaviors and brain health outcomes.

Social Ecological Model

The social ecological model has been widely utilized to guide research in order to comprehensively understand individuals' health and behaviors [11]. According to the social ecological model, individuals' behavioral decisions are influenced by multiple facets of individual, social, and built environments. The analyses of a behavior require a focus not only of the factors from the individual level but also of the multi-dimensional and complex nature of surrounding environments [11,12].

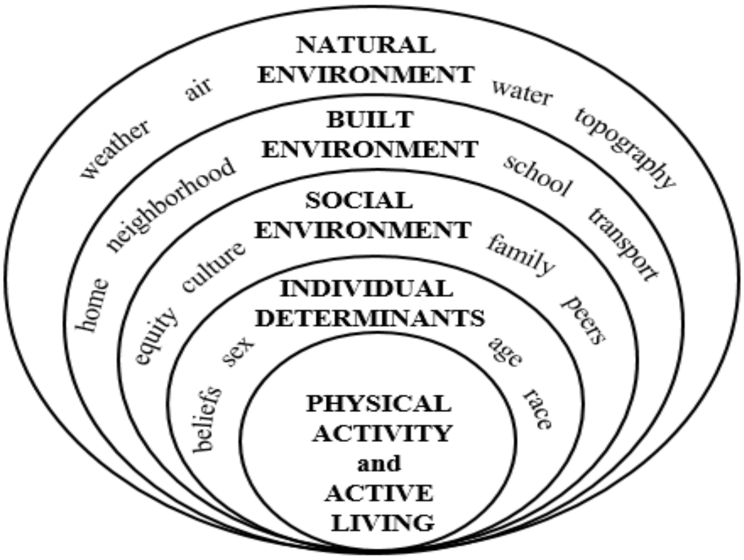

Figure 1. Social Ecological Model Adapted from Sallis et al. [12]

Specifically, individual factors, including socio-demographic factors (e.g., age, sex, race/ethnicity, weight status) and sociocultural characteristics (e.g., perceived competence and motivation) are related to the changes of one's movement behaviors [13,14]. Perceived competence, especially perceived competence of PA and sport, refers to one's confidence in abilities/capabilities to participate in PA and master sports skills. Individuals with higher perceived competence tend to have higher PA participation, especially moderate-to-vigorous physical activity (MVPA) [15–18].

Besides the individual factors, perceived social support from family and peers can also affect one's behaviors [12,19]. The social support environment is primarily created by the interactions of individuals with their family members, peers, colleagues, teachers, and coaches. Perceived social support refers to one's perceptions of the support (any behavior that assists one in achieving desired goals or outcomes) he/she received from others, such as perceived encouragement/feedback for PA from family and peers. Research has shown that when a person perceives positive social support for PA participation, he/she is more likely to engage in PA and reduce sedentary behavior [19,20].

In the social ecological model, the supportive built environment (i.e., physical and organizational settings at school, home, and neighborhood) can also influence one's behaviors [14,21]. The built environment refers to the physically external and objective factors one would come into contact with during the day. For instance, people's daily activities, such as PA and sedentary behavior, must take place in a physical setting that may influence his/her decisions of being physically active or sedentary. Limited studies have showed that a supportive built environment for PA including the school (e.g., indoor and outdoor facilities), home (e.g., equipment and backyard), and neighborhood settings (e.g., sidewalk, traffic safety, crime safety), is correlated to one's PA participation and sedentary behavior [14,22,23].

24-hour Movement Behaviors

During a consecutive 24-hour cycle, people spend their time in mainly three movement behaviors, including different intensity levels of PA (i.e., light PA [LPA], moderate PA [MPA], and vigorous PA [VPA]), sedentary behavior, and sleep [24]. PA has been defined as any bodily movement produced by the contraction of skeletal muscles that results in energy consumption [25]. According to the metabolic equivalents (METs) generated by the body movement, daily activities such as slow walking and dusting are categorized as LPA (1.5-3 METs); fast walking, baseball, and vacuuming are categorized as MPA (3-6 METs); running, basketball, and heavy yard work are categorized as VPA (over 6 METs). Sedentary behavior is any waking behavior with less than 1.5 METs while in a sitting or reclining posture [26]. Research documented that people in general spent, on average, approximately 20% of their time involving in different levels of PA (~5-hour), 40% of their time on sedentary behavior (~9-hour), and another 40% of their time on sleep (~9-hour) [24]. In 2016, Canada released the Canadian 24-hour Movement Behavior Guidelines for residents to regulate healthy daily movement behaviors for health benefits (MVPA ≥ 60 minutes/day; screen time < 2 hours/day; sleep ≥ 8 hours/night) [27]. Despite these recommendations, young adults in the U.S. spent over 10 hours/day being sedentary [28]; over 60% of them slept less than 7 hours per night [29,30]; and only 55.3% of them achieved the daily 60-minute MVPA recommendation [30].

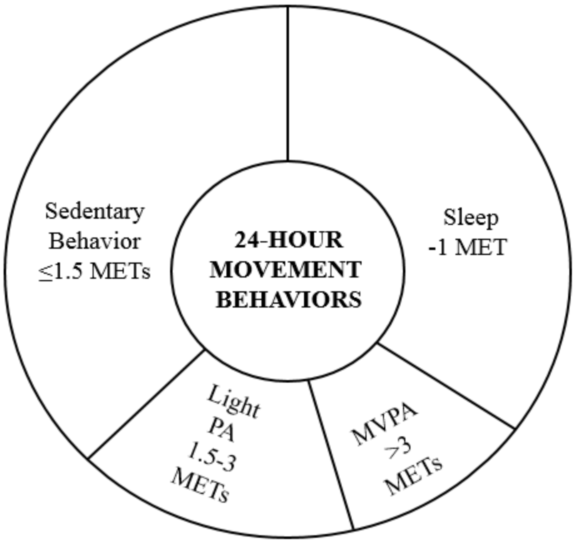

Figure 2. 24-hour Movement Behaviors Adapted from Tremblay et al.[31]

In past decades, researchers in social and behavioral sciences have emphasized the importance of using a social ecological approach to understand young adults' movement behaviors [13,14,19,32,33]. Researchers have come to a consensus that college students' PA participation is associated with multi-level factors, such as self-efficacy and motivation at the individual level [20,34] and family's and peer's support at the social environmental level [19,20]. The emerging evidence indicated that built environmental factors, especially the neighborhood environment were also a significant correlate of PA participation among the adult population [14,22,23,32,33]. For instance, college students' perceived walkability on campus and neighborhood safety were associated with their walking behaviors and PA participation [14,23]. It was noted that the effects of social support and built environmental support were limited when individual-level factors (i.e., perceived barrier, self-efficacy, enjoyment of PA) were taken into account [14]. A recent review identified over 40 studies that simultaneously examined social and built environment factors on PA among an adult population and reported significant associations between PA and both social and built environmental factors [35]. However, among those studies, only one study used accelerometer-measured PA among adults in the U.S., which found that many built environmental factors (walkability, crime safety) were associated with PA [36].

The social ecological model has also been implemented to understand the sedentary behavior in the adult population [37–40]. When separately testing factors in each layer in the social ecological model, individual-level factors, such as perceived self-efficacy and weight status, have been reported to correlate with sedentary behavior among young adults [37–39]. One's sedentary behavior is also likely to be influenced by their peers' perceptions and PA behaviors [41]. Some researchers found that built environment (e.g., neighborhood socioeconomic status [SES], crime safety, PA resources at home/apartment) is an important determinant of sedentary behavior among college students [21,42]. For instance, when living in a lower-SES and a higher risk of crime neighborhoods, college students tended to be more sedentary than those living in higher-SES neighborhood [21]. However, when concurrently examining the associations between all social ecological factors and sedentary behavior, only the factors at the individual-level (e.g., occupation, education level) became significant predictors among adults [40].

Very few studies have applied a social ecological model to explain one's sleep behavior [43]. Individual factors such as sex and race/ethnicity have been found to be influential factors in college students' sleep duration [44,45]. In de Grey and colleagues' literature review, they articulated the favorable associations of social support and sleep outcomes (e.g., sleep disturbance, sleep quality) and pointed out the scarcity of studies (n = 9) that examined sleep duration [46]. Meanwhile, no associations were found between social support and the actigraphy based sleep duration [47]. Built environmental factors such as the home design, light, traffic, noise, and density in the neighborhood are associated with individuals' length and sleep [48–50]. Although the factors in each level of the social ecological model were correlated with sleep, more evidence is needed to examine their collective effects on sleep using a social ecological framework.

It is clear that the influences of the social ecological factors on 24-hour movement behaviors, particularly on self-reported PA and sedentary behavior among adults have been well-documented [14,35,51–54]. To date, however, comprehensive associations of the 24-hour movement behaviors with various-levels of social ecological factors in young adult groups are not clear, and studies using objective measures of 24-hour movement behaviors are scarce [43,55]. Using accelerometer-measured PA, for example, Mama and colleagues found that individual factors (weight status and body image) were precedents to PA and mediated the effects from built environmental factors among adults [32]. After adjusting individual demographic factors, Whitakers and colleagues found that perceived neighborhood environments were only associated with accelerometer-measured MVPA but not with either LPA or sedentary behavior in their cross-sectional analysis [56]. Nevertheless, it remains unknown how each level of factors in the social ecological model are associated with objectively measured 24-hour movement behaviors.

Brain Health Outcomes

As defined in the 2018 Physical Activity Guideline for Americans, brain health is conceptualized as "the optimal or maximal functioning of behavioral and biological measures of the brain and the subjective experiences arising from brain function" [57]. Based on this definition, brain-related health outcomes are categorized as biological brain morphology and subjective manifestations of brain functions, such as cognitive function, depression, quality of life, and anxiety. Among them, depression has been a leading cause of disability and mortality across the lifespan [58]. Depression is "an illness characterized by persistent sadness and a loss of interest in activities, accompanied by an inability to carry out daily activities" [58]. Individuals with depression are at an increased risk of academic failure, social isolation, premature mortality, and suicide than their peers without depression [59–61].

Cognitive function, another major outcome of brain health, is known as a function to gain knowledge and comprehension [62]. Cognitive function is critical to one's performance on academic tests and performance on neuropsychological tests, such as mental processing speed, working memory, and executive function [57,62]. College students with cognitive impairment or poor cognitive function, such as poor attention, decreased processing speed or declined working memory, tend to procrastinate more on academic tasks, take cognitive-enhancing drugs, have higher risks of psychological distress, depression, morbidity and mortality [63–65]. Cognitive impairment has been demonstrated as a core feature of depression, which was estimated to occur in two-thirds of depressed individuals [58,63].

A number of studies have investigated the associations between movement behaviors and brain health outcomes among college students [4,5,66,67]. Being physically active, reducing sedentary behavior, and maintaining an appropriate length of sleep are suggested to relieve depressive symptoms and improve cognitive performance [29,66,68,69]. In a 24-hour timeframe, however, one can be a physically active person (high MVPA) while still holding a predominantly sedentary lifestyle [70]. Thus, providing a comprehensive assessment of movement behaviors can help distinguish the specific daily movement behavior and how their interactions may correlate with brain health outcomes. Nevertheless, a paucity of research investigated the 24-hour movement behaviors concurrently, and the existing evidence remains inconclusive.

Some evidence showed that sedentary behavior is independently associated with depression regardless of PA levels among the adult population [70–73]. For example, Vallance and colleagues claimed that the lower odds of depression were associated with both accelerometer assessed MVPA and sedentary behavior among overweight and obese adults [72]. By examining the 24-hour movement behaviors among both young and middle-aged adults, researchers found that sedentary behavior exhibited a small but positive association with cognitive function (more sedentary behavior was associated with better performance on processing speed) whereas neither PA nor sleep were associated with cognitive function [74]. In a research among college students, however, being more sedentary (study time) was significantly associated with higher levels of emotional exhaustion regardless of PA and sleep [73]. Sedentary behavior is likely more prominent than PA and sleep behavior on brain health outcomes when they were simultaneously involved in the analysis. Given the limited evidence, more research is warranted.

Although some researchers have documented the associations of each layer of social ecological factors with brain health outcomes, the field, in examining the comprehensive social ecological determinants of brain health, is still in its infancy [75]. Individual factors, such as sex, age, race/ethnicity, and weight status, have been found to correlate with brain health outcomes (e.g., depression, anxiety, stress, quality of life) [2,29,76,77]. Social environmental factors, such as support from family, peers, and significant others in general, were found to impact ones' brain health, in which a higher perception of social support was associated with less depression, hopelessness, and anxiety among young adults [78,79]. The built environmental factors, such as higher levels of crime safety and lower levels of walkability in the neighborhood, were associated with higher depression and lower quality of life among college students and middle-aged adults [14,80].

Given the associations between 24-hour movement behaviors and brain health outcomes, it is likely that a joint effect of the multi-level environmental factors and 24-hour movement behaviors can be assumed to explain young adults' brain health. A recent peer-supported PA intervention program provided evidence of such combined effects [81]. That is, a social-supportive environment from peers had favorable effect on reducing depressive symptoms in addition to its positive impact on PA participation [81]. More evidence is needed in regard to which social ecological factors and 24-hour movement behaviors are influential among young adults.

Future Research Directions

Given the importance of active living and brain health promotion among young adults, there is a need for studies to examine associations among social ecological factors, 24-hour movement behaviors, and brain health outcomes to capture the whole range of potential individual and environmental determinants. This study would fill the gap in understanding the behavioral, psychosocial, and environmental mechanisms towards brain health among young adults. Also, this research endeavor would launch an interdisciplinary research chain that ties different disciplines and fields to address increasing brain health issues.

First, it is likely that individual factors (e.g., perceived competence) may serve as a mediator in the psychosocial mechanism of relationships between movement behaviors and brain health among young adults. Such psychosocial mechanism of brain health has been advised among children and adolescents in Lubans et al.'s conceptual model [82]. That is, perceived competence beliefs of PA would mediate the effects of movement behaviors (PA, sedentary behavior, and sleep) on brain health outcomes. Evidence is needed to test the mediational role of perceived competence in the psychosocial mechanism among young adults.

Second, future research needs to identify the most influential behavioral, psychosocial, and environmental factors towards brain health in order to improve the effectiveness of intervention and treatment. Hence, a comprehensive approach is necessary to understand the combined and concurrent effects of all three layers of social ecological factors and all three 24-hour movement behaviors on brain health outcomes. Researchers may also consider testing the potential moderation effects of individual characteristics such as sex, race/ethnicity, weight status, and adherence to the 24-hour movement behavior guidelines (meet vs. not meet guidelines) on those associations.

Further, future research is needed to explore the possible bi-directional relationships among those variables. For example, whether it is the depression and cognitive impairment that causes the low perceived competence and low perception of social and built environmental support, and/or unhealthy movement behaviors among young adults. As such, longitudinal studies are needed to examine the longitudinal associations among social ecological factors, 24-hour movement behaviors, and brain health outcomes over several time periods and to test the reciprocal effects of those constructs.

Finally, brain health is critical to each individual at different stages of the lifespan. However, the measurements of brain health remain a significant challenge due to brain health's complexity, unpredictability, and instability. Researchers may need sophisticated instruments and approaches to study brain health and its correlates. As such, interdisciplinary research collaborations are required in future research for a better and comprehensive understanding of brain health and its correlates at the individual, social, and built environmental levels.

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CHAPTER TWO

Adherence to the 24-hour Movement Behavior Guidelines and Associations with Depression among Young Adults

Abstract

Background: Engaging in healthy daily 24-hour movement behaviors (e.g., moderate-to-vigorous physical activity [MVPA] $\geq$ 60 minutes, screen time < 2 hours, and sleep $\geq$ 7 hours) is suggested to be associated with favorable mental health outcomes (e.g., less depression and higher quality of life). Given the high prevalence of depression among young adults worldwide, the primary purpose of this study was to examine the effects of sociodemographic factors, weights status, and adherence to the 24-hour movement behavior guidelines on depression among college students. **Methods:** A total of 278 college students (187 females; *Mage* = 22.38, *SD* = 3.91) completed the validated depression survey and worn the accelerometers (GT9X ActiGraph) objectively assessing their light PA [LPA], moderate-to-vigorous PA [MVPA], sedentary behavior, and sleep duration. **Results:** The significant effects of sociodemographic factors (sex, academic level, race/ethnicity) and weight status on the prevalence of depression were observed ($p < 0.05$), but not on adherence of the 24-hour movement behavior guidelines. No significant associations were found between adherence to the 24-hour movement behavior guidelines and the likelihood of depression (odds ratios ranged from 0.56 to 1.85; $p > 0.05$). **Conclusions:** Adherence to the 24-hour movement behavior guidelines was not a direct determinant of the prevalence of depression in this study. Further studies are needed to explore the underlying psychosocial mechanisms (e.g., perceived competence, social supports) towards adherence to the 24-hour movement behavior guidelines and depression among young adults.
Keywords: Depressive symptoms; physical activity; sedentary behavior; sleep

Introduction

Depression has become one of the three leading causes of disability and one of the most common mental disorders worldwide [1,2]. From 1990 to 2017, the number of diagnosed cases of depression has reached to 25.8 million, with an increasing rate nearly 50% [1]. Young adults, especially college students, have a higher prevalence of depression than other age groups, and one in five college students in the United States was diagnosed with depression in 2019 [3,4]. People with depression have a higher risk of suicide, premature mortality, and lower life expectancy than general population [5,6]. According to the 2018 Physical Activity Guideline for Americans, young adults should engage in 150 to 300 minutes of weekly moderate-to-vigorous physical activity (MVPA) and shift from sedentary behavior to PA in any duration/intensities for the accumulative health benefits (e.g., depression, quality of life) [7]. The National Sleep Foundation suggests that an appropriate sleep duration for adults should be seven or more hours per night [8]. Researchers found that individuals with depression tend to be less active, sit more, and sleep less [9–11]; while some other studies claimed that there are no associations of depression with PA and sedentary behavior [12,13]. Given the prevalence of depression worldwide, more research is needed to explore the behavioral determinants of depression and the underlying psychosocial mechanism among young adults.

In 2016, the Canadian 24-hour Movement Behavior Guidelines were released to guide researchers and professionals in evaluating and monitoring an individual's movement behaviors (MVPA $\geq$ 60mins/day; screen time < 2 hours/day; sleep $\geq$ 8 hours) within a 24-hours cycle [14]. The individual's 24-hour movement behaviors can be distributed into a broad intensity spectrum of movements, including different intensity levels of PA (i.e., light PA [LPA], moderate PA [MPA], and vigorous PA [VPA]), sedentary behavior, and sleep [15]. Within 24 hours, the time-use components of different intensities of PA (~20%), sedentary behavior (~40%), and sleep (~40%) are mutually exclusive and exhaustive parts, in which increasing or decreasing the time on one behavior must cause the expense or rise of other behaviors [15]. However, only 55.3% of American college students achieved the daily 60-minute MVPA recommendation [16]; most college students spent over 10 hours being sedentary [17]; over 60% of college students slept less than 7 hours per night [11,16]. Some pioneering research found that adherence to the 24-hour movement behavior guidelines among different age groups was associated with individuals' health conditions [18,19]. For instance, children and youth who met three 24-hour movement behavior guidelines (MVPA, screen time, sleep) tended to have favorable health conditions (e.g., healthy weight, less emotional problems) compared to those who met one or none guideline [18]. Adamson and colleagues also found that, in a sample of 3045 adults (*Mage* = 47 years), meeting the MVPA guideline was associated with reduced depression regardless of sedentary behavior, while not meeting the MVPA guideline along with excessive sedentary behavior was related to increased depression [19].

Investigating the adherence to the 24-hour movement behavior guidelines can provide a holistic understanding of college students' daily behavior patterns and associations with mental health (i.e., depression). It was well-documented that PA participation plays a vital role in the prevention and management of depression among the adult population [20,21]. Researchers pointed out that people with depression often do not achieve the recommended level of MVPA [9,22]. Meanwhile, college students who engaged in MVPA were eight times less likely to have depression than those inactive students [23]. However, most previous studies did not consider whether the engagement in different intensities of PA (LPA, MVPA) would associate with different depression status (depressed vs. non-depressed) and only a few of them used objective

PA measures [9]. A recent review articulated that objectively assessed LPA is independently associated with many health outcomes after adjustment for MVPA among the adult population, while only a handful of studies tested the associations of LPA with mental health outcomes (n = 4; 3 of them were among old adults) [24].

Sedentary behavior has been consistently reported a detrimental factor toward physical, psychosocial, and mental health [10,25]. Excessive sedentary behavior was found to correlate with an increased risk of depression (OR = 1.25, 95% CI [1.16 to 1.35]) [10]. Adult (21-77 years) with depression, on the other hand, engaged in excessive sedentary behavior (8.5 hours per day) compared to their non-depressed counterparts [9]. However, Liao and colleagues did not find significant associations of sedentary behavior (< 3 hours/day, 3-6 hours/day, ≥ 6 hours/day) with depression regardless of MVPA among a group of Japanese adults [26]. They also pointed out that individuals who met both MVPA and sedentary behavior guidelines were less likely to show depressive symptoms than individuals who had higher sedentary behavior and were physically inactive [26]. Therefore, more evidence is warranted to examine if adherence to the recently released 24-hour movement behavior guidelines may lower the prevalence of depression among the young adult population.

Studies have shown that sleep quality (e.g., sleep duration, sleep onset latency, sleep disturbance) was closely associated with depression in young adults [27,28]. For instance, college students who slept less than 6 hours per night showed twice as high of a risk of depression than those who slept longer [29], while an additional increment of 30-minute sleep time was associated with a decreased likelihood of mental illness [27]. Vice versa, depression was also reported to correlate with sleep problems (i.e., less sleep duration, more sleep disturbance) among college students [11]. Such bidirectional relationships between sleep and depression have been presented in many studies [30]. While the bidirectional associations between sleep and depression exist, sleep as one major movement behavior in a day has not yet been investigated in combination with other movement behaviors (PA and sedentary behavior) among college students.

From the social-ecological model's perspective, the individuals' socio-demographics such as sex, age, education, race/ethnicity, and weight status are influential factors to one's behavioral choices[11,31,32] and mental health status [23,33]. For instance, female college students were less active than their male peers; White college students tended to have longer sleep duration than non-White/minority peers; and overweight/obese college students were less active but more sedentary than healthy weight peers [3,11,34]. Besides, researchers consistently report a higher rate of depression among females than their male counterparts [35,36]. College students in different academic levels of college were found to have different depression statuses [23,33]. Due to limited research collecting and objectively measuring 24-hour movement behaviors, it is critical to test the effects of sociodemographic factors on the associations between 24-hour movement behaviors and depression among college students.

This line of research can provide preliminary evidence of the adherence to the 24-hour movement behavior guidelines in the young adult population. Therefore, the purposes of this study were: 1) to test the effects of sociodemographic factors and weight status on depression and on the adherence to 24-hour movement behaviors guidelines (LPA, MVPA, sedentary behavior, sleep) among college students; and 2) to examine the effects of adherence to the 24-hour movement behavior guidelines on depression among college students after controlling for the sociodemographic factors and weight status. We hypothesize that: 1) the prevalence of depression and adherence to the 24-hour movement behavior guidelines will be significantly influenced by the sociodemographic factors (i.e., sex, academic level, race/ethnicity) and weight status (healthy vs. unhealthy weight); and 2) the prevalence of depression will be influenced by adherence to the 24-hour movement behavior guidelines (meet vs. not meet guideline) among college students.

Methods

Participants

A cross-sectional study was conducted in the 2019-2020 academic year. A total of 278 college students (91 males, 187 females; Mage = 22.38, SD = 3.91, range 18-44 years) were recruited from a public university in North Texas. Over half of them were juniors (52.9%), 19.1 % were sophomores, 15.5% were freshmen, and 9% were seniors. Their races consisted of White (30.2%), Black (21.9%), Hispanic (21.9%), Asian (18.3%), and other races (7.6%). The university institutional review board approved this study. Participants signed consent forms prior to the data collection.

Measures

24-hour movement behaviors. Participants' time spent in LPA, MVPA, sedentary behavior, and sleep (i.e., sleep duration) within a 24-hour cycle was measured objectively using the ActiGraph Link GT9X accelerometers (ActiGraph LLC, Pensacola, FL, USA). Participants were asked to wear the accelerometers on their non-dominant wrist for 24 hours per day for five consecutive school days (Monday-Friday). Participants' average daily time spent on LPA, MVPA, and sedentary behavior from 8 am to 8 pm throughout five school days was calculated and used in the final data analysis. Accelerometers were set up to capture data in 60-second epochs. The accelerometer data from the participants with a minimum of 8 hours wearing time per day for at least three days was included in the final data processing. Participants' height, weight, date of birth, and sex were inputted before downloading the data from the device. The activity counts were used to categorize different intensity levels of PA according to the recommended cut-off points: 100-2019 counts/minute for LPA, ≥ 2020 counts/minute for MVAP, and 0-99 counts/minute for sedentary behavior, respectively. Participants' sleep duration was detected using Cole-Kripke algorithm implemented in the ActiLife software (Version 6.13.3; ActiGraph, Pensacola, FL, USA) [37]. Each participant's sleep data were manually checked and double-checked with the participant's time log as needed. Their average daily sleep duration in a week was used for data analysis. In accordance with the 24-hour movement behavior guidelines [14], we categorized each of these movement behaviors into two groups: sedentary behavior < 3 hours vs. ≥ 3 hours; LPA < 50 percentile vs. ≥ 50 percentile; MVPA < 60 minutes vs. ≥ 60 minutes; and sleep < 7 hours vs. ≥ 7 hours. ActiGraph accelerometers have been previously validated to measure movement behaviors among young adults [38].

Depression. Depression was assessed using the 20-item Center of Epidemiologic Studies Depression Scale (CES-D) [39]. The CES-D assesses depressive symptoms, including depressed mood, feelings of guilt and worthlessness, feelings of helplessness and hopelessness, psychomotor retardation, loss of appetite, and sleep disturbance. Participants indicated how often they experienced the symptoms within the past seven days from *rarely/less than 1 day* (0), *a little/1-2 day* (1), *occasionally/3-4 days* (2), to *always/5-7 days* (3). Sample questions include: "I had trouble keeping my mind on what I was doing"; and "I talked less than usual". After reversely coding 4 out of the 20 items, the final depression score was the summary of the score of the 20 items (ranges from 0 to 60). The higher score indicates greater/severer of the depressive symptoms; students with a CES-D score equal or above 16 indicate a current depression and are categorized into the depressed group. This scale has been well validated and applied among young adults [40]. The internal consistency of this scale in the current study was sufficient (α =

0.75).

Weight status. Participants' weight status was generated from self-reported height (inches) and weight (lbs). Their body mass index (BMI) were then calculated based on the equation: (weight in lbs / (height in inches)^2) x 703. According to the Adult BMI Category, participants were categorized into the healthy weight group (BMI < 25.0) and the unhealthy weight group (BMI ≥ 25.0).

Procedures

The participants were a convenient sample recruited through a variety of ways, including classrooms, flyers, and snowball sampling techniques. Each participant was visited for a total of 2-3 times in order to complete all the assessments. In the first visit, participants filled out the depression survey and sociodemographic information. After the survey, participants were asked to wear a numbered watch-typed accelerometer (GT9X ActiGraph) for 24-hours a day for the following five school days and to record their wake up and sleep time using a time log. After five school days, participants were revisited in the classroom or in the lab to return the accelerometer to the research team. Participants were informed that participation is voluntary, and their answers to the survey and their daily activities during the week will not influence any of their academic performance.

Data Analysis

The data analysis was processed using SPSS Version 25.0 (IBM Corp, Armonk, NY, USA). Because all variables were dummy coded, a listwise deletion was applied [41]. Three main steps of data analysis were initiated. First, the descriptive analysis was utilized to describe the distributions of depression and adherence to the 24-hour movement behavior guidelines across different sociodemographic factors (sex, academic level, race) and weight status. Second, a series of binary logistic regression tests were conducted to examine the effects of sociodemographic factors and weight status on depression and on the adherence to the 24-hour movement behavior guidelines, respectively. All variables were dummy coded as follows: depressed vs. non-depressed ([CES-D <16] = 0; [CES-D ≥ 16] = 1); LPA (< 50 percentile = 0; ≥ 50 percentile = 1); MVPA (< 60-minute = 0; ≥ 60-minute = 1); sedentary behavior (≥ 3-hour = 0; < 3-hour = 1); and sleep (< 7-hour = 0; ≥ 7-hour = 1), sex (male = 0; female = 1); academic level (freshman = 0; sophomore = 1; junior = 2, senior =3); race/ethnicity (White = 0; Black = 1; Hispanic = 2; Asian = 3; others = 4); and weight status (healthy weight = 0; unhealthy weight = 1). Lastly, the binary logistic regression was applied to test the effects of adherence to the 24-hour movement behavior guidelines on depression, and the sex, academic level, race/ethnicity, and weight status were entered as confounders in the model. The odds ratios (OR) and 95% confidence interval (CI) were presented as estimates of effect measures. The statistical significance was set up at an alpha level of 0.05 for all tests.

Results

Table 1 shows the descriptive results of depression and adherence to the 24-hour movement behavior guidelines in terms of sociodemographic factors and weight status. Among these college students, the prevalence of depression was 27.0% (i.e., CES-D ≥ 16) with twice as high of a risk of depression among females than males. By increased academic levels in college (freshman to senior), an increased prevalence of depression was observed (from 16.3% to 40.0%). Minority college students held a higher prevalence of depression than their White peers. A slightly higher prevalence of depression was observed in college students with unhealthy weights compared to their peers with healthy weights. Most studied college students met the 60-minute daily MVPA guideline (87.2%). Students who were below or above 50 percentiles of LPA were distributed relatively evenly, except only around 30% of sophomores and 30% of Hispanics reached above 50 percentiles. Students who had sedentary behavior, lower or more than 3 hours, were also evenly distributed across different socio-demographics and weight status. Only 33.3% of college students met the sleep guideline (≥7 hours/night). A higher proportion of females than males and a higher proportion of White students than other minority students met the sleep guideline.

----------------------------------insert Table 1 here -------------------------------------

Table 2 demonstrates the effects to sociodemographic factors and weight status on depression and the adherence to the 24-hour movement behavior guidelines. It revealed that sex, race/ethnicity, and weight status had significant effects on depression prevalence. Specifically, females had more than twice the odds of reporting depressive symptoms than male peers; senior students and Asian students had more than triple the odds of reporting depressive symptoms than their freshmen and White peers, respectively. In terms of adherence to the 24-hour movement behavior guidelines, sex, race/ethnicity, and weight status showed different effects on different movement behaviors. Compared to White students, the odds of reaching/above 50 percentiles of LPA were lower among students of Hispanic origin (OR = 0.36). Females were more likely to meet the sleep guideline compared to male peers (OR = 2.58). Compared to White students, the odds of meeting the sleep guideline were significantly lower among Black and Hispanic students (OR = 0.24 and OR = 0.43, respectively).

----------------------------------insert Table 2 here -------------------------------------

Table 3 shows the effects of adherence to the 24-hour movement behavior guidelines on depression after controlling for sociodemographic factors and weight status. Adherence to the 24-hour movement behavior guideline (LPA ≥ 50 percentile; MVPA ≥ 60-minute; sedentary behavior < 3-hour; sleep ≥ 7-hour) had non-significant effects on depression among this sample, with OR ranging from 0.56 to 1.85. A lower rate of depression was observed among college students who met the MVPA, sedentary behavior or sleep guidelines compared to students who did not meet those guidelines, respectively. College students with LPA above 50 percentiles had a higher rate of depression than their peers below 50 percentiles of LPA.

----------------------------------insert Table 3 here -------------------------------------

Discussion

Targeting the 24-hour movement behaviors (e.g., LPA, MVPA, sedentary behavior, and sleep) provides a comprehensive picture of young adults' daily living and movement patterns. This is one of the first studies that collectively investigated college students' adherence to the 24-hour movement behavior guidelines and its associations with depression. The most salient and interesting finding is that young adults who adhered to the 24-hour movement behavior guidelines exhibited somewhat less of likelihood of depression (OR ranged from 0.56 to 1.85) but such associations did not reach a significant level in this population. Instead, the findings highlighted the sociodemographic factors and weight status as individual-level determinants of depression. Minority female students who are overweight/obese tend to have higher risks of depression compared to their White male peers with healthy weights. The risk of depression is more likely to increase from freshman to senior years at college. Specific discussions are as follows.

Consistent with most past reports, this study revealed the high prevalence of depression (27%) among studied college students, especially twice among females than males (32.1% vs. 16.5%) [3,33,35]. Though college students were fairly distributed in meeting the LPA and sedentary behavior guidelines, nearly 90% of them were very active and met the 60 minutes daily MVPA guideline, but only one-third of them had 7 hours of sleep per night. Many previous studies also observed the lower proportion of college students met the sleep guideline [11,29]. The result of their high participation in MVPA, however, is contracted with many previous findings, which found only half of the college students met the 150 minutes weekly MVPA guidelines [3,16]. Data from the current study seems exceptional, while a few reasons might explain such differences. First, most participants in this study were from the majors of Kinesiology/Exercise Science/Athletic Training (79.1%), while the rest were from majors of Nursing (20.9%). Thus a higher daily MVPA might be expected because some of their courses are activity-oriented/hands-on practices, and students enrolled in the Kinesiology program were also found to be more active than non-Kinesiology majors [42]. It was also nearing the end of the semester and students may have been sleeping less to complete assignments and prepare for examinations. Second, the built environment on campus might also contribute to students' PA participation [43]. The campus where those participants were studying at has good walkability and has at least 10-15 minutes walking distance from one campus to another. Meanwhile, students in Kinesiology and Nursing majors have massive travel requirements between campuses because main buildings in their departments are located on both campuses. A third reason might be attributed to the wrist-worn accelerometer in the present study. Research has previously found that wrist-worn accelerometer overreported PA levels compared to the hip-worn measures [44].

A critical finding of this study was to identify the effects of sociodemographic factors and weight status on depression among studied young adults. Consistent with most past reports, sex as a key sociodemographic factor, revealed a higher risk of depression among females than males [3,35,36]. College students' sociodemographic status, such as academic level and race/ethnicity, also exhibited significant effects on the prevalence of depression in this sample. College students are at a transition stage from adolescence to adulthood experiencing reduced family support, marked shifts in social roles, and increased relational instability [45]. They encounter a high risk for negative mental health consequences and are vulnerable to academic and financial stress [46]. Those stress and discomfort would be accumulated throughout their college years. Asian college students in the United States were also reported to have higher depression than their White peers [47]. Researchers have observed the higher prevalence of depression among obese college students compared to normal-weight students [34,48]. This finding highlights the importance of addressing depression issues among college students who are females, minorities, seniors, and under unhealthy weight conditions. Although these individual-level determinants of depression were supported by previous studies, research with more representative samples is warranted due to the limited sample size in the current study.

It was interesting that minority groups, especially Hispanic students, tended to have less LPA compared to their White peers. As stated earlier, the increasing or decreasing time in one movement behavior would cause a reduce or rise of other movement behaviors within a 24-hour cycle. In our sample, the adherence of the MVPA guideline was higher among minority groups compared to White group, which might explain a lower adherence to LPA in minority groups. The effect of sex on sleep duration was inconsistent across studies. When using objective measures on sleep, Lemola and colleagues observed longer sleep duration among female adults than male counterparts [49]. By subjectively measuring sleep duration (self-reported Pittsburgh Sleep Quality Index), Quick and colleagues found no significant sex differences in achieving 7-hour sleep per night while Orzech and colleagues reported longer sleep duration among male college students [50,51]. Also, researchers observed that minority students, in particular Black and Hispanic students, were less likely to meet the sleep guideline compared to their White peers [49].

Noting that reduced sleep duration may impair college students' mental health and academic performance [50], the health professionals in college may need to provide effective coping strategies and interventions for college students, especially males and minority groups. For example, adding the sleep guideline into the newsletters or webpages, or including questions of sleep on the health history form.

One primary purpose of this study was to test the effects of adherence to the 24-hour movement behavior guidelines on depression. In contrast to our hypothesis, we did not observe significant effects of adherence to each 24-hour movement behavior guideline on the likelihood of depression. Similar findings were also observed in previous studies. Using self-reported PA, Nyström and colleagues found that engaging in high PA or low PA was not significantly or negatively associated with depression in adults [13]. Teychenne and colleagues followed 1511 adult women (18-45 years) over three years and found being sedentary (< 4 hours vs. ≥ 4 hours) did not influence depression cross-sectionally and longitudinally [12]. Although no significant effects were observed in the current study, the odds ratios revealed that students who achieved MVPA, sedentary behavior, and sleep guidelines had less likelihood of depression (OR = 0.56-0.86). By investigating self-reported PA and sleep, Ghrouz and colleagues also observed that college students engaged in MPA and VPA were in a significantly lower likelihood of depression than those in LPA. College students with good sleep quality were less likely to have depression than those with poor sleep quality [23]. Thus, adhering to the 24-hour movement behavior guidelines (i.e., MVPA, sedentary behavior, and sleep) may provide positive effects in the treatment of depression among college students.

Adhering to the 24-hour movement behavior guidelines may not be indicative to the likelihood of depression. This might due to other unassessed factors (e.g., motivation, competence, social support, and built environmental support), which may play a more significant role to depression among college students. For example, Keeler and colleagues found that a peer-supportive PA intervention program focusing on college students' basic psychological needs improved their PA participation and reduced depressive symptoms [52]. When participating in PA provides positive experiences, such as engagement, competence, and enjoyment, a treatment function on depression can be achieved in the PA-oriented interventions [53]. The built environment conditions, such as walkability and residential condition, were found to influence college students' movement behaviors, including PA, sedentary behavior, and sleep [54,55], as well as depression [56]. Peltz and Rogge found that environmental factors (e.g., noise, environmental sleep hygiene) were associated with sleep, and therefore influenced depressive symptoms among college students [54]. As such, future studies may need to consider the potential mechanism of the individual factors (e.g., motivation, perceived competence), social support (e.g., parent and peer support), and built environmental support (e.g., campus and neighborhood walkability) on 24-hour movement behaviors and depression among the college student population.

A marked strength of this study is the massively and objectively assessed movement behaviors in a 24-hour cycle among a large sample of college students. We applied the most updated 24-hour movement behavior guidelines to explore the effects of adherence to the 24-hour movement behavior guidelines on depression [7,14]^{7,14}(7,14). In terms of limitations, the study was only able to recruit college students from one public university in North Texas, which limited its generalizability to other universities and regions. Though objective assessment of 24-hour movement behaviors is the strength of this study, it cannot capture the screen-based sedentary behavior and other sleep characteristics (e.g., sleep disturbance). Future studies may combine both objective and subjective assessments to understand college students' 24-hour movement behaviors comprehensively. Lastly, in addition to the sociodemographic variables and weight status, investigating other individual factors (e.g., perceived competence), social support factors (e.g., parent and peer support), and built environmental support factors (e.g., neighborhood environment for PA) are suggested to extend the understanding of mental health disorders [57].

Conclusion

This study has provided objective and evitable knowledge to the growing body of research regarding the effects of individual-level determinants (i.e., sociodemographic factors, weight status, adherence to the 24-hour movement behavior guidelines) on depression among college students. The adherence to 24-hour movement behavior guidelines was not a direct determinant of the prevalence of depression in this population, whereas sociodemographic factors (i.e., higher risks in females, greater academic levels, and Asian students) and weight status (i.e., higher risk in obese students) were more influential. Since it is the first study to simultaneously investigate the adherence to the 24-hour movement behavior guidelines and their associations with depression among college students, any interpretations and conclusions should be cautious, and confirmation of these findings in larger and more representative samples is needed. Future research may also consider examining other factors (e.g., perceived competence, social support, built environmental support) to further understand the mechanisms between 24-hour movement behaviors and depression in young adults.

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Table 1. Descriptive Results of the Outcomes

Variables	Total (N)	Depressed	Non-depressed	LPA <50 percentile	LPA ≥50 percentile	MVPA <60-minute	MVPA ≥60-minute	SB <3-hour	SB ≥3-hour	Sleep <7-hour	Sleep ≥7-hour
Total	278	27.0%	73.0%	50.4%	49.6%	12.8%	87.2%	52.4%	47.6%	66.7%	33.3%
Sex											
Male	91	16.5%	83.5%	56.8%	43.2%	17.1%	82.9%	50%	50.0%	76.9%	23.1%
Female	187	32.1%	67.9%	47.6%	52.4%	10.7%	89.3%	53.6%	46.4%	61.6%	38.4%
Academic level											
Freshman	43	16.3%	83.7%	51.4%	48.6%	8.1%	91.9%	37.8%	62.2%	71.4%	28.6%
Sophomore	53	28.3%	71.7%	69.6%	30.4%	17.0%	83.0%	48.9%	51.1%	65.1%	34.9%
Junior	147	28.6%	71.4%	41.9%	58.1%	12.5%	87.5%	55.9%	44.1%	63.1%	36.9%
Senior	25	40.0%	60.0%	55.6%	44.4%	19.0%	81.0%	57.1%	42.9%	75.0%	25.0%
Race/ethnicity											
White	84	20.2%	79.8%	44.2%	55.8%	16.9%	83.1%	55.8%	44.2%	52.0%	48.0%
Black	61	24.6%	75.4%	56.1%	43.9%	15.5%	84.5%	44.8%	55.2%	78.9%	21.1%
Hispanic	61	29.5%	70.5%	66.7%	33.3%	7.8%	92.2%	52.9%	47.1%	70.8%	29.2%
Asian	51	39.2%	60.8%	45.5%	54.5%	11.4%	88.6%	52.3%	47.7%	69.2%	30.8%
Others	21	23.8%	76.2%	30.0%	70.0%	5.0%	95.0%	60.0%	40.0%	72.2%	27.8%
Weight status											
Healthy	143	25.9%	74.1%	45.7%	54.3%	15.0%	85.0%	52.0%	48.0%	68.1%	31.9%
Unhealthy	132	28.0%	72.0%	54.5%	45.5%	10.7%	89.3%	53.7%	46.3%	65.0%	35.0%

Note. LPA = light physical activity; MVPA = moderate-to-vigorous physical activity; SB = sedentary behavior.

Table 2. Logistic Regression of Individual Determinants on Outcomes

Variables	Depression (CES-D≥16)		LPA ≥50 percentile		MVPA ≥60-minute		SB <3-hour		Sleep ≥7-hour	
	OR (95% CI)	*p*	OR (95% CI)	*p*	OR (95% CI)	*p*	OR (95% CI)	*p*	OR (95% CI)	*p*
Sex										
Male	1.00 (referent)		1.00 (referent)		1.00 (referent)		1.00 (referent)		1.00 (referent)	
Female	**2.39 (1.22, 4.71)**	**0.01**	1.14 (0.63, 2.07)	0.67	2.23 (0.97, 5.15)	0.06	1.12 (0.59, 2.12)	0.72	**2.58 (1.30, 5.11)**	**0.01**
Academic level										
Freshman	1.00 (referent)		1.00 (referent)		1.00 (referent)		1.00 (referent)		1.00 (referent)	
Sophomore	2.14 (0.75, 6.08)	0.15	0.49 (0.19, 1.23)	0.13	0.48 (0.11, 2.02)	0.31	0.40 (0.15, 1.06)	0.06	1.44 (0.52, 4.00)	0.48
Junior	2.08 (0.82, 5.24)	0.12	1.45 (0.66, 3.18)	0.35	0.51 (0.13, 1.99)	0.33	0.54 (0.23, 1.22)	0.14	1.08 (0.45, 2.61)	0.86
Senior	**3.27 (0.98, 10.85)**	**0.05**	0.58 (0.18, 1.89)	0.37	0.24 (0.04, 1.33)	0.10	0.41 (0.12 1.41)	0.16	0.67 (0.18, 2.50)	0.55
Race/ethnicity										
White	1.00 (referent)		1.00 (referent)		1.00 (referent)		1.00 (referent)		1.00 (referent)	
Black	1.28 (0.55, 2.94)	0.57	0.73 (0.35, 1.52)	0.41	1.07 (0.41, 2.82)	0.89	1.28 (0.59, 2.79)	0.53	**0.24 (0.10, 0.56)**	**0.00**
Hispanic	1.65 (0.74, 3.65)	0.22	**0.36 (0.17, 0.78)**	**0.01**	2.56 (0.77, 8.54)	0.13	0.80 (0.35, 1.80)	0.58	**0.43 (0.19, 0.96)**	**0.04**
Asian	**3.39 (1.47, 7.79)**	**0.00**	0.88 (0.39, 1.96)	0.75	1.69 (0.54, 5.31)	0.37	0.92 (0.39, 2.20)	0.86	0.52 (0.22, 1.24)	0.14
Others	1.21 (0.37, 3.94)	0.76	1.90 (0.62, 5.78)	0.26	5.21 (0.59, 45.64)	0.14	0.63 (0.20, 2.02)	0.44	0.43 (0.13, 1.36)	0.15
Weight status										
Healthy	1.00 (referent)		1.00 (referent)		1.00 (referent)		1.00 (referent)		1.00 (referent)	
Unhealthy	1.44 (0.80, 2.57)	0.22	0.74 (0.42, 1.28)	0.28	1.81 (0.81, 4.04)	0.15	1.08 (0.60, 1.94)	0.80	1.44 (0.79, 2.63)	0.23

Note. SB = sedentary behavior; LPA = light physical activity; MVPA = moderate-to-vigorous physical activity; OR = odds ratio.

Table 3. Logistic Regression of Adherence of the 24-hour Movement Behavior Guidelines on Depression

Variables	Depression (CES-D≥16)		
	Depression rate[a]	OR (95% CI)	*p*
LPA			
<50 percentile	23.8%	1.00 (referent)	
≥50 percentile	27.4%	1.85 (0.90, 3.80)	0.10
MVPA			
<60-minute	31.3%	1.00 (referent)	
≥60-minute	24.8%	0.56 (0.20, 1.59)	0.28
SB			
≥3-hour	27.7%	1.00 (referent)	
<3-hour	23.7%	0.86 (0.43, 1.69)	0.65
Sleep			
<7-hour	26.6%	1.00 (referent)	
≥7-hour	24.1%	0.75 (0.37, 1.52)	0.42

Note. Adjusted for sex, academic level, race/ethnicity, and weight status; [a] = rate of participants had CES-D ≥ 16; SB = sedentary behavior; LPA = light physical activity; MVPA = moderate-to-vigorous physical activity; OR = odds ratio.

CHAPTER THREE

Brain Health and Active Living among Young Adults: A Social Ecological Approach

Abstract

Background: Guided by the social ecological model, the primary purpose of this study was to examine the relationships among social ecological factors (individual [i.e., socio-demographic variables, perceived competence], social [i.e., perceived social support], and built environmental support [i.e., home, neighborhood, and school environment]), 24-hour movement behaviors (physical activity, sedentary behavior, and sleep), and brain health outcomes (i.e., depression and cognitive function). **Methods:** A total of 111 college students (81 females, $M_{age} = 22.20 \pm 2.25$) were recruited. All participants completed surveys assessing social ecological factors and depression and wore accelerometers measuring their 24-hour movement behaviors. A subgroup (n = 60) performed a cognitive function test assessing their spatial working memory. **Results:** College students perceived similar competence beliefs and social and built environmental support, regardless of meeting or not meeting 24-hour movement behavior guidelines. Perceived competence ($\beta = -0.25$, $p < 0.05$) was the most influential factor of depression and served as a mediator in the relationships of perceived social support and home environment with depression. Sedentary behavior ($\beta = -0.30$, $p < 0.05$) exhibited significant associations with spatial working memory after controlling for other movement behaviors and social-ecological factors. **Conclusion:** Improving young adults' competence beliefs toward physical activity is an operational strategy to alleviate depressive symptoms among young adults. Sedentary behavior demonstrated to be beneficial for spatial working memory in this study while more evidence is warranted.

Keywords: Built environment; cognitive function; depression; physical activity; sleep

Introduction

In the United States, one in five college students are depressed and many college students experience cognitive impairment, such as executive dysfunction, poor memory, and symptoms of Attention Deficit Hyperactivity Disorder (ADHD) [1,2]. It is suggested that healthy movement behaviors, such as regular physical activity (PA) participation, reduced sedentary behavior, and appropriate length of sleep are needed to enhance and retain brain health [3–6]. However, physical inactivity, excessive sedentary behavior, and insufficient sleep are common behavioral phenomena among college students [7–9]. Advocating active lifestyles and enhancing brain health have been clearly stated in the goals of Healthy People 2030 [10]. Given the high rate of depression and cognitive impairment among college students [2,11], it is of public health importance to understand the influential factors associated with their daily behaviors from a comprehensive perspective.

The social-ecological model is a well-known and comprehensive framework in understanding individuals' behavioral choices among different age groups [12]. According to the social ecological model, the analysis of one's behavior (e.g., PA, sedentary behavior) requires not only the factors from the individual level but also the multi-dimensional and complex nature of surrounding environments [12,13]. Specifically, the individual level factors include socio-demographic characteristics (e.g., age, sex, race/ethnicity, and weight status) and sociocultural characteristics (e.g., perceived competence and motivation). The environmental aspects are composed of social, built, and natural environments. Social environmental support refers to one's perceived social support from parents, peers, and other individuals, such as perceived family or peers' encouragement/feedback for PA participation.

Built environmental support includes one's perceived physical and organizational settings for PA at school, home, and in their neighborhood. The social-ecological model has been recommended as an overarching guideline for the promotion of health behaviors and the prevention of detrimental behaviors [14]. In the past decades, researchers in the social and behavioral sciences have provided ample evidence regarding the importance of using a social ecological approach to understand young adults' health-related behaviors, especially physical activities and sedentary behavior [15–19].

In recent years, the term "24-hour movement behavior" has been articulated to fully describe one's daily activities, including different intensity levels of PA (i.e., light PA [LPA], moderate-to-vigorous PA [MVPA]), sedentary behavior, and sleep [20]. In a 24-hour cycle, the amount of time one spends on one movement behavior would result in an increasing or decreasing of time on other movement behaviors. Thus, a simultaneous assessment of all 24-hour movement behaviors is necessary to capture ones' behavioral patterns in a daily basis. However, a dearth of research has simultaneously examined 24-hour movement behaviors, and their correlations with individual and environmental factors need further exploration from a social-ecological perspective. Few research attempts have investigated the social ecological factors with two of the 24-hour movement behaviors, in particular, PA and sedentary behavior among young adults. After adjusting individual demographic factors, Whitakers and colleagues found that perceived neighborhood environments were only associated with accelerometer-measured MVPA and but not with LPA nor with sedentary behavior in their cross-sectional analysis [21].

A growing number of researchers started to investigate the associations between movement behaviors and brain health outcomes among college students [3,4,22,23]. As a major indicator of brain health, depression is a mental illness with persistent sadness, tiredness, and a loss of interest and ability to perform daily activities [24]. Cognitive function has been another investigated outcome of brain health which represents brain function in gaining knowledge and comprehension, such as working memory, attention, and processing speed [25,26]. Each individual movement behavior has been examined to correlate with depression and cognitive function in adults [7,22,27,28]. However, when researchers tested the effects of the three-movement behaviors on brain health outcomes simultaneously, sedentary behavior demonstrated to be a more promising behavior than other movement behaviors [29–32]. For example, during the young and middle-aged adulthood, people who had more sedentary behavior were found to have better performance in processing speed [33]. However, people's time in PA and sleep were not predictive for their cognitive performance [33]. The significant effect of sedentary behavior on depression was also presented among young adults in another study, in which being more sedentary was associated with a higher risk of emotional exhaustion regardless of PA and sleep [32]. Given the limited evidence, more research is warranted.

It is known that individual characteristics, such as sex, age, race/ethnicity, and weight status, are associated with brain health outcomes (e.g., depression, anxiety, stress, quality of life) [2,7,34,35]. Researchers articulated that social and built environmental factors are also influential factors on one's brain health [15,36,37]. It has been found that a higher perception of social support from family and peers is associated with less depression, hopelessness, and anxiety [36,38]. The built environmental factors, such as crime safety and walkability in the neighborhood, was associated with depression and quality of life among the adult population [15,37].

Given the effectiveness of using the social ecological model to explain one's movement behaviors, emerging research started investigating the combined effects of social ecological factors and movement behaviors on brain health outcomes. A recent intervention study illustrated the effectiveness of a peer-supported PA program on both depression alleviation and PA participation [39]. Such findings provide vital messages to researchers and practitioners, in which navigating the social ecological factors on the purpose of promoting healthy 24-hour movement behaviors might also be an effective and sustainable approach to address the brain health problems among college students. To begin with, more evidence is needed in regard to which social ecological factors and 24-hour movement behaviors are more prominent to brain health outcomes among young adults. Therefore, guided by the social ecological model, the primary purpose of this study was three-folds:

1) To examine whether or not social ecological indicators at various levels (individual, social, and built environmental levels) will be associated with the adherence to 24-hour movement behavior guidelines. It was hypothesized that college students who meet the 24-hour movement behavior guidelines (MVPA, LPA, sedentary behavior, and sleep) would have higher perceptions on each social ecological indicator.
2) To examine whether or not the social ecological indicators (individual, social, and built environmental levels) will be associated with brain health outcomes (i.e., depression and cognitive function) among college students. It was hypothesized that there would be significant associations of the social ecological indicators (individual, social, and built

environment levels) with depression and cognitive function;

3) To examine the combined effects of social ecological indicators (individual, social, and built environmental levels) and 24-hour movement behaviors on brain health outcomes (depression and cognitive function), and to test the potential direct and indirect effects (i.e., mediators). It was hypothesized that the combined effects/associations between social ecological indicators (individual, social environment, and built environment) and 24-hour movement behaviors would significantly contribute to brain health outcomes (depression and cognitive function) and the individual factor (i.e., perceived competence) may serve as mediator in the hypothesized associations.

Methods

Participants

A cross-sectional research design was administered, and the data collection was completed in Spring 2020. A total of 278 college students from one public university were recruited while 111 of those college students completed all the survey scales. The final sample for this study was 81 females and 30 males aged from 18 to 42 (M_{age} = 22.20, *SD* = 2.25). Nearly half of them were juniors (49.5%), 19.8% were freshmen, 15.3% were sophomores, and 12.6% were seniors. They consisted of 27% White, 27% Hispanics, 20.7% Black, 19.8% Asians, and 5.4% other races. A subgroup (n = 60; 42 females, 18 males; *Mage* = 22.65, *SD* = 4.89) completed the cognitive function test. Among this subgroup, 41.7% were juniors, 20% were freshmen, 18.3% were sophomores, and 15.0% were seniors. The race/ethnicity of this subgroup consisted of 28.3% White, 28.3% Hispanics, 23.3% Black, 16.7% Asians, and 3.3% other races. The approval of this study was obtained from the university institutional review board. Participants signed informed consent forms prior to the data collection.

Procedures

Participants were recruited from classrooms, flyers, and snowball rolling techniques in the 2019-2020 academic year. Participants filled out two surveys regarding social demographic information, depression, perceived competence, perceived social support, and perceived built environmental support. They also wore a numbered watch-type accelerometer (GT9X ActiGraph) 24 hours a day for five consecutive school days to capture their time distribution in the 24-hour movement behaviors. A subgroup of participants was invited to complete an 8-minute iPad-based neuropsychological cognitive function test.

Measures

Social ecological factors: Individual level

Sociodemographic factors. Participants self-reported their age, sex (male and female), current academic level (freshman, sophomore, junior, and senior), and race/ethnicity (White, Black, Hispanic, Asian, Others) in the survey.

Weight status. Participants' weight status was represented by body mass index (BMI) calculated from their self-reported height (inches) and weight (lbs). The raw score of BMI was used in the data analysis.

Perceived competence. Participants' perceived competence in PA /sport was assessed using five items modified from the Sport Competence subscale in the Physical Self-Perception Profile [40]. Participants responded to a 5-point Likert scale on five statements indicating how true each statement is to him/her from "*not true for me*" (coded as 1) to "*really true for me*" (coded as 5). The five statements were: (1) "I do very well at all kinds of PA/sports"; (2) "I feel that I am better at PA/sport than others"; (3) "I am good at new PA/sports right away"; (4) "I feel like I am very athletic"; and (5) "I think I could do well at just about any new PA/sports". The average score of the five items was used in the data analysis. This scale yielded an acceptable internal consistency (Cronbach's alpha = 0.77) in the current study.

Social ecological factors: Social environmental level

Perceived social support. The perceived social support for PA includes two subscales: *perceived family support* and *perceived peer support*. The assessment of participants' perceived family (parents/partner) support was adjusted from a parental support scale [41]. Participants reported to two questions assessing their perceived encouragement of PA participation from parents/partner using a 5-point Likert-type scale ranging from *strongly disagree* (coded as1) to *strongly agree* (coded as 5). A sample question is "My significant others (i.e., parents/partner) encourages me to do PA or sports". Perceived peer support was assessed using a 4-item peer support scale developed by Sallis et al. [41]. Their perceived peer's encouragement, participation, and praise were assessed using a 5-point Likert scale (*ranged from strongly disagree to strongly agree; coded from 1 to 5*). A sample question is "Friends encourage me to do PA or sports". The mean of the six items from both perceived family support and peer support scales was calculated and used in the final data analysis. The internal consistency of this perceived social support scale in the current study was acceptable (Cronbach's alpha = 0.76).

Social ecological factors: Built environmental level

Home environment. Participants' perceived home environment for PA was assessed using the 2-item developed by Motl et al. [42]. Participants perceived home environment were assessed by two questions: (1) home equipment: "At home/apartment, there are enough supplies and pieces of sports equipment (like balls, bicycles, skates) to use for PA"; and (2) home facilities: "At home/apartment, there are playgrounds, parks, or gyms close to my home/apartment that I can get to easily". Participants rated the two items using a 5-point Likert scale ranging from *strongly disagree* (coded as 1) to *strongly agree* (coded as 5). Participants' rating in each item was averaged and the mean score was used in final data analysis. The internal consistency of this scale was poor (Cronbach's alpha = 0.50) but deemed acceptable as the scale measures two aspects of home environment [43].

Neighborhood environment. Participants' perceived neighborhood environment was assessed using six items from the Physical Activity Neighborhood Environment Scale (PANES) [44]. Participants perceived built environment in their neighborhood were assessed in five different perspectives: crime safety, traffic safety, aesthetic quality, pedestrian infrastructure, and land-use mix. Sample questions include: (1) "The crime rate in my neighborhood makes it unsafe to go on walks at night"; (2) "There is so much traffic on the streets that it makes it difficult or unpleasant to walk/ ride a bicycle in my neighborhood". The six items were rated on a 5-point Likert scale ranging from *strongly disagree* (coded as 1) to *strongly agree* (coded as 5). The average score from the six items were used in the final data analysis. The overall internal consistency of the neighborhood environment scale was poor (Cronbach's alpha = 0.59) but acceptable as five different domains of neighborhood environment were assessed in this scale [43].

School environment. The 5 items about school environment from Questionnaire Assessing School Physical Activity Environment (Q-SPACE) [45] was used to assess participants' perceived school built environmental support for PA. Students' perceived built environment at school including equipment, indoor, and outdoor facilities were assessed. Sample questions include: (1) "My school has enough equipment for students to use"; and (2) "The indoor area (e.g., gym) at my school are in good condition". Students rated the five items using a 5-point Likert scale ranging from *strongly disagree* (coded as 1) to *strongly agree* (coded as 5). The average score from the five items was used in the final data analysis. The internal consistency of this scale was good (Cronbach's alpha= 0.82).

24-hour movement behaviors

The 24-hour movement behaviors, including MVPA, LPA, sedentary behavior, and sleep (i.e., sleep duration) were assessed objectively using the ActiGraph GT9X accelerometers (*ActiSleep+*; ActiGraph LLC, Pensacola, FL, USA). The accelerometers were small, lightweight devices designed to monitor bodily movement from three dimensions [46]. Participants were asked to wear the accelerometers on their non-dominant wrist to avoid the overestimation of movement behaviors as well as increase the compliance of wearing the device because of more frequent use of their dominant arm than the non-dominant arm [47]. Each accelerometer was identical to each participant's sex, date of birth, height, and weight before data download. The 60-second epoch was utilized to capture participants' movement in each one minute of wearing. The data from 8 am to 8 pm were customized to represent daily movement behaviors except sleep, and only the data with a minimum of 8 hours wearing time per day for at least three days were included in the final analysis.

Participants' time spent in MVPA, LPA, sedentary behavior, and sleep was carried out using the software *ActiLife 6* [48]. According to Toriano et al. (2008), the specific cut-points for LPA (100-2019 counts/min), MVPA (≥ 2020 counts/min), and sedentary behavior (0-99 counts/min) in a sample rate 30Hz were applied. Counts were calculated by summing raw accelerometer data into epoch "chunks" and the higher values of the counts meaning a higher frequency and intensity of the raw accelerometer data. Participants' sleep duration was detected automatically using Cole-Kripke algorithm [49] and checked manually to assure the accuracy with participants' self-reported time log about their sleep time. Participants' average daily time (minutes/day) spent on MVPA, LPA, sedentary behavior, and sleep was calculated for data analysis. In accordance to the guidelines, the 24-hour movement behaviors were categorized into: MVPA < 60-minute vs. MVPA ≥ 60-minute; LPA < 50 percentile vs. LPA ≥ 50 percentile; sedentary behavior < 3-hour vs. sedentary behavior ≥ 3-hour; and sleep < 7-hour vs. sleep ≥ 7-hour [50,51]. A previous study has validated the utility of ActiGraph accelerometers in young adults [52].

Brain health outcomes

Depression. The 20-item Center of Epidemiologic Studies Depression Scale (CES-D) [53] was applied to assess participants' symptoms of depression. Participants responded to 20 statements by indicating the occurrence of each statement within the past seven days from 0 (rarely/less than 1 day) to 3 (always/5-7 days). Sample questions include: (1) "I had trouble keeping my mind on what I was doing"; and (2) "I felt that people dislike me". After reversely coded four items, the final depression score was summed from the 20 items with a range from 0 to 60. The higher score indicates higher levels of depressive symptoms. This scale has been well validated and applied among young adults [54,55]. The internal consistency in the current study was acceptable (Cronbach's alpha = 0.74).

Spatial working memory. Spatial working memory was used to represent the cognitive function in the current study. Spatial working memory was assessed using a computerized neuropsychological test from the Cambridge Neuropsychological Test Automated Battery (CANTAB) [56]. This is a self-paced searching test conducted on a 10x10 inch iPad with participants' age, sex, and academic level pre-uploaded. Participants were asked to find one small square/token in a number of boxes (increasing from 4, 6, to 8 boxes) and fill them into an empty column to the right side of the screen. Participants were instructed that once a token is discovered from a box on a trial, that box will not hide another token on subsequent trials. This task evaluates participants' searching strategy (whether a consistent/planned strategy is adopted), such as always beginning a search from the same starting point. The score of spatial working memory was automatically generated from the CANTAB system (ranging from 2 to 14), calculating the number of times a beginning with a search from the same box or many different boxes. A lower score indicates a more consistent use of the strategy (1 = always begin the search from the same box). The raw score of strategy generated from the CANTAB system was used in the final data analysis.

Data Analysis

The data analysis was processed using SPSS 25.0 version. Because less than 5% of the data were missing, a series of mean replacement were employed on study variables except the subgroup's spatial working memory (n = 60). The internal consistency of all surveys in the study were detected using the Cronbach's alpha coefficients. After that, descriptive statistics including mean, standard deviation, range, and normal distribution were examined. Further, the Pearson's product-moment correlational analysis was used to examine the associations among social-ecological variables, 24-hour movement behaviors, and brain health outcomes. Variables were chosen to be included in the subsequent multiple linear regression models when they demonstrated significant correlates.

To examine the purpose 1, a series of independent sample *t*-tests were administrated to test the group differences (those who met vs. those who did not meet the 24-hour movement behavior guidelines) on socio ecological factors including perceived competence, perceived social support, and the three factors of perceived built environmental support (school, home, and neighborhood environment).

To address the purpose 2, two stepwise multiple linear regression models were performed to examine the predictive strengths of socio ecological factors (individual, social, and built environmental factors) on depression and spatial working memory, respectively. Individual factors such as sex was dummy coded (male = 0, female = 1).

To test the purpose 3, two hierarchical regression models were performed to test the combined effects of the 24-hour movement behavior factors (entered in step 1) and the social ecological factor (entered in step 2) on depression and spatial working memory, respectively. Those social-ecological factors showed significant predictions with brain health outcomes at the stepwise regression for purpose 2 were included.

Finally, an exploratory analysis was performed to determine if perceived competence serves as a mediator in the relationships between social and built environmental factors and depression. The structural equation modeling (SEM) was applied using AMOS Version 26.0.

First, a confirmatory factor analysis (CFA) was conducted on items measuring perceived competence of PA to examine the scale's structural validity.

After that, the SEM model was structured: perceived social support and home environment were exogenous variables; perceived competence was a mediator in the model; depression was the endogenous variable. The model fit was tested using the goodness-of-fit indices, including the chi-square to degrees of freedom ratio (χ^2/df), comparative fit index (CFI), incremental fit index (IFI), Tucker-Lewis Index (TLI), root mean square error of approximation (RMSEA). Of these, values larger than 0.90 for CFI, IFL, and TLI and less than 0.08 for RMSEA indicate an adequate fit of the model; and values larger than 0.95 for CFI, IFI, and TLI and less than 0.06 for RMSEA demonstrate a good fit model [57]. The χ^2/df with a value less than 3.0 indicates a close fit of the model to the data [58]. To test the magnitude of mediation effect, a bootstrapping technique, a powerful test on mediation analyses when a sample size is small, was processed, [59,60]. Bootstrapping technique provides more accurate type I error rates and greater power in determining indirect effects [61].

The unadjusted variances (R^2), unstandardized coefficient (B), and standardized coefficient (β) in each model were reported. Two-tailed level of significance was set at an alpha level of 0.05 in all the data analyses, and it was used to retain variables in the multiple regression models.

Results

Table 1 demonstrated the descriptive statistics of the study variables. All variables showed less than 3.00 absolute skewness values (ranging from -1 to 2.25) and less than 3.00 absolute kurtosis values (ranging from -0.86 to 2.66) except age and sleep, which had a kurtosis value of 6.53 and 4.60, respectively. This set of results indicates the normal distribution of study variables. On average, these college students' BMI was 25.35 (SD = 4.99), with 42.3% of them being classified as overweight and obese (BMI ≥ 25.0). They had a relatively low competence beliefs with a mean of 2.86 (SD = 1.15), slightly higher than the mid-point in the 5-point Likert scale. College students held a moderate-level perception of social support from family and peers (*M* = 3.70, SD = 0.76). Their perceptions of built environmental support were higher in terms of school environment (*M* = 4.29, SD = 0.70) compared to home (*M* = 3.51, SD = 1.01) and neighborhood environment (*M* = 3.44, SD = 0.77).

Regarding the accelerometer-assessed 24-hour movement behaviors, in a typical week, college students spent an average of 96.78 minutes/day (SD = 33.05) in MVPA and another 334.38 minutes/day (SD = 63.03) in LPA. Their daily average time spent in sedentary behavior and sleep duration were around 3 hours and 6.5 hours, respectively. According to the 24-hour movement behavior guidelines, there were 79.3%, 42.3%, 48.6%, and 28.4% of studied college students that met the guidelines of MVPA (≥ 60-minute), LPA (≥ 50 percentile), sedentary behavior (< 3-hour), and sleep (≥ 7-hour), respectively. On average, these college students reported a score of 12.89 (SD = 8.14) in the CES-D scale and 29.7% of them were categorized as depressed (CES-D scores ≥16) [62]. Their performance in spatial working memory had an average of 7.72 (SD = 2.21) in a range of score between 2 to 14 (the lower number indicates a more consistent searching strategy).

-----------------------------------insert Table 1 here----------------------------------

Table 2 demonstrated the bivariate correlations among social ecological variables, 24-

hour movement behaviors, and brain health outcomes. The social ecological factors at different levels showed significant associations with brain health outcomes. Specifically, perceived competence was associated with depression (r = -0.31, $p < 0.01$) and with spatial working memory (r = 0.25, $p < 0.05$). Perceived social support was significantly and negatively associated with depression (r = -0.22, $p < 0.05$). Among the three factors of perceived built environmental support, only home environment was significantly associated with depression (r = -0.24, $p < 0.05$). In terms of the correlations between 24-hour movement behaviors and brain health outcomes, only sedentary behavior showed significant associations with spatial working memory (r = -0.29, $p < 0.05$). Perceived competence, perceived social support, and home environment were significantly associated with each other (*rs* ranged from 0.29 to 0.49, *ps* < 0.01).

------------------------------------insert Table 2 here----------------------------------

The independent sample *t*-tests' results were visually presented from Figure 1 to Figure 4. Among the comparisons between groups who met and who did not meet the 24-hour movement behavior guidelines, only participants who met the sleep guideline (sleep ≥ 7-hour) showed significantly lower perceptions of built environmental support from home environment than those who did not meet sleep guidelines (M = 3.63 vs. M = 3.19, Cohen's d = 0.44, $p < 0.05$). Even though no significance was reached, students who met MVPA and sedentary behavior guidelines displayed higher perceptions of home environment than their peers who did not meet those guidelines, yielding small to moderate effect sizes (Cohen's d = 0.38 and Cohen's d = 0.36, respectively).

----------------insert Figure 1, Figure 2, Figure 3, Figure 4 here-----------------

Two stepwise multiple regressions were conducted to examine the predictability of social-ecological factors on college students' depression and spatial working memory. The results were presented in Table 3. In the model for depression (dependent variable), sex, perceived competence, perceived social support, and home environment were entered. With a stepwise approach, perceived competence (β = -0.22, $p < 0.05$) and sex (β = 0.21, $p < 0.05$) subsequently demonstrated to be significant predictors of depression, accounting for 13.2% of the variances. In the model for spatial working memory (dependent variable), perceived competence and perceived social support were entered. After the stepwise regression, only perceived social support (β = 0.26, $p < 0.05$) served as the significant predictor on spatial working memory accounting for 6.9% of the variances.

-----------------------------------insert Table 3 here----------------------------------

The hierarchical regression models were conducted to predict depression and spatial working memory, respectively, by testing the combined effects of 24-hour movement behaviors (in step 1; MVPA, LPA, sedentary behavior, and sleep) and social ecological factors (in step 2; perceived competence and sex in the model for depression; perceived social support in the model for spatial working memory) (see Table 4). The results revealed that perceived competence (β = -0.25, $p < 0.05$) was the only significant predictor on depression and the overall model accounted for 15.8% of variances in depression ($p < 0.05$). Higher perceived competence was associated with lower depressive symptoms when holding 24-hour movement behaviors and sex constant. Sedentary behavior (β = -2.04, $p < 0.05$) demonstrated to be the only significant predictor on spatial working memory and the overall model accounted for 21.9% of variances in spatial working memory ($p < 0.05$). More time spending on sedentary behavior was associated with lower scores in the spatial working memory test, indicating a better functioning of spatial working memory, while holding other movement behaviors and perceived social support constant.

-----------------------------------insert Table 4 here----------------------------------

A CFA was conducted to examine the structural validity of the perceived competence scale. After examination of modification indices, the residuals of selected items in the perceived competence scale were correlated to improve model fit. The adjusted model showed adequate fit to the data ($\chi^2/3$= 1.529, $p > 0.05$, CFI = 0.997, IFI = 0.997, TLI = 0.989, RMSEA = 0.069, 90% CI [0.000, 0.188]), with all factor loadings significant at $p < 0.001$.

After that, the SEM was structured to test whether perceived competence mediates the relationships of perceived social support and home environment with depression (Figure 5). The model showed good fit to the data: $\chi^2/15 = 1.23$, $p > 0.05$, CFI = 0.994, IFI = 0.994, TLI = 0.988, RMSEA = 0.046, 90% CI (0.000, 0.106). According to the bootstrapping test, the standardized indirect effect of perceived social support to depression through perceived competence was statistically significant (indirect effect = -0.084, $p = 0.028$, 95% CI [-0.175, -0.016]), indicating a full mediational role of perceived competence. Similarly, the indirect effect of home environment to depression through perceived competence was marginally significant (indirect effect = -0.038, $p = 0.056$, 95% CI [-0.087, -0.003]. Thus, a full mediational role of perceived competence was assumed as well. Overall, perceived social support ($\beta = 0.43$, $p < 0.01$) and home environment ($\beta = 0.19$, $p < 0.05$) accounted for 27% of variances in perceived competence, and the mediational model explained 12% of variances in depression.

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Discussion

Grounded in the social ecological framework, this study tested the associations of three layers of social ecological factors (individual, social, and built environmental levels) with accelerometer-measured 24-hour movement behaviors and brain health outcomes among a group of college students. This study provided preliminary evidence of the joint effects of social ecological factors and accelerometer-measured 24-hour movement behaviors on brain health outcomes in the young adult population. The most promising findings were that individual level factors (i.e., sex and perceived competence of PA) served as the most salient predictors on depression, and perceived competence mediated the relationships of perceived social and home environmental support with depression. Meanwhile, 24-hour movement behavior (i.e., sedentary behavior) was the most influential factor in college students' spatial working memory. Further, a few group differences of social ecological factors were observed between groups who met and who did not meet the 24-hour movement behavior guidelines. Detailed discussions are as follows.

Among the studied college students, those who met the MVPA and sedentary behavior guidelines had higher perceptions of PA support from home environment compared to their peers who did not meet those guidelines. This indicates that college students who live in a supportive home environment for PA, such as having PA/exercise equipment in home/apartment or living in an area with adequate recreational facilities, are more likely to achieve the MVPA and sedentary behavior guidelines compared to those who live in a less supportive home environment. It is noted that college students who met the sleep guideline (≥

7-hour) perceived less PA support of home environment compared to those who did not meet the sleep guideline. It is likely that a PA supportive home setting would distract college students' sleep. However, this result might be misrepresented. Because females had lower perceptions of home environment when compared to males ($M = 3.41$ vs. $M = 3.75$; results were not presented in the present study), and 88.9% of college students were females in the group of meeting the sleep guideline as opposed to 64.7% of females in the group of not meeting the sleep guideline. Lastly, college students demonstrated similar levels of perceptions in competence beliefs, social support, and built environmental support in neighborhood and school settings regardless of whether they met or did not meet the 24-hour movement behavior guidelines. These findings were contradicted with a previous study, in which college students who met the MVPA guideline had significantly higher levels of self-efficacy and perceived stronger social support for PA [16]. More research is needed to identify their relationships in young adults.

The correlational analysis suggested that all layers of social ecological factors were associated with depression. Aligned with most previous studies [2,63,64], the significant effect of sex in the individual level indicated a higher risk of depression among female college students compared to their male counterparts. This study highlighted the significance of perceived competence on depression, and the further SEM model disclosed the mediational role of perceived competence between social and built environmental support and depression. In other words, college students who have high perceptions of their abilities and competence in PA or sport are at a low risk of depression. Social support for PA from parents, partners, and/or peers, can positively contribute to college students' perceived competence beliefs, which would further prevent or alleviate college students' depression. Home environment also plays a role in improving college students' perceived competence of PA and eventually facilitating ones' brain health and reducing mental illness. It is suggested that living in a home/apartment surrounded with PA facilities (e.g., gym, parks) or preparing some exercise/sport equipment in home can positively influence one's perceived competence of PA. Verse vice, individuals who perceive high competence of PA also tend to choose locations with PA facilities and purchase exercise equipment to maintain PA participation. These results suggest families and societies create a supportive environment for PA participation, such as positive feedback and accessible PA facilities and playgrounds.

The significant effect of perceived competence on depression is consistent with many previous studies [65–67]. Noted that feelings of low self-worth, having poor self-concept, and losing interests and enjoyment are common depressive symptoms, improving perceived competence of PA and sport may improve individuals' global self-perception and self-esteem, thus alleviate the depressive symptoms [67,68]. Such mediational role of perceived competence has been observed in PA or exercise-oriented intervention programs [66–68]. That is, college students who participated in the PA intervention tended to improve self-efficacy (i.e., perceived physical abilities), physical self-concept, and global self-esteem in the early stage, and then followed with a considerable reduction of depression [66–68].

It is noted that females had significantly lower perceived competence than their male peers ($r = -0.41$). Gender-appropriate PA intervention may be targeted on improving perceived competence toward PA. Encouraging college students to reach out to family members and friends for assistance can be effective strategy for those who already show depressive symptoms [36,38]. On the other hand, family members and peers can help relieve symptoms of depression by creating supportive climate for college students' PA participation, such as playing sports or doing exercise with them regularly, and/or providing positive feedback to encourage active lifestyles.

When testing the combined effects of 24-hour movement behaviors and social ecological factors on depression, no significant predictions of accelerometer-measured 24-hour movement behaviors on depression were observed. Similar findings were also observed in two previous studies [32,69]. Janurek and colleagues assessed the relationships between mental health indicators (i.e., emotional exhaustion) and accelerometer-assessed 24-hour movement behaviors (i.e., MVPA, sleep) among young adults (M_{age} = 22.48) and found no significant associations of MVPA and sleep duration with emotional exhaustion. Accelerometer-measured 24-hour movement behaviors (MVPA, LPA, sedentary behavior) were also found to have low to no associations with depression and other mental health indicators among college students [69]. It is likely that objectively assessed movement behaviors are uncorrelated with depression as opposed to self-reported movement behaviors, which were consistently found to significantly correlate with depression in young adults [27,28,70]. More research focusing on associations between the 24-hour movement behaviors and mental health disorders (i.e., depression) is warranted.

A unique and important contribution of this study was to investigate the combined effects of 24-hour movement behaviors and social ecological factors on objectively assessed spatial working memory. When 24-hour movement behaviors included in the model, the contributions of perceived social support were diminished. Specifically, sedentary behavior served as the sole predictor of spatial working memory. The spatial working memory test assesses one's abilities in temporary retention and strategic manipulation of visuo-spatial information [71]. Interestingly, the finding of this study indicated that more time on sedentary behavior was associated with better performance in the spatial working memory test, namely, having a more efficient manipulation strategy to perform visuo-spatial related tasks.

A growing body of evidence suggests cognitive enhancements may be linked to 24-hour movement behaviors, which begets improvement in key areas of cognitive function [72,73]. This finding revealed that increasing time on sedentary behavior tended to improve cognitive performance in spatial working memory, which was inconsistent with several studies on different age groups [74,75]. Using an isotemporal substitution analytical technique, Fanning and colleagues found that replacing 30 minutes of daily accelerometer-measured sedentary behavior with LPA and MVPA could improve older adults' spatial working memory [74]. In Loprinzi and Kane's experiments on young adults, they observed that higher visual-related cognitive function was associated with less self-reported sedentary behavior but not with accelerometer-measured sedentary behavior [75]. Additionally, accelerometer-measured sedentary behavior had no associations with spatial working memory among the child population ($M_{age} = 12.2$) [76].

The interpretation that more time on sedentary behavior is associated with better performance in spatial working memory need to be cautious in this study, because the regression coefficient ($B = -0.01$) and sample size ($n = 60$) were very small. Future studies are warranted to test the associations of accelerometer-measured sedentary behavior and visual-spatial related cognitive function among young adults. Researchers noted that PA is not necessarily associated with many domains of cognitive functions, including working memory, because of the overlap of working memory with other cognitive processes in the brain circuitry [77,78]. This might explain the non-significant associations between objectively measured PA and spatial working memory in this study.

Perceived social support for PA participation were found to positively correlate with spatial working memory in the current study, although no significance was reached after controlling for the movement behavior factors. This means that college students who had high perceptions of social support for PA tend to use multiple start points in the spatial working memory tests. Generally, a consistent starting point (lower score) indicates more efficient strategies being used in the spatial working memory tasks when compared to different starting points (higher score). It is noted that all the participants in this study indicated that this was their first time of the computerized spatial working memory test and the test was difficult. Since this is the first time to explore the social ecological factors (i.e., perceived social support) on spatial working memory in young adult population, future research is needed to verify or refute this finding.

There are several limitations to this study. The cross-sectional nature of this study restricts the causal inferences of the results. Future research may consider using prospective, longitudinal, or experimental design to elucidate the underlying causalities among studied variables. Using objective measures of 24-hour movement behaviors can avoid the potential respondent bias, however, it provided little information about the context or activity of which types of PA and sedentary behavior occurred. Researchers suggest that the types of PA (e.g., aerobic activity, strength/flexibility activity), the contexts of sedentary behavior (passive or mentally active sedentary behaviors), and quality of sleep (sleep efficiency, sleep disturbance, dreaming) are essential factors to consider when investigating their roles on brain health [79–81]. Thus, combining self-report and objective measures of 24-hour movement behaviors in large-scale studies may provide more solid evidence in identifying the associations between 24-hour movement behaviors and brain health outcomes.

Conclusion

This was the first study to examine the associations of all three layers of social ecological variables with 24-hour movement behaviors and brain health outcomes (depression and cognitive function). This study identified the individual (sex, perceived competence), social (social support for PA from family and peers), and built environmental support for PA (i.e., home environment) as well as behavioral factor (i.e., sedentary behavior) that were influential factors on depression and cognitive function among young adults in college. The results outlined above can provide implications to other universities as well as institutions when they seek to address college students' brain health. Developing systematic and continuous methods to educate and disseminate knowledge and coping strategies of brain health among college students is suggested. For example, health centers or counseling and psychological services in the higher education institutions can provide college students regular knowledge-based education/seminars (bi-weekly or monthly) on various issues of brain health problems and its coping mechanisms.

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Table 1. Descriptive Statistics of Study Variables

Variables	N	Min	Max	M	SD	Skewness	Kurtosis
Individual factors							
Age	111	18	42	22.20	4.07	2.25	6.53
Sex							
Male	30						
Female	81						
Academic level							
Freshman	21						
Sophomore	17						
Junior	54						
Senior	14						
Race/ethnicity							
White	30						
Black	23						
Hispanic	30						
Asian	22						
Others	6						
BMI	111	16.30	46.59	25.35	4.99	1.31	2.66
Perceived competence	111	1.00	5.00	2.86	1.15	0.20	-0.86
Perceived social support	111	1.00	5.00	3.70	0.76	-1.00	1.31
Built environmental support							
Home environment	111	1.00	5.00	3.51	1.01	-0.30	-0.30
Neighborhood environment	111	1.17	5.00	3.44	0.77	-0.43	0.16
School environment	111	1.80	5.00	4.29	0.70	-0.99	0.58
24-hour movement behaviors							
MVPA (min/day)	111	29.50	215.40	96.78	33.05	0.45	0.46
LPA (min/day)	111	171.25	523.14	334.38	63.03	-0.03	0.34
SB (min/day)	111	44.67	331.25	172.66	51.41	0.24	0.22
Sleep (min/day)	111	214.25	783.60	382.67	88.36	1.37	4.60
Brain health outcomes							
Depression	111	0	44	12.89	8.14	1.08	1.55
Spatial working memory	60	2	11	7.72	2.21	-0.82	.40

Note. BMI = body mass index; MVPA = moderate-to-vigorous physical activity; LPA = light physical activity; SB = sedentary behavior.

Table 1. Results of Pearson Correlation on Study Variables

	1	2	3	4	5	6	11	12	13	14	15	16
1. Depression	0.74											
2. SWM	0.09	-										
3. MVPA	0.09	-0.02	-									
4. LPA	-0.04	0.19	0.12	-								
5. SB	-0.07	**-0.29***	**-0.51****	-0.16	-							
6. Sleep	0.15	0.20	0.04	0.13	-0.10	-						
11. BMI	0.02	0.03	0.04	-0.14	-0.07	-0.15	-					
12. Perceived competence	**-0.31****	**0.25***	-0.10	-0.17	0.07	-0.01	0.04	0.94				
13. Perceived social support	**-0.22***	**0.26***	0.03	-0.10	0.01	-0.06	-0.01	**0.49****	0.76			
14. Home environment	**-0.24***	0.07	0.12	-0.04	**-0.25***	-0.11	**-0.19***	**0.31****	**0.29****	0.50		
15. Neighbor environment	-0.14	0.13	0.14	0.08	-0.05	-0.02	-0.09	0.13	**0.29****	**0.60****	0.59	
16. School environment	0.02	-0.02	0.05	0.14	-0.02	-0.01	-0.05	0.03	0.08	**0.27****	**0.29****	0.82

Note. SWM = spatial working memory; MVPA = moderate-to-vigorous physical activity; LPA = light physical activity; SB = sedentary behavior; BMI = body mass index; Cronbach's alpha was presented in the diagonal line; * = $p < 0.05$; ** = $p < 0.01$.

Table 2. Results of Stepwise Regression on Brain Health Outcomes

Steps	Independent variable	R^2	β	t	p
Dependent variable: *Depression*[a]					
Step 1		0.094**			
	Perceived competence		-0.31	-3.36	0.001
Step 2		0.132**			
	Perceived competence		-0.22	-2.24	0.03
	Sex		0.21	2.16	0.03
Dependent variable: *Spatial working memory*[b]					
		0.69*			
	Perceived social support		0.26	2.08	0.04

Note. Unadjusted variances (R^2) are presented; * = $p < 0.05$; **= $p < 0.01$.

[a] In the model to predict depression, perceived social support and home environment were excluded.

[b] In the model to predict spatial working memory, perceived competence was excluded.

Table 3. Results of Hierarchical Regression on Brain Health Outcomes

Steps	Independent variable	R^2	*B*	*β*	*t*	*p*
Dependent variable: *Depression*						
Step 1		0.036				
	MVPA		0.02	0.08	0.73	0.47
	LPA		-0.01	-0.07	-0.77	0.45
	Sedentary behavior		0.00	-0.02	-0.22	0.83
	Sleep		0.01	0.16	1.61	0.11
Step 2		0.158**				
	MVPA		0.01	0.02	0.23	0.82
	LPA		-0.01	-0.11	-1.22	0.22
	Sedentary behavior		-0.01	-0.06	-0.56	0.57
	Sleep		0.01	0.11	1.20	0.23
	Perceived competence		**-1.74**	**-0.25**	**-2.42**	**0.02**
	Sex		3.26	0.18	1.70	0.09
Dependent variable: *Spatial working memory*						
Step 1		0.164*				
	MVPA		-0.02	-0.22	-1.50	0.14
	LPA		0.01	0.16	1.18	0.24
	Sedentary behavior		-0.02	-0.34	-2.30	0.03
	Sleep		0.01	0.16	1.28	0.20
Step 2		0.219*				
	MVPA		-0.02	-0.23	-1.62	0.11
	LPA		0.01	0.20	1.53	0.13
	Sedentary behavior		**-0.01**	**-0.30**	**-2.04**	**0.046**
	Sleep		0.00	0.14	1.10	0.28
	Perceived social support		0.67	0.24	1.94	0.06

Note. Unadjusted variances (R^2) are presented; MVPA = moderate-to-vigorous physical activity; LPA = light physical activity; * = $p < 0.05$; **= $p < 0.01$

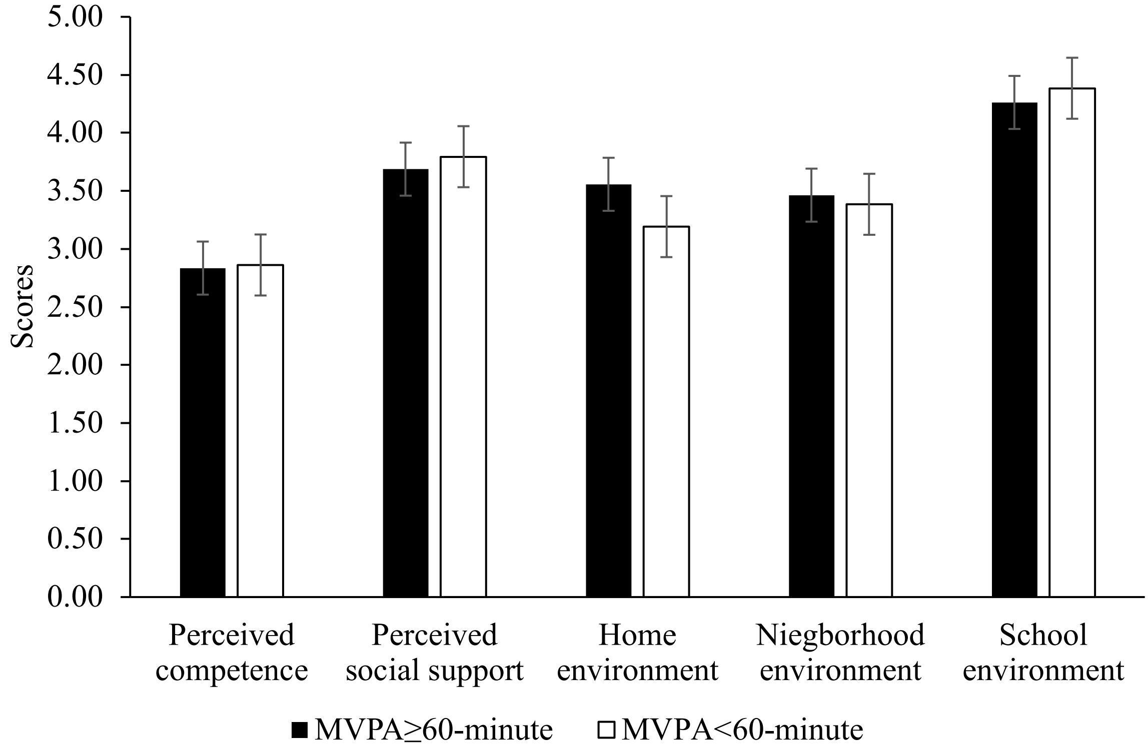

Figure 1. Mean Differences in the Social Ecological Variables based on MVPA
Note. No group differences were found in social ecological variables ($p > 0.05$); MVPA = moderate-to-vigorous physical activity.

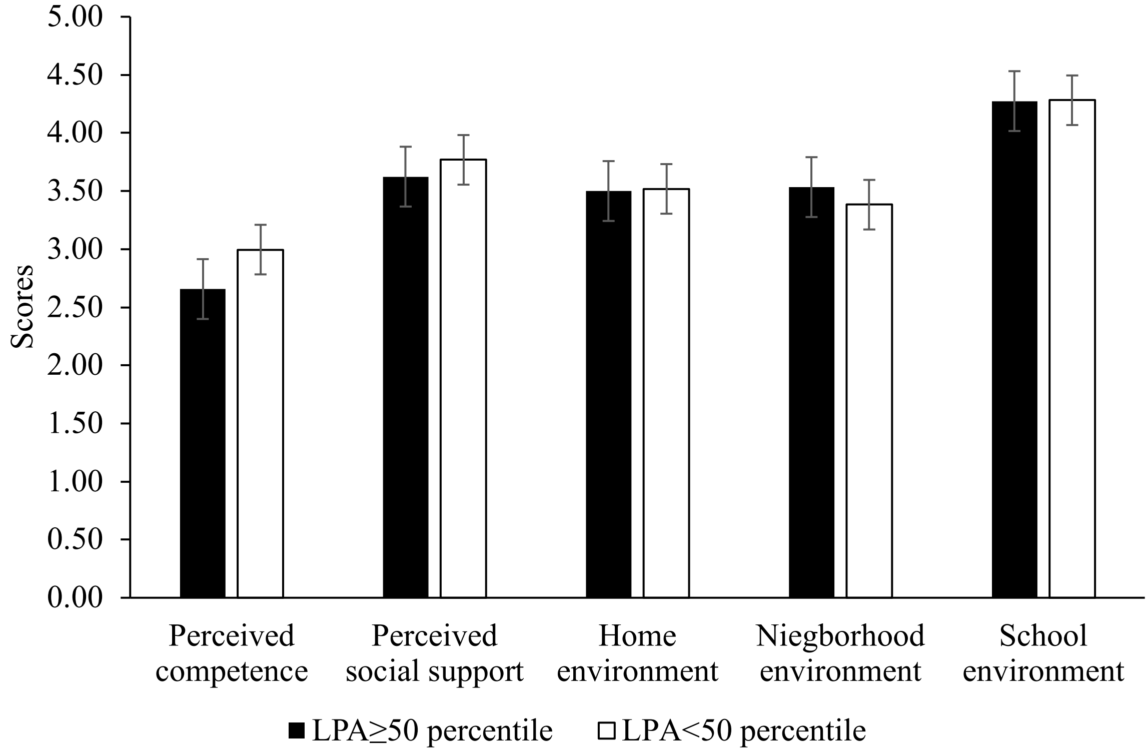

Figure 1. Mean Differences in the Social Ecological Variables based on LPA

Note. No group differences were found in social ecological variables ($p > 0.05$); LPA = light physical activity.

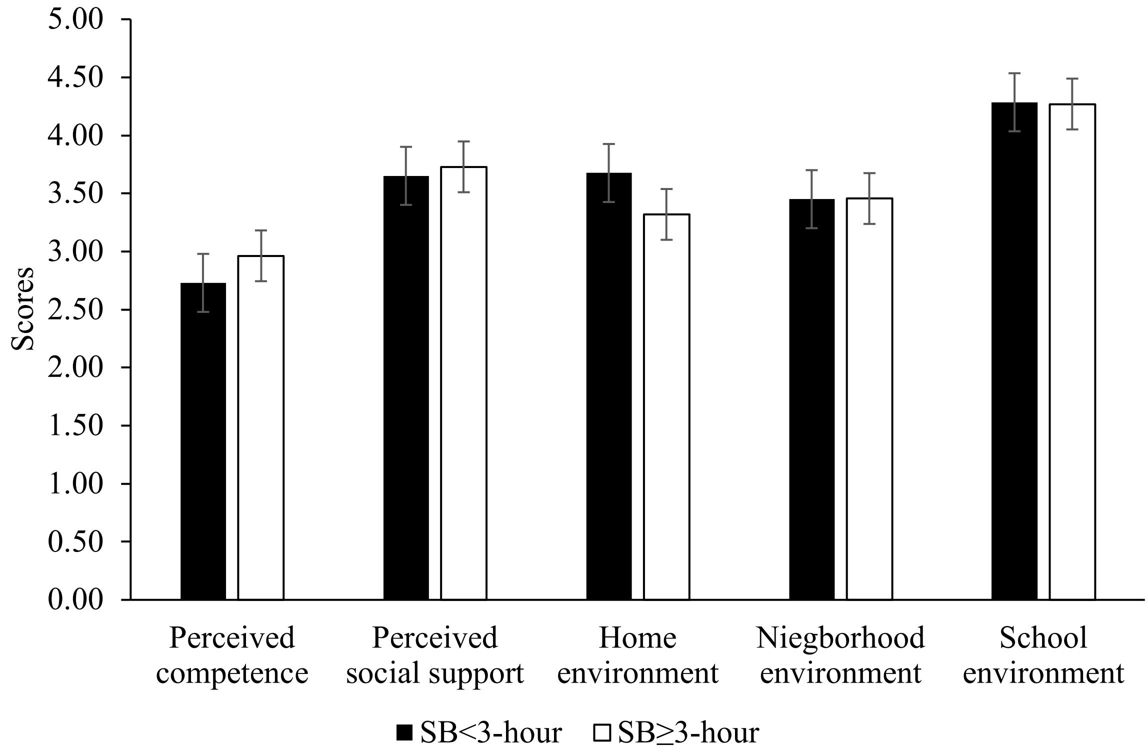

Figure 2. Mean Differences in the Social Ecological Variables based on Sedentary Behavior

Note. No group differences were found in social ecological variables ($p > 0.05$); SB = sedentary behavior.

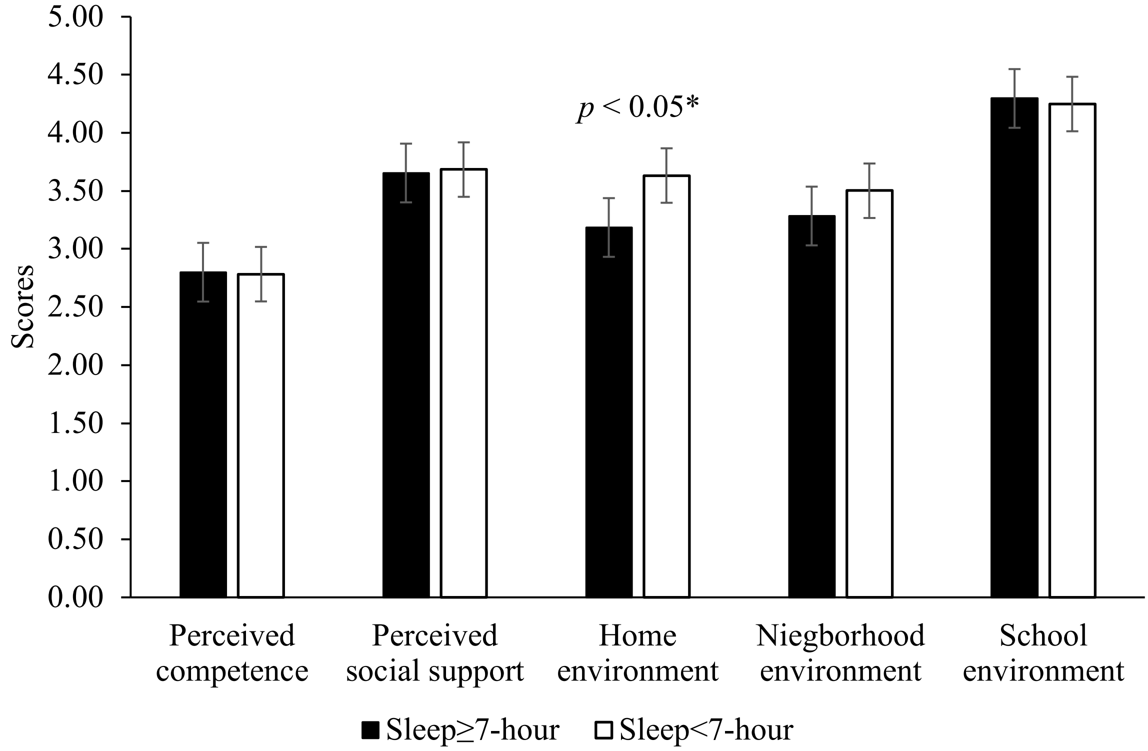

Figure 3. Mean Differences in the Social Ecological Variables based on Sleep

Note. Group differences were found in home environment ($p < 0.05$*).

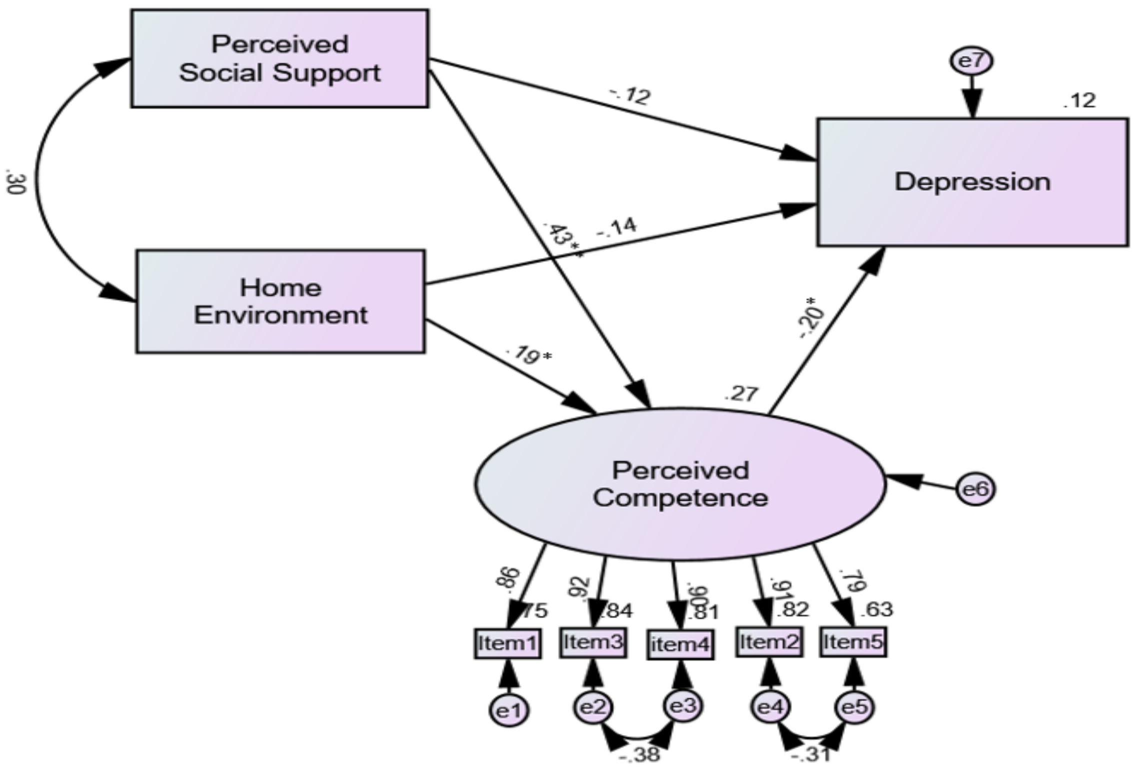

Figure 4. The Direct and Indirect Effects of Social Ecological Variables on Depression

Note. Model fit: $\chi^2/15 = 1.23$, $p > 0.05$, CFI = 0.994, IFI = 0.994, TLI = 0.988, RMSEA = 0.046, 90% CI (0.000, 0.106). * = $p < 0.05$; ** = $p < 0.01$.

Appendix A

Survey- 1

INSTRUCTIONS: Please answer the following questions as completely and as honestly as you can. There are no right or wrong answers. Some questions will have choices provided, please √ your answer. For other questions, please write your answer. Your information is kept confidential.

1. Your Name: ____________________________Your Email: __________________________
2. Your Grade: □ Freshman □ Sophomore □ Junior □ Senior
3. Gender: □ Male □ Female Date of Birth: _____Month________Year
4. Are you Spanish, Hispanic, or Latino or none of these? □ Yes □ None of these
5. Choose one or more races that you consider yourself to be:

□ White □ Black or African American □American Indian

□ Hispanic □ Asian □ Native Hawaiian or Pacific Islander

□ Others_________

6. Please check any medical problems you had or have been with in the past and present.

□ Diabetes □ Significant chronic pain □ Addiction

□ Sleep disorder □ Nutrition/obesity/eating disorder □ Cardiac illness

□ Fertility issue □ Hypertension □ Other___________

7. Are you currently under treatment for any medical condition? □Yes □ No

If yes, 1) What is/are the medications ____

2) How long have you been taking it/them? _________________

<u>8. Below is a list of the ways you might have felt or behaved. Please tell me how often you have felt this way during the past week.</u>

Rarely or none of the time (less than 1 day)
Some or a little of the time (1-2 days)
Occasionally or a moderate amount of time (3-4 days)
Most or all of the time (5-7 days)

Check √ in only ONE box on each line.	Rarely <1day	A little 1-2 days	occasionally 3-4 days	always 5-7 days
1. I was bothered by things that usually don't bother me.	□	□	□	□
2. I did not feel like eating; my appetite was poor.	□	□	□	□
3. I felt that I could not shake off the blues with help from my family or friends.	□	□	□	□
4. I felt I was just as good as other people.	□	□	□	□

5. I had trouble keeping my mind on what I was doing.	□	□	□	□
6. I felt depressed.	□	□	□	□
7. I felt that everything I did was an effort.	□	□	□	□
8. I felt hopeful about the future.	□	□	□	□
9. I thought my life had been a failure.	□	□	□	□
10. I felt fearful.	□	□	□	□
11. My sleep was restless.	□	□	□	□
12. I was happy.	□	□	□	□
13. I talked less than usual.	□	□	□	□
14. I felt lonely.	□	□	□	□
15. People were unfriendly.	□	□	□	□
16. I enjoyed life.	□	□	□	□
17. I had crying spells.	□	□	□	□
18. I felt sad.	□	□	□	□
19. I felt that people dislike me.	□	□	□	□
20. I could not get “going.”	□	□	□	□

Appendix B

Survey-2

Instructions: *There are no right or wrong answers. Please select the answer that reflects how you really feel. Your information will be anonymous and kept confidential so no one at school or home will know.*

Your full name:______________________________

Date of birth (mm/dd/yyyy):___________________ Gender ① Female ②Male

I. Instruction: *Please respond to each statement by checking how much you disagree or agree with it.*

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
1) My significant others (i.e., parent/partner) encourages me to do physical activity or sports	①	②	③	④	⑤
2) My significant others (i.e., parent/partner) tells me I am doing well in physical activity or sports	①	②	③	④	⑤
3) My significant others (i.e., parent/partner) encourage me to go to bed at specific time?	①	②	③	④	⑤
4) My significant others (i.e., parent/partner) encourage me to limit the time spent looking at screens?	①	②	③	④	⑤
5) I encourage friends to do physical activity or sports	①	②	③	④	⑤
6) Friends encourage me to do physical activity or sports	①	②	③	④	⑤
7) Friends do physical activity or sports with me	①	②	③	④	⑤
8) Friends tell me I am doing well in physical activity or sports	①	②	③	④	⑤

II. Instruction: *Please answer the following questions about the environment in your school, neighborhood (the area within a 10- to-15-minute walk from home.), or home.*

About school…	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
9) *My school has enough equipment for students to use.*	①	②	③	④	⑤
10) *The outdoor areas at school are big enough for students to be physically active.*	①	②	③	④	⑤
11) The outdoor areas (e.g., playground, field) at my school are in good condition.	①	②	③	④	⑤

12) The indoor area at school is big enough for students to be physically active.					
13) The indoor areas (e.g., gym) at my school are in good condition.	①	②	③	④	⑤
About Neighborhood…	Strongly disagree	Disag ree	Neutral	Agree	Strongly agree
14) There are sidewalks on most of the streets in my neighborhood	①	②	③	④	⑤
15) Many shops, stores, markets or other places to buy things I need are within easy walking distance of my home.	①	②	③	④	⑤
16) There are many interesting things to look at while walking in my neighborhood	①	②	③	④	⑤
17) The crime rate in my neighborhood makes it unsafe to go on walks at night.	①	②	③	④	⑤
18) There is so much traffic on the streets that it makes it difficult or unpleasant to walk/ ride a bicycle in my neighborhood.	①	②	③	④	⑤
19) There are many places to go within easy walking distance of my home.	①	②	③	④	⑤
About home…	Strongly disagree	Disag ree	Neutral	Agree	Strongly agree
20) At home/apartment, there are enough supplies and pieces of sports equipment (like balls, bicycles, skates) to use for physical activity	①	②	③	④	⑤
21) There are playgrounds, parks, or gyms close to my home/apartment that I can get to easily	①	②	③	④	⑤

III. Instruction*: Please read through the statements and tell us how true it is to you.*

	Not true to me		Sort of True to me		Really True to me
22) I do very well at all kinds of physical activity/sports	①	②	③	④	⑤
23) I feel that I am better at physical activity/sports than others	①	②	③	④	⑤
24) I am good at new physical activity/sports right away	①	②	③	④	⑤
25) I feel like I am very athletic	①	②	③	④	⑤
26) I think I could do well at just about any new physical activity/sports	①	②	③	④	⑤