Effects of Virtual Reality Exercise on Promoting Physical Activity and Health among College Students: A 4-week Randomized Controlled Trial

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Dedication

This dissertation is first and foremost dedicated to my mother, Jianhua Che, and my father, Yuchun Liu. In addition, I would like to dedicate this dissertation to my grandfather, Derong Liu, and my grandmother, Yulan Cao.
Abstract

Background: Despite the known benefits of physical activity, the prevalence of physical inactivity and sedentary behavior are significant issues in public health. Young adults, such as college students, are a population at risk for decreased physical activity participation due to the newfound responsibility of balancing school, work, and personal responsibilities. Previous findings indicated the lack of motivation was one of the important factors explaining the decreased physical activity participation. The emerging technology of immersive virtual reality combining with exercise provide a fun and motivating means for promoting physical activity and health-related outcomes. The cross-sectional studies have shown the promising influences of immersive virtual reality exercise on health-related outcomes, however, there is no experimental study to further conclude the findings. Therefore, the purpose of this randomized control trial was to examine the effectiveness of a 4-week VR-based exercise intervention on promoting PA and improving physiological and psychological outcomes among college students.

Methods: A total of 36 college students were recruited from the University of Minnesota Twin Cities. Participants were randomly assigned to two groups: (1) intervention group – participants were asked to exercise on an immersive virtual reality-based exercise bike for one hour per session, two times per week, for 4 weeks; (2) control group – participants were asked to maintain their usual activities for 4 weeks. Participants’ weight, height, percentage of body fatness, and cardiovascular fitness were assessed by the validated instruments at baseline and 4 weeks. The exercise motivation, mood states, and depressive symptoms were assessed via a battery of surveys at baseline and 4 weeks.
Participants’ physical activity levels were assessed via International Physical Activity Questionnaire at baseline and post-intervention follow-up. A two-way repeated measures ANOVA was used to examine the differences between intervention and control group on physiological and psychological outcomes over time. The within-subjects factor was “time” and the between-subjects factor was “group”.

**Results:** The Chi-Square test and the independent t-test indicated that there was no statistically significant difference regarding baseline demographic, physiological, and psychological outcomes between intervention and control group at baseline. Regarding exercise motivation, significant interactions were observed on identified regulation \( (F(1,34) = 6.55, p = 0.02, \eta_p^2 = 0.16) \) and intrinsic regulation \( (F(1,34) = 11.21, p = 0.02, \eta_p^2 = 0.25) \). Regarding mood states, significant interactions were observed on confusion \( (F(1,34) = 6.72, p = 0.01, \eta_p^2 = 0.17) \), fatigue \( (F(1,34) = 6.46, p = 0.02, \eta_p^2 = 0.16) \), tension \( (F(1,34) = 10.44, p = 0.03, \eta_p^2 = 0.24) \), and vigor \( (F(1,34) = 7.22, p = 0.01, \eta_p^2 = 0.18) \). In addition, a significant interaction was observed on the depression symptoms \( (F(1,34) = 5.53, p = 0.03, \eta_p^2 = 0.14) \). Regarding physiological outcomes, significant interactions were observed on percentage of body fatness \( (F(1,34) = 17.26, p < 0.001, \eta_p^2 = 0.34) \) and cardiovascular fitness \( (F(1,34) = 30.05, p < 0.001, \eta_p^2 = 0.47) \). Lastly, a significant interaction was observed on physical activity levels \( (F(1,34) = 17.35, p < 0.001, \eta_p^2 = 0.36) \).

**Conclusion:** The findings of current study indicated that a 4-week virtual reality-based exercise intervention is effective in promoting college students’ intrinsic motivation and identified regulation toward exercise, improving overall mood states, depressive
symptoms, cardiovascular fitness, body composition, and enhancing greater physical activity. It is suggested that immersive virtual reality exercise could be a fun and motivating means for promoting young adults’ physical activity and health-related physiological and psychological outcomes.
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Chapter One: Introduction and Rationale

Despite the known benefits of physical activity (PA), the prevalence of physical inactivity and sedentary behavior are significant issues in public health. Young adults, such as college students, are a population at risk for decreased PA participation due to the newfound responsibility of balancing school, work, and personal responsibilities (Calestine et al., 2017). Findings from previous research found a significant decline in PA participation and an increase in sedentary behavior during young adulthood during the college years (Small et al., 2013). According to the most recent National College Health Assessment (NCHA), only 49.8% male and 44% female college students met the recommended guidelines for at least 30 minutes of moderate-to-vigorous physical activity (MVPA) each day in 2019 (American College Health Association, 2019). Notably, The NCHA report also indicated 40.7% male and 36.1% female college students were either overweight or obese (American College Health Association, 2019). Previous meta-analysis study that examined the college students’ PA behaviors indicated enjoyment, self-efficacy, and motivation were important determinants for engaging sustained PA, in addition, overall results on PA interventions were not very encouraging, with only moderate impact on college students (Keating et al., 2005). It is, therefore, imperative to examine innovative ways to motivate college students to participate in regular PA to improve physical and psychological well-being in this population.

The young adult population is technology-savvy and interested in videogame play. According to the Pew Research Center, among college students, 70% reported playing videogames, computer games, or online games at least once a week. Moreover,
approximately 65% of college students reported being regular or occasional game players—possibly contributing to increased sedentary time (NW et al., 2003). Virtual reality (VR)-based exercise is an active form of videogame-based technology potentially attractive to the college population as an enjoyable means of promoting regular PA participation. VR is an interactive computer-generated experience taking place within a simulated environment, with this technology primarily incorporating auditory and visual feedback (Zeng et al., 2017). There are two types of VR technology—immersive VR and non-immersive VR. In detail, immersive VR utilizes a head-mounted apparatus, body motion sensor, real-time graphics, and an advanced interface device to simulate the complete virtual environment, which envelopes players in a virtual world. Non-immersive VR uses a flat computer/television screen linked to a keyboard, gamepad, and joystick to interact with the gaming system, and is sometimes referred to as exergaming or active video games (Gao, 2017; Zeng et al., 2018). In other words, Immersive VR makes player feels like they are “actually in the virtual world,” whereas non-immersive VR does not simulate a virtual environment to a deeper degree.

Currently, VR technology has been primarily used as a rehabilitation tool among clinic-based applications, such as using VR technology for improving mobility and balance among post-stroke patients (Deutsch, 2011; Li et al., 2016). However, there is a paucity of literature regarding the implementation of VR technology on PA promotion in healthy populations. Recently, researchers and health professionals have begun to explore the feasibility and effectiveness of VR-based exercise as an innovative health promotion approach among healthy population. Zeng et al. recently conducted a pilot study that
compared an immersive VR-based exercise bike and a traditional exercise bike on physiological and psychological responses (Zeng et al., 2017). The study found participants during VR-based exercise had significantly higher enjoyment and self-efficacy compared to traditional stationary bike exercise, suggesting VR-based exercise to be an effective, enjoyable, and motivating tool for promoting PA among adult populations. In addition, another recent study examined the enjoyment and intensity of PA during immersive VR-based treadmill exercise, which suggested that active video game in immersive VR using a multi-directional treadmill may be an effective tool for increasing leisure-time PA participation in healthy population (Dębska et al., 2019). A study conducted by Baños et al. (2016) shows that walking on a treadmill performed in the virtual world can be better tolerated by obese children than the same physical effort in a traditional form. VR allows for the distraction of the participants from the discomfort that accompanies PA. According to the authors, the use of VR technology in training programs may be a factor for increased motivation to exercise, which may be important in the prevention of overweight and in the fight against obesity. Because such immersive VR technology just emerged in the past few years, currently, most of published studies are focusing on the feasibility of implementation in public health research, which mainly used observational or pre- and post- study design examining the acute effects of such innovative technology. However, there is a lack of randomized control trial to examine the long-term effects of VR-based exercise on physiological and psychological outcomes. Therefore, to fill the research gap, the purpose of present study is to examine the effects
of a 4-week immersive VR-based exercise intervention on college students’ physiological and psychological outcomes.

**Purpose of Study**

The purpose of this randomized control trial was to examine the effectiveness of a 4-week VR-based exercise intervention on promoting PA and improving health-related physiological and psychological outcomes among college students. In detail, the following specific aims and associated hypotheses were proposed:

*Study Aim 1.* Examine the effects of a 4-week VR-based exercise intervention on college students’ psychological outcomes (e.g., exercise motivation, mood states, and depressive symptoms) in comparison with control group (usual practice).

*Hypothesis 1.* Participants in the intervention group would have significant improvement on psychological outcomes (e.g., exercise motivation, mood states, and depressive symptoms) in comparison to control group after 4 weeks.

*Study Aim 2.* Examine the effects of a 4-week immersive VR-based exercise intervention on college students’ physiological outcomes (e.g., body mass index, percentage of body fatness, and cardiovascular fitness) in comparison with control group.

*Hypothesis 2.* Participants in the intervention group would have favorable changes on physiological outcomes (e.g., body mass index, percentage of body fatness, and cardiovascular fitness) in comparison with control group after 4 weeks.

*Secondary Aim.* Examine the effects of a 4-week VR-based exercise intervention on college students’ PA in comparison with control group.
Hypothesis. Participants in the intervention group would have significant improvement on PA in comparison with control group after 4 weeks.
Chapter Two: Literature Review

Physical Inactivity Among College Students

Considerable research findings have indicated that PA is associated with lower risk of obesity, stroke, type-2 diabetes, and improves global health and quality of life (Kwan et al., 2012). The American College of Sports Medicine (ACSM) updated PA guidelines for Americans, which recommends adults engage in at least 30 minutes moderate-intensity PA daily, or 75 minutes vigorous-intensity PA for at least 3 days per week, or an equivalent combination of the two (Physical Activity Guidelines Advisory Committee ([PAGAC], 2018). However, the physical inactivity is rapidly becoming one of the most pressing public health concerns. According to the report from the U.S. Department of Health and Human Services, only one in three adults meet the recommended amount of PA each week, moreover, less than 5% of adults participate in 30 minutes PA each day (U.S. Department of Health and Human Services [HHS], 2010). Young adults, such as college students, are a population at risk for decreased PA participation due to the newfound responsibility of balancing school, work, and personal responsibilities (Calestine et al., 2017). Findings from previous research found a significant decline in PA participation and an increase in sedentary behavior during young adulthood during the college years (Small et al., 2013). According to the most recent National College Health Assessment (NCHA), only 49.8% male and 44% female college students met the recommended guidelines for at least 30 minutes of moderate-to-vigorous physical activity (MVPA) each day in 2019 (American College Health Association, 2019). Previous studies indicated a significant PA decline during young
adults’ transition into early adulthood, especially at the time of entering a university (Fagaras et al., 2015). A study of 233 undergraduate students reported PA levels decreased during the transition from high school to college years; 65% of students reported engagement in regular vigorous and 26% in regular moderate PA during high school. Upon follow-up, however, during their college years, 38% of students participated in regular vigorous and 20% moderate PA (Calestine et al., 2017). The effective PA intervention is urgently needed in this population.

In order to meet the PA guidelines, college and university health promotion services ought to encourage regular participation in both moderate and vigorous PA among this population. Health benefits can be achieved by participating in either 150 minutes of moderate or 75 minutes of vigorous PA per week (PAGAC, 2018), however, the motivation to participate in these 2 types of activity would differ. For example, activities that are vigorous include short bouts of high-intensity movements such as basketball, soccer, or plyometric training, whereas moderate exercise might include walking, biking, or weight lifting. College students will have very different motivation for participating in these various exercises. Some researchers have looked at exercise motivation in order to better understand participation in PA (Seo et al., 2007). Research evidence indicates that people with higher exercise motivation may participate more regularly over a sustained period of time than people with low exercise motivation (Frederick et al., 1996). Previous study has indicated that people have many different motivations to maintain exercise adherence (Biddle, 1995). Deci and Ryan’s (1991) self-determination theory provides a frame work to understanding the multidimensional
approach to exercise motivation. The theory allows researchers to examine the antecedents of exercise motivation, as well as the correlates and consequences of those processes. It suggests that specific exercise motivation variables can be intrinsic or extrinsic. Intrinsic motivation variables are related to competence and interest—enjoyment, whereas extrinsic motivational variables center on the achievement of outcomes that are extraneous to participation in the exercise (Deci & Ryan, 1985; Mullan et al., 1997; Pelletier et al., 1995). Overall, participants listed general health issues (e.g., positive health, ill-health avoidance), appearance, strength and endurance, and weight management as their top motivations behind exercising (Egli et al., 2011). Kimbrough et al (2002) indicated that weight management, performance, psychological motives, and general health were among the top reasons for PA in college population. These reasons have been broken down further by designating these motivations as either extrinsic or intrinsic motivators. Extrinsic factors such as appearance, weight management, and stress management proved to be related to exercise motivators, whereas intrinsic factors such as enjoyment and challenge proved to be related to engagement in sport (Kilpatrick et al., 2005). It is essential and important to understand those motives that encourage college students participate sustained PA and maintain active, as well as develop effective strategies and programs for prompting PA and overall health.

**Self-Determination Theory**

Self-determination theory (SDT) is an approach to human motivation and personality that uses traditional empirical methods while employing an organismic meta-theory that highlights the importance of human’s evolved inner resources for personality
development and behavioral self-regulation (Ryan et al., 1997). SDT is uniquely placed among theories of human motivation to evaluate the effects of different types of motivation that underlie behaviors. The theory originated from the investigation of human’s basic psychological needs and fulfillment for the self-motivation and personality integration (Ryan & Deci, 2000). In other words, SDT emphasizes the investigation of an individual’s inherent growth tendencies and innate psychological needs that are the basis for their self-motivation and personality integration, and for the conditions for the positive process (Ryan & Deci, 2000). SDT supports three basic psychological needs – competence, relatedness, and autonomy, which must be satisfied to foster overall well-being and health. Specifically, the need for competence is to seek to control the outcome and experience mastery (White et al., 1959); the need for relatedness is the universal want to interact, be connected to, and experience caring others (Baumeister et al., 1995); the need for autonomy is the universal urge to be causal agents of one's own life and act in harmony with one's integrated self (Deci et al., 2004). These needs can be applied universally; however, some may be more salient than others at certain times and are expressed differently based on time, culture, or experience.

The SDT-based motivation was comprised by three major components: intrinsic motivation, extrinsic motivation, and amotivation (Ryan et al, 1997). According to SDT, an individual’s motivation is categorized into levels of higher to lower self-determination, namely, intrinsic motivation, identified regulation, external regulation, and amotivation. From a regulatory perspective, the intrinsic motivation was considered as intrinsic regulation (i.e., interest, enjoyment, inherent, satisfaction); the extrinsic motivation was
comprised of external regulation, introjected regulation, identified regulation and integrated regulation; Motivation was considered as non-regulation. Concerning the participation of PA, intrinsically motivated behaviors are those performed purely for the satisfaction or enjoyment gained from PA itself. The literature indicated the primary satisfaction associated with intrinsically motivated actions were feelings of competence and interest/enjoyment (Deci & Ryan 1985; Pelletier et al., 1995; Reve & Deci, 1996; Csikszentmihalyi & Rathunde, 1993; Koestner & McClelland, 1990). In contrast, extrinsically motivated behaviors are those performed to obtain rewards or outcomes which are separate from the activity itself, such as body-related motives (appearance and fitness). In other words, intrinsic motivation is present when behavior is intrinsically motivated by experiencing satisfaction and pleasure. Identified regulation occurs when a behavior is valued and perceived as being chosen by oneself. In contrast, external regulation is present when an individual engages in a behavior to obtain rewards or avoid punishment. Finally, when amotivation occurs, individuals experience a lack of contingency between their behaviors and outcomes.

Several studies have explored the exercise motivation in particular college population (Maltby & Day, 2001; Smith et al., 1998; Vartanian & Shaprow, 2008). One study examined the motivation of college students before and after spring break, and found that students’ weight management, performance motives, and general health motives were the most cited motivation for exercise (Maltby & Day, 2001). Specifically, the findings indicated that college students who have continually lived an exercise-led lifestyle in an organized program for 6 months are more likely to be active in one or two
years later. Maltby and Day (2001) found exercise motivation to be different according to the length of adherence; furthermore, they also related exercise adherence with intrinsic and extrinsic motivation. Specifically, college students who were physically active for less than 6 months showed more extrinsic motivations, which were significantly related to poorer psychological well-being; whereas college students physically active for more than 6 months were more intrinsically motivated and had significantly higher positive psychological well-being. In addition, previous study that examined the sex difference in exercise motivation in the adult population, revealing men and women had different motives to exercise (Halliwell et al., 2007). Consistent finding from previous studies have indicated that women were found to be more motivated by weight management, whereas men were motivated by challenge and appearance (Grogan et al., 2006; Kilpatrick et al., 2005).

Previous studies have examined the motivation and PA among college students and pointed out the lack of motivation can broadly be explained by two orders of factors. First, as mentioned in the previous statistics, college students may not be sufficiently interested in exercise or value its outcomes enough to make it a priority in their lives (Ryan et al., 2009). Specifically, many college students experience competing demands on their time from educational, career, and family obligations, possibly at the expense of time and resources that could be invested in exercising regularly. Second, some individuals may not feel sufficiently competent at physical activities, feeling neither physically fit enough nor skilled enough to exercise, or due to health limitations that present a barrier to perform activities (Korkiakangas et al., 2009). Whether it be low
interest or low perceived competence, from SDT perspective, those individuals are unmotivated, which have no intention to be more physically active, or are insufficiently motivated in the face of other interests or demands on their time (Teixeira et al., 2012). In addition to those who are unmotivated, another source of short lived persistence in exercise behaviors comes from individuals who do express personal motivation to exercise regularly. Specifically, significant percentage of people may exercise because of controlled motivations, where participation in activities like going to the gym or running regularly is based on a feeling of “having to” rather than truly “wanting to” participate (Ryan et al., 2009). Controlled motivation, which by definition are not autonomous, are predominant when the activity is perceived primarily as a means to an end and are typically associated with motives or goals such as improving appearance or receiving a tangible reward (Markland, 2009).

Although there is no specific study that uses SDT to examine the effects of VR-based PA intervention, there is one study I found to be very informative. Specifically, the study applied SDT to examine the effects of VR-based creative learning as compared to traditional classroom lecture, in the context of education (Huang et al., 2018). They focused the concept of psychological needs satisfaction regarding how VR learning environments satisfy psychological needs and thus foster the sustained engagement and affect behavioral intentions. The findings indicated that the experience of autonomy and relatedness had positive relationship with intrinsic motivation, indicating that higher levels of perception of autonomy and feeling connected with others in virtual environments link to increased intrinsic motivation, thus, facilitating the engagement.
Moreover, the results revealed that the satisfaction of autonomy and relatedness are significantly associated with behavioral intentions, indicating that individuals who experience autonomy satisfaction and feel connected to others in the VR environments have a positive relationship with behavioral intentions. However, the perceived competence did not predict the behavioral intentions in this study. They explained this may due to the insufficient of challenging tasks in their educational VR learning environments, since the optimal challenging task would meet the competence needs, thus, stimulating behavioral intentions. The findings of this study provide support for the use of SDT to understanding the factors that mediate between VR environments and behaviors.

When corresponding to the VR-based PA intervention, it appears feasible and meaningful to adopt SDT framework to understand the potential mechanism pathway and potential factors that mediate the relationships between VR-based exercise and long-term participation. According to SDT, the individuals’ inherent growth tendency and innate psychological needs are the basis for their self-motivation and personality integration (Ryan & Deci, 2000). The overall pathway under SDT framework is that the satisfaction or fulfillment of one’s psychological needs lead to the increased levels of self-determination, in turn, lead to behavioral changes. Regarding my proposed study, I plan to adopt two sub-concepts of SDT: concept of psychological needs satisfaction and motivational regulations. According to SDT, the competence, relatedness, and autonomy are those three basic psychological needs. Specifically, the need for competence is to seek to control the outcome and experience mastery. The need for relatedness is the
universal want to interact, be connected to, and experience caring others. During the intervention, each participant will have an account and their biking or gaming records will be recorded in the system, participants can choose to ride with other participants in the VR gaming environment (a ghost rider will be generated in game that represents other participant’s biking records). The need for autonomy is the universal urge to be causal agents of one's own life and act in harmony with one's integrated self (Deci et al., 2004). Corresponding to the proposed intervention, intervention participants are able to customize their preference in VR environment settings (change biking environment, bike routines, and goal settings), and VR game mode (comfort and intense mode).

On the other hand, the motivational regulation was comprised by three major components: intrinsic motivation, extrinsic motivation, and amotivation (Ryan et al, 1997). According to SDT, an individual’s motivation is categorized into levels from higher to lower self-determination, namely, intrinsic motivation, identified regulation, external regulation, and amotivation. From a regulatory perspective, the intrinsic motivation is considered as intrinsic regulation (i.e., interest, enjoyment, inherent, satisfaction); the extrinsic motivation was comprised of external regulation, introjected regulation, identified regulation and integrated regulation. Concerning the participation of PA, intrinsically motivated behaviors are those performed purely for the satisfaction or enjoyment gained from PA itself. The literature indicated the primary satisfaction associated with intrinsically motivated behaviors were feelings of competence and interest/enjoyment (Deci &Ryan 1985; Pelletier et al., 1995; Reve & Deci, 1996; Csikszentmihalyi & Rathunde, 1993; Koestner & McClelland, 1990). In contrast,
extrinsically motivated behaviors are those performed to obtain rewards or outcomes which are separate from the activity itself, such as body-related motives (appearance and fitness). Intrinsic motivation is present when behavior is intrinsically motivated by experiencing needs satisfaction and sense of enjoyment. Identified regulation occurs when a behavior is valued and perceived as being chosen by oneself. In contrast, external regulation is present when individual engages to obtain rewards or avoid punishment. Finally, when amotivation occurs, individuals experience a lack of contingency between their behaviors and outcomes. Recall the study conducted by Huang et al. (2018), their findings indicated that the satisfaction of autonomy and relatedness in VR-based exercise led to greater intrinsic motivation, in turn, promoting greater behavioral intentions and engagement. The failure of meeting needs for competence was explained by lack of challenging tasks in the VR environments. However, the need for competence can be easily addressed by the VR-based exergames. As aforementioned those highly customizable exergames, there are different levels of difficulty game modes, participants can adjust to a proper challenge level and exercise on it. As indicated by previous study, only having ease of control is not enough to motivate users’ behavioral intentions, whereas optimal challenges would stimulate the greater behavioral intentions (Jung, 2011). I would expect to see the consistent motivational pathway as demonstrated by the SDT, which participants’ psychological needs are satisfied during the VR-based exercise, and participants are intrinsically motivated to engage the enjoyable exercising experiences, hopefully, after 8 weeks intervention, they may maintain the increased self-determination and develop an actively lifestyle.
Virtual reality on Physical Activity

As the development the technologies, VR technology has been considered as one of the most innovative and exciting technologies. Virtual reality is a digital technology that replicates a real or imagined environment and simulates a user’s physical presence in this environment allowing for user interaction (Isaac, 2016). Currently standard virtual reality systems use either VR headsets or multi-projected environments to generate realistic images, sounds and other sensations that simulate a user's physical presence in a virtual environment. Generally, there are two types of VR – immersive VR and non-immersive VR. The immersive VR which frequently uses head-mounted displays, body-motion sensors, real-time graphics, and advanced interface devices (e.g., specialized helmets) in the simulation of an environment for the user. Conversely, non-immersive VR uses interfaces such as flat-screen televisions/computer screens with associated keyboards, game pads, and joysticks—not simulating an environment to as deep a degree as immersive VR. Simply stated, VR creates an environment in which visual, auditory, and other perceptual stimuli are incorporated in a sequence of manipulated events to which a person is expected to react (Pasco, 2013).

The latest commercially-available VR headsets, such as the Oculus Rift, Oculus Go, Sony PlayStation VR, Samsung Gear VR, and HTC Vive artificially generate sensory experiences, which may include visual, auditory, touch and scent stimuli, while allowing a user to manipulate objects within the virtual environment (Isaac, 2016). Notably, VR environments are split into two categories. Simple VR environments consist of a two-dimensional (2D) viewing environment, whereas a complex virtual reality
environment can include three-dimensional (3D) digital objects and user-controlled avatars displayed in real-time (i.e., without any time delay in movement between the users’ and avatars’ actions). The 3D environment provides a condition where individuals are immersed in close-to-reality situations while interacting with digital objects and avatars. VR interaction concepts within these environments have been widely used to help understand VR applications. The immersive VR features immersion, interaction, and presence. Such exciting technology successfully drew health professional and researchers’ attention, exploring its potential for PA and health promotion.

VR technology has been widely used in many health domains, with most VR systems designed to facilitate cognitive learning, motor function, and psychological well-being in clinical population. Notably, as the increased prevalence of VR among normal population, there is a trending for implementing VR in PA and health promotion. Specifically, VR systems present opportunities for implementation of interventions aimed at increasing PA and promoting health in environments including, but not limited to school-based physical education classes, community-based fitness programs, or home-based rehabilitation, among others. To this end, VR has received considerable attention in the promotion of PA participation in healthy individuals in addition to being used rehabilitation purposes in patients (Miller et al., 2014). Indeed, in an effort to provide diverse workout experiences, some researchers and health professionals have even integrated traditional PA equipment with virtual reality technology. For example, combining virtual reality with standard gym-based exercise equipment, such as a stationary exercise bike, may serve to enhance the psychological benefits of exercise (Liu
et al., 2019; Zeng et al., 2017). These psychological benefits may increase chances of long-term adherence to an exercise program through provision of a sense of challenge and regulated competition and result in a more enjoyable exercise experience (Liu et al., 2019; Plante et al., 2003). Therefore, virtual reality as an emerging technology is rapidly becoming a popular intervention technique for PA and health promotion among various populations. However, among those limited studies, findings were based on the observational study design, there is a lack of experimental design for determining those promising findings and examining the potential of VR-based intervention for promoting PA and health in normal population.

**Immersive Virtual Reality-Based Interventions**

As mentioned earlier, most immersive-based VR interventions were conducted among clinical population, such as suing VR-based training for improving mobility and balance on post-stroke patients (Deutsch, 2011; Li et al., 2016). However, there are very limit number of studies have been conducted on healthy population. Fortunately, there is an increasing number of studies that aim to promote PA and health outcomes among healthy young adults. For example, Dębska and colleagues (2019) conducted an experiment to examine the enjoyment and intensity of VR-based exercise by using two immersive VR devices (immersive VR treadmill and immersive VR flight simulator). Notably, the study also included the results of subjective research on the usefulness of VR-based exercise in the opinion of users. A total of 61 healthy adults complete two separate 10-minute immersive VR exercise sessions. The enjoyment was assessed by using the intrinsic motivation inventory. The exercise intensity was assessed during 10-
minute sessions via heart rate monitor. The results indicated that participants in both forms of immersive VR exercise sessions reported greater level of enjoyment and in favor of exercise on immersive VR treadmill and in favor of VR treadmill. Moreover, the intensity of physical activity during immersive VR sessions were at the recommended level for obtaining health benefits. The assessment of the usability of immersive VR-based exercise was emphasized by the participants’ declarations, which indicated that they would be happy to train on them and considered a useful tool to meet the needs of exercise during free time. Overall, the higher level of enjoyment and attractiveness of such immersive VR-Such interesting form of physical activity may be considered as an effective tool for motivating those people who are not physically active, thus, may increase the participation and adherence. In addition, the high level of enjoyment associated with physical exertion during immersive VR exercise seems to be important to overcome the insufficient physical activity frequency. Previous study has indicated that VR allows for the distraction from the experienced discomfort and lower the perception of pain observed during exercise, the immersive VR seems to have the potential for activation of people who avoid physical activity due to various discomforts associated with physical effort (Baños et al., 2016; Matsangidou et al., 2018). In my opinion, novel finding of this study is the VR-induced high level of enjoyment, which is considered as a significant predictor for PA engagement. Commonly, people are more willing to engage activities that make them feel interesting and fun. The findings of this study provided strong evidence regarding the feasibility of immersive VR-based intervention for
promoting PA among young adults, and the subjective research on participants’ feedbacks are favorable.

Similar findings were found on another study, Zeng and colleagues (2017) conducted an experiment to examine the acute effects of VR exercise bike games on college students’ physiological and psychological outcomes. In detail, a total of 12 healthy college students completed two separate 20-minute exercise sessions on a commercially available VR exercise bike (VirZoom) and a traditional stationary exercise bike. The blood pressure, ratings of perceived exertion, self-efficacy, and enjoyment were assessed as primary outcomes. The results revealed participants in the VR exercise bike had significantly lower ratings of perceived exertion in comparison to traditional stationary exercise bike. Moreover, participants reported significantly higher self-efficacy and enjoyment during the VR exercise bike session compared with traditional stationary exercise bike session. The authors suggest the use of immersive VR-based exercise bike may be considered an effective, enjoyable, and motivating tool for promoting PA participation and potentially improving PA adherence among young adult population.

Along with this study, another study has been conducted by Liu et al. (2019). The study aimed to compare the differences in young adults’ situational motivation between immersive VR exercise bike, non-immersive VR exercise bike, and traditional stationary exercise bike. A total of 49 healthy college students completed three separate 20-minute exercise sessions. In light of self-determination theory, participants’ intrinsic motivation, identified regulation, external regulation, and amotivation were assessed as the primary study outcomes. The results showed participants in the immersive VR exercise bike
session had the highest level of intrinsic motivation compared with the non-immersive VR and traditional stationary exercise. In addition, participants in the immersive VR exercise had higher identified regulation than non-immersive VR exercise. Lastly, participants had lower external regulation in both immersive and non-immersive VR exercise in comparison to traditional exercise. The findings indicated that exercise on immersive VR-based bike may induce greater self-determined motivation such as intrinsic motivation and identified regulation, which lead to greater PA participation and improve adherence to PA.

Matsangidou and colleagues (2018) conducted a study to examine the effectiveness of VR in reducing the feeling of exercise pain and effort. As the pain and effort are subjective feelings, they are influenced by variety of psychological factors, including one’s awareness of internal body sensations, also known as private body consciousness. This study examined whether exercise in VR condition have influences on the private body consciousness. In detail, a total of 80 young adults were randomly assigned to VR and non-VR groups. All participants were required to maintain a 20% 1RM isometric bicep curl, whilst reporting ratings of pain intensity and perception of effort. Participants in the VR group completed the isometric bicep curl task whilst wearing a VR device which simulated an exercising environment. Participants in the non-VR group completed a conventional isometric bicep curl exercise without VR. Participants’ heart rate was continuously monitored along with time to exhaustion. A questionnaire was used to assess PBC. The results indicated that participants in the VR group reported significantly lower pain and effort and exhibited longer time to exhaustion.
compared to the non-VR group. However, there was no interaction between private body consciousness and VR simulation. The findings indicated that exercise under VR condition was effective in reducing exercise-induced pain among adults age ranges from 18 to 45 years old. The possible mechanism of this finding may explain by the distraction from virtual environment and decreased perception of time, which may contribute to the longer duration of exercise. In addition, the findings also indicated participants in the VR group reported lower perceived exertion in comparison to non-VR group, which also contribute to the adherence of exercise.

It seems VR-based exercise can attract the user’s attention and induce less perception of exercise-related pain and effort, thus, may increase the duration of exercise participation. Similar findings were also reported in other study. Baños and colleagues (2016) conducted a study to examine the effectiveness of using VR to enhance attentional distraction in overweight children during exercise. In a counterbalanced design, a total of 109 children were asked to complete two separate 6-minute between VR-based treadmill walking and traditional treadmill walking. During the VR-based walking, participants were asked to focus their attention on a virtual environment, whereas, participants during traditional treadmill walking were asked to focus their physical feeling. The attentional focus during exercise, feeling states, perceived exertion, enjoyment and heart rate were assessed as primary study outcomes. The results indicated that participants focused on internal information under the traditional treadmill walking, however, they significantly shifted their attention to the external environment in the VR treadmill walking. Also, participants were favored exercising on VR treadmill walking. The findings indicated that
the use of VR for treadmill walking was effective to promote attentional distraction from bodily sensations. However, there was no difference between groups were found when examining the changes in feeling states and perceived exertion. Overall, they suggested that VR can be a useful tool to promote distraction and enjoyment during exercise.

Similarly, Neumann and Moffitt (2018) investigated the affective and attentional states in a virtual running task. A total of 40 college students were randomly assigned to two running condition: running on treadmill with a computer-generated VR environment that included other virtual runners and running on treadmill while viewing the neutral images. Participants in both conditions showed a pattern of reduced positive affect and increased tension during the run with a return to high positive affect after the run. In the VR condition, higher levels of immersive tendencies and attention/absorption in the virtual environment were associated with more positive affect after the run. In addition, participants in the VR condition focused attention more on external task-relevant stimuli and less to internal states than participants in the neutral images condition. The findings suggested that the effects of exercising in a VR environment would depend on individual factors, such as attention/absorption in the virtual environment. The ability to distract users’ attention via VR-generated environment has been further confirmed.

Sakhare and colleagues (2019) conducted a feasibility study to explore cycling in a cognitively enriched and immersive spatial navigation VR environment in young and older adults. A total of 20 younger and 20 older adults completed four trials of cycling while wear a head-mounted device and navigating in a VR park environment. The adverse effects, mood, presence, and physical exertion levels associated with cycling in
the VR environment were assessed via a battery of questionnaires. The results indicated that exposure to the virtual environment was associated with high arousal and low stress levels, suggesting a state of excitement, and most participants reported enjoyment of the spatial navigation task and VR environment. No association was found between physical exertion levels and simulator sickness levels. VR provides clinicians and researchers with a safe and controlled environment for combining spatial navigation with exercise, as well as monitoring cognitive and physical performance. It also provides flexibility to manipulate spatial navigation task difficulty based on one’s fitness level, cognitive status, and age. Moreover, rewards and achievements can easily be incorporated into a virtual environment to enhance enjoyment and increase the likelihood of participation and adherence to an intervention. These benefits make VR a promising tool for interventions aimed at improving cognitive and physical health.

What makes VR-based physical activity more enjoyable than the other activities? A greater level of immersion with deeper sense of presence, and various interactions make immersive VR uniquely placed among other activities. In detail, the concept of presence has been defined by Slater and Wilbur (1997), which describe it as the subjective feeling of “being there” in the VR environment. The immersive VR technology is well capable of providing users an inclusive, extensive, surrounding, and vivid illusion of reality, which make them feel being in the virtual world. Previous study has indicated that the stronger a person experiences the feeling of being in the VR environment, the more likely he or she will report behaving to that in the real world (Bowman & McMahan, 2007). Thus, given the greater immersion and presence of VR-
based exercise, it is possible to deliver physical activity promotion content via this novel technology, in turn, transfer the physical activity behaviors into reality.

Moreover, the immersive VR-based exercise provides a variety of interactions, which increase the interest and fun experiences during exercising. The most notable interaction of VR-based exercise is the interaction between users’ movements in real world and reflecting in the virtual environment. The VR system can be compatible with many exercise devices, such as linking with treadmill, stationary exercise bike, and balance bord. Within the exergaming content, there are customizable goals, tasks, and virtual avatars which provide immediately feedbacks when exercising. The high interaction of VR-based exercise provides greater interestingness.

In addition, the effects of VR-based exercise on bodily sensation may facilitate the physical activity participation. Research has shown that workouts can become more appealing with the notion that they will not cause the body physical pain. VR-based exercise can potentially make exercise more appealing and may increase the time spent working out by providing a distraction from bodily sensations. De Bourdeaudhuij and colleagues (2002) examined the effects of attentional distraction on treadmill running time in obese youth. The findings suggest that when the mind is distracted, it takes longer to realize the bodily discomfort and allowing participants to prolong the exercise period. With the greater level of immersion and interactions, VR can easily drive one’s attention and may distract from the exercise-induced bodily discomfort.

In addition to those psychological benefits, the physiological outcomes remain largely unexplored. There is one study investigated the effects of a fully immersive VR-
based training system on young adults’ cardiovascular and muscular outcomes (Feodoroff et al., 2019). This study used a cross-sectional design to analyze muscle activity (electromyography), heart rate, perceived exertion, motion sickness symptoms, perceived workload, and PA enjoyment in 33 young adults performed 15-minute flight simulator training activities. The results indicated that participants’ performance of the planking position required to play the game resulted in moderate aerobic intensity. To achieve the most immersive experience, the virtual horizon was adjusted to a 45° angle, which required the participants to tilt their heads back. This position requires an almost constant isometric muscle contraction of the neck extensors. Moreover, the majority participants reported that they enjoyed the exercise, however, there were 6 participants had to drop out from the study due to the incidence of motion sickness. The findings suggested that a fully immersive VR training system can contribute to muscle-strengthening activities for healthy adults.

Based on the findings from the limited VR-based physical activity intervention, it appears that VR-based exercise can induce greater enjoyable activity experience while promoting greater self-determined motivation (e.g., intrinsic motivation and identified regulation), which may lead to greater participation in the intervention. However, VR as a novel technology, most studies mainly focus on examining the feasibility and effectiveness of VR-based intervention for promoting physical activity and health among healthy population. Question remains regarding the sustainability of benefits on VR-based intervention. Further research is warranted to examine the long-term effects of VR-
based intervention for promoting active lifestyle and understand the underlying mechanism for behavior changes.

**Non-Immersive Virtual Reality-Based Interventions**

As mentioned earlier, there are generally two types of VR, immersive and non-immersive. The non-immersive VR-based exercise game is also known as the active video game or exergame. Comparing with the immersive VR, the non-immersive VR has less degree of immersion, players may feel less sense of being in the virtual environment. The non-immersive VR-based exergaming have been well studied in the past two decades. Many studies support the use of exergame for promoting PA and health-related outcomes across ages. To some extent, the non-immersive VR-based exergame can be consider a precursor of newly immerged immersive VR exergame. Next, I will briefly review the typical studies which use non-immersive VR systems for promoting PA and health among healthy adults.

Warburton and colleagues (2007) conducted a randomized control trial to evaluate the effectiveness of interactive video games on health-related physical fitness and exercise adherence in comparison with traditional aerobic training. A total of 14 college students were randomly assigned to intervention (exergaming bike) and control (traditional stationary exercise bike) groups. The participants were asked to engage 3 days (30 minutes each session) per week, for 6 weeks. The intervention attendance, health-related physical fitness (maximal aerobic power, body composition, muscular strength, muscular power, and flexibility), and resting blood pressure were measured before and after the training sessions. The results revealed that the intervention
attendance was significantly higher in the active video game intervention group compared with traditional exercise bike control group. Moreover, there was significantly increased maximal aerobic power and reduced systolic blood pressure after active video game but not traditional exercise. However, there was no significant changes in body composition after either training sessions. The findings indicated that a training program that links interactive active video games to exercise results in greater improvements in health-related physical fitness in comparison with the traditional cycling exercise.

Kraft and colleagues (2011) compared the college students’ heart rate response and ratings of perceived exertion between two exergames and traditional exercise. A total of 37 college students completed three self-selected intensity trials: (a) video game interactive bicycle ergometer (CatEye GB300), (b) interactive video dance game (Dance Dance Revolution), and (c) traditional cycle ergometer while watching television. The results indicated that participants showed significantly higher mean heart rate and peak heart rate in exergaming bike in comparison to dance exergame and traditional exercise bike. In addition, the lower perceived exertion was found in the dance exergaming. The overall findings support that exergames are capable of eliciting physiological responses necessary for fitness improvements. They also suggest the exergaming can be an effective tool for motivating young adults participating in PA.

O’Donovan and Hussey (2012) conducted a cross-sectional study to examine the effects of active video games on college students’ energy expenditure and heart rate response. A total of 28 college students completed two 15-minute exergaming sessions, either Wii Sports Boxing, Tennis plus Baseball, or Wii Sports Boxing plus Wii Fit Free
Jogging game sessions. The percentage maximal heart rate and metabolic equivalents were measured as the primary outcomes. The results of this study provided PA intensity and dose-response guidance for future prescriptions of PA dose. Specially, Wii Sports Boxing, Tennis and Baseball are light-intensity activities, and Wii Fit Free Jogging is a moderate-intensity activity. In addition, the findings also indicated that the experience of gaming may affect the exercise intensity during active video game playing.

Regarding the intensity during exergaming, Polechoński and colleagues (2019) conducted study to assess the intensity of aerobic PA during exergame training sessions with a moderate and high level of difficulty of the interactive program “Your Shape Fitness Evolved 2012” for Xbox 360 Kinect in the context of health benefits. A total of 30 healthy college students completed two exergaming sessions under moderate and high level of difficulty of the exergames. The average percentage of maximum heart rate and heart rate reserve during the exergaming were calculated and referred to the criterion of intensity of PA. The results indicated both medium and high level of exergames` intensity met the criterion of moderate and vigorous PA intensities. Moreover, the time spent in recommended moderate-to-vigorous intensity during 15-min exergame session was 14.6 minutes for medium level of difficulty exergaming playing and 14.8 minutes for paying in the high level of difficulty. The findings provided evidence that exergames can be used to increase weekly dose of PA for achieving the recommended PA levels.

Rhodes, Warburton, and Bredin (2009) conducted study to examine the effects of interactive exergaming bike on the constructs of the theory of planned behavior and adherence in comparison to a traditional cycling condition where participants listen to
self-selected music. A total of 29 inactive college students were randomly assigned to exergaming bike and traditional cycling conditions. Participants were asked to engage 3 days/week for 30 minutes/day, for 6 weeks. At the end of the first session, participants were asked to complete the theory of planned behavior-based measures, and these were subsequently measured 6 weeks later. The results indicated that participants showed higher level of affective attitude and adherence across the 6 weeks in the exergaming bike condition in comparison to the traditional cycling. The findings indicated that the exergaming has the potential to be effectively implemented among young adults for motivating PA engagement and adherence. The favorable findings point out the potential for using exergaming as a means for promoting prolonged PA and obtaining health benefits.

Furthermore, Lyons and colleagues (2012) conducted an experiment to examine the effects of game enjoyment and game type on energy expenditure in active video games, which compared the enjoyment and energy expenditure between exercise-themed and game-themed active video games. A total of 100 college students played two of four Wii Fit games (at least one aerobic game and one balance game) for 10 minutes each session. The energy expenditure was measured during the exergaming sessions and the enjoyment was assessed after the sessions. The results indicate that aerobic games produced greater energy expenditure but lower enjoyment than balance games, and a game-themed exergame was found more enjoyable than an exercise-themed exergame. The findings suggest integrating more strenuous activity into game-themed exergame may be an effective way to promote greater PA among college population.
Several studies have examined the effects of non-immersive VR exercise on mood states. A randomized control trial has investigated the effects of a 2-week exergame program young adults’ mood states (Huang et al., 2017). The participants were required to play exergames for 30 consecutive minutes each week for 2 weeks and responded to the surveys measuring vigor, happiness, and perceived stress. The results indicated that playing exergames enhanced vigor and happiness for participants in the intervention group. The findings of this study provide new insight showing that playing exergames may be a means for improving mood states. In addition, the study authors also suggested future study direction exploring whether the positive impacts of play exergames can be sustained for extend periods. Consistent findings were also found in the other study. McEachen and colleagues (2011) conducted a study investigating the flow experience and mood states when playing body movement-controlled video games. 14 college students performed 6 different exergames and traditional cycling exercise, with 6 minutes each session. The results indicated that participants experienced more enjoyment and positive mood states than traditional cycling exercise. The findings suggest such exergaming may have the potential to act as a significant gateway for sedentary individuals to become more physically active. Furthermore, Gao and Chen (2014) conducted a systematic review study examining the effects of exergaming in preventing childhood obesity, the view on both physiological and psychological outcomes. They indicated that children’s habitual PA and obesity-related outcomes such as weight loss and body composition remain unclear due to inconsistent methodological issues, whereas positive psychological impacts were found across reviewed studies.
Overall, studies on non-immersive VR exercise indicated that exergaming can be an effective tool in combating obesity, inactivity, and health problems associated with sedentary lifestyle by its potential to increase energy expenditure and reduce sedentary screen time, enhance exercise effectiveness, and improve program compliance (Bryanton et al., 2006; Harris & Reid, 2005; Jannink et al., 2008; Gao et al., 2015). These findings indicated that people enjoy playing exergames, and this seemed to increase their motivation to keep playing. It appears to be effective using exergaming as a motivating tool to promote PA and health in a fun manner.

Virtual Reality on Motivation

According to the SDT, an individual’s motivation is categorized into levels, from higher to lower level of self-determined, namely, intrinsic motivation, identified regulation, external regulation, and amotivation. Simply saying, behaviors that regulated by intrinsic motivation and identified regulation usually led to positive outcomes, such as adherence to activities. Conversely, behaviors regulated by external regulation and amotivation would possibly lead to negative consequences. The current young adult population is technology-savvy and interested in videogame play. VR as a cutting-edge technology, which drives more and more young adults’ attention and interests for gaining such experiences. In addition, the use of virtual reality is assumed to immerse the user in an environment that portrays and simulates familiar or quite novel visual/auditory stimuli, this technology's combination with usual exercise apparatus (e.g., stationary exercise bicycle, rowing machine) may serve to promote adherence to exercise over other equipment. Possibly, the fun nature of VR-based exercise may increase the chances of
long-term maintenance of an exercise program, which provides a sense of challenge and regulated competition, and encouraging an increasingly enjoyable experience. Previously, VR system has been extensively used among patients with mental or physiological disorders under clinical settings. However, there is limit study examining the effectiveness of VR exercise among healthy population. In detail, Kim and Biocca (2018) have conducted an experimental study evaluating the effectiveness of immersive VR games (combined with stationary cycling) on health-related PA in comparison to stationary cycling with the same game in a non-immersive (2D) setting. The study findings indicated that participants experienced more positive feeling states and motivation for exercising during immersive VR cycling compared with non-immersive traditional cycling. The potential explanation for this finding may be due to the unique fun and enjoyable features via VR technology. According to SDT, enjoyment is highly positively related to intrinsic motivation (Ryan & Deci, 2000). Past research has provided empirical support for SDT to increase PA behaviors (King et al., 2002; Mullan, Markland, & Ingledew, 1997; Chatzisarantis & Biddle, 1998). In addition, Liu et al (2019) examined the acute effects of VR-based exercise on college students’ situational motivation comparing with traditional exercise. The findings also revealed VR exercise led to greater intrinsic motivation for exercising than traditional exercise, moreover, the VR exercise-induced higher intrinsic motivation may improve the adherence of exercise. The study also suggests further intervention for examining the long-term effects of VR-based exercise on physiological and psychological outcomes. Given that active video games can provide intrinsic motivation by challenging players at different levels of
expertise (Malone, 1981) and offer game enjoyment which can act as a strong motivation for exercise (Sun, 2012), VR-based exercise with greater immersion, presence, and interaction, may have greater potential for motivating PA and health. Moreover, one recent study used VR exergame (Astrojumper) to engage participants in a fully immersive gaming environment that involved full-body exercise, the promising findings suggest immersive VR exergames have strong potential to motivate PA in both children and adults (Finkelstein et al., 2011). Notably, the game enjoyment and fun while exercising has been emphasized by the participants.

Although the past decade has seen the development of a number of new research based exergames, very few longitudinal studies have been conducted, and most have focused on single sessions. An exception is the American Horsepower Challenge (AHPC) study of a pedometer-based video game aimed at primary school children (Eiríksdóttir et al., 2011). The program encourages children to become more physically active by accumulating points on the number of steps they take. Over a year long period and sixty schools, the researchers found a significant increase in PA among participants when using the game in comparison to their pre-game activity. Although this study is promising, there appeared to be a plateau effect, which the step counts decreased back to pre-game levels by the third trial of the exergame. Question is remained regarding whether the exergame would be likely to have any long-term impact on PA levels.

As previously mentioned that there are two types of VR – immersive VR and non-immersive VR. Because the immersive VR system just emerged in the recent years, to the best of author’s knowledge, most published VR-based exercise studies were based on
non-immersive condition, and there is a lack of literature examining the effects of immersive VR-based exercise on physiological and psychological outcomes across various populations. Previous studies on non-immersive VR exercise indicated that exergaming can be an effective tool in combating obesity, inactivity, and health problems associated with sedentary lifestyle by its potential to increase energy expenditure and decrease body mass index, reduce sedentary screen time, enhance exercise effectiveness, and improve program compliance (Bryanton et al., 2006; Harris & Reid, 2005; Jannink et al., 2008). These findings indicated that people enjoy playing exergames, and this seemed to increase their motivation to keep playing. However, this motivation might be temporary as the interest to play exergames is likely to decrease after a short period of time (Madsen et al., 2007). Exergaming seen as a social activity might encourage participation. A longitudinal study regarding children’s motivation to play dance games at home suggests multiplayer sessions can reduce dropout and may increase children’s motivation to keep playing exergames (Chin A Paw et al., 2008).

When addressing the motivation in exergaming, SDT seems appropriate to help us to understand why people choose to play exergames. Because exergaming shares components from physical exertion and computer games, the motivations behind exercising and playing computer games were also investigated to identify key factors that support such participation, all within the SDT framework. Previous studies investigating motivation in exercise suggest people exercise because they enjoy it; however, participation can also be driven by health reasons or medical conditions. Perceived enjoyment (intrinsic motivation) and the awareness of being healthier (identified
regulation) seem to be the primary reasons why people participate in exercise (Edmunds et al., 2006). Motivation in exergaming can be studied with SDT because it has been applied to recreational contexts such as exercise and sports (Ryan et al., 2006). One study examined gamers’ psychological need satisfaction of the need for autonomy and the need for competence in computer games can predict greater enjoyment and preference for future play (Sweetser & Wyeth, 2005). One explanation would assume that participation in exergaming is driven by the enjoyment experienced during VR session, and the intrinsic motivation would be the main regulation encouraging people to play. Another study investigated the motivations that encourage participation in exercise, computer games, and exergaming (Osorio et al., 2012). Results indicate playing computer games and exergaming share similar motivations as intrinsic motivation was the highest regulation followed by identified regulation in both groups, which suggests enjoyment is a major factor that encourage participation in such activities followed by perceptions of feeling better and being in a better mood after playing. In addition, Autonomy was the highest psychological need rated by all groups, followed by relatedness, which suggests exercisers, gamers, and exergamers share motivations that are driven by the desire to engage in these activities voluntarily and within a social context.

With innovative and fun features, VR-based exergaming has been uniquely placed among other activities and has the potential to promote greater engagement when playing. A greater level of immersion with deeper sense of presence, and various interactions make immersive VR uniquely placed among other activities. In detail, the concept of presence has been defined by Slater and Wilbur (1997), which describe it as
the subjective feeling of “being there” in the VR environment. The immersive VR technology is well capable of providing users an inclusive, extensive, surrounding, and vivid illusion of reality, which make them feel being in the virtual world. Previous study has indicated that the stronger a person experiences the feeling of being in the VR environment, the more likely he or she will report behaving to that in the real world (Bowman & McMahan, 2007). Thus, given the greater immersion and presence of VR-based exercise, it is possible to deliver PA promotion content via this novel technology, in turn, transfer the PA behaviors into reality.

Moreover, the immersive VR-based exercise provides a variety of interactions, which increase the interest and fun experiences during exercising. The most notable interaction of VR-based exercise is the interaction between users’ movements in real world and reflecting in the virtual environment. The VR system can be compatible with many exercise devices, such as linking with treadmill, stationary exercise bike, and balance board. Within the exergaming content, there are customizable goals, tasks, and virtual avatars which provide immediately feedbacks when exercising. The high interaction of VR-based exercise provides greater interestingness.

In addition, the effects of VR-based exercise on bodily sensation may facilitate the PA participation. Research has shown that workouts can become more appealing with the notion that they will not cause the body physical pain. VR-based exercise can potentially make exercise more appealing and may increase the time spent working out by providing a distraction from bodily sensations. De Bourdeaudhuij and colleagues (2002) examined the effects of attentional distraction on treadmill running time in obese
youth. The findings suggest that when the mind is distracted, it takes longer to realize the bodily discomfort and allowing participants to prolong the exercise period. With the greater level of immersion and interactions, VR can easily drive one’s attention and may distract from the exercise-induced bodily discomfort.

To sum up, the current findings of exergaming showed us a promising future for motivating people participating in PA, however, the study on immersive VR-based exercise is less studied. The exploration of underlying motivations in an immersive VR-based exergaming is warranted.

**Virtual Reality on Mood States**

A large amount of research has been dedicated to exploring the effects of exergames, identifying benefits such as increased PA, improved physical health and mental health (Daley, 2009; Foley & Maddison, 2010; Gao et al., 2015; Staiano & Calvert, 2011). Despite the mixed findings, the effects of exergaming on psychological states are consistent across studies, which can lead to positive psychological states when playing. Specifically, Shirley et al (2017) conducted a study that focus on the presence, enjoyment, and mood experience in predicting children’s attitude toward exergaming. They considered the “presence” as important mechanism through which players were engaged with exergames and developed positive attitudes toward them. Presence can be defined as “the perceptual illusion of non-mediation” (Lombard & Ditton, 1997), occurring when one perceives and responds to media content as if the medium did not exist. In the context of game design, it can be used to measure the extent to which players feel that they are inside the game, rather than an external agent controlling the characters
from outside the game world (Ryan et al., 2006). In other words, presence is related to the feeling of existing in another virtual reality environment offered by the game. Past research has shown that presence increases satisfaction of the gaming experience (Nunez & Blake, 2006), and is a strong predictor of game enjoyment (Horvath & Lombard, 2010; Shafer et al., 2011). Despite findings in that non-immersive VR-based exergaming, the fully immersive VR technology offers a deeper level of presence where player can be fully immersed into the virtual environment, and this may lead to greater positive feelings under this condition. Zeng et al. (2017) investigated the acute effects of VR exercise bike on college students’ physiological and psychological outcomes, which suggests that a commercially available VR-based exercise bike has the potential to be an effective, enjoyable, and motivating tool for promoting PA and health among healthy population. However, there is a lack of randomized control trial to support previous findings. Study on investigating relationship between immersive VR-based exercise and mood states is warranted.

Several studies have examined the effects of non-immersive VR exercise on mood states. A randomized control trial has investigated the effects of a 2-week exergame program young adults’ mood states (Huang et al., 2017). The participants were required to play exergames for 30 consecutive minutes each week for 2 weeks and responded to the surveys measuring vigor, happiness, and perceived stress. The results indicated that playing exergames enhanced vigor and happiness for participants in the intervention group. The findings of this study provide new insight showing that playing exergames may be a means for improving mood states. In addition, the study authors also
suggested future study direction exploring whether the positive impacts of play exergames can be sustained for extend periods. Consistent findings were also found in the other study. Thin et al. (2011) conducted a study investigating the flow experience and mood states when playing body movement-controlled video games. 14 college students performed 6 different exergames and traditional cycling exercise, with 6 minutes each session. The results indicated that participants experienced more enjoyment and positive mood states than traditional cycling exercise. The findings suggest such exergaming may have the potential to act as a significant gateway for sedentary individuals to become more physically active. Furthermore, Gao and Chen (2014) conducted a systematic review study examining the effects of exergaming in preventing childhood obesity, the view on both physiological and psychological outcomes. They indicated that children’s habitual PA and obesity-related outcomes such as weight loss and body composition remain unclear due to inconsistent methodological issues, whereas positive psychological impacts were found across reviewed studies. Specifically, the most appealing aspects of exergames lies in its entertaining or motivating features. Most studies have reported the higher level of enjoyment during exergaming session. The consistent findings suggest children and adolescents are willing to and enjoy playing exergames (Gao, 2012; Sun, 2013).

The available literature regarding the effects of exergaming on mood states are favorable, however, there is limited study examined the effects of immersive VR exercise on college population. Immersive VR as the newly emerged technology may promote
greater psychological effects than non-immersive VR, experimental study is warranted for supporting the current findings.

**Virtual Reality on Situational Interest**

The fully immersive VR as the most advanced and innovative technology in the recent years, has attracted more and more people’s attention and interests. As mentioned earlier, immersive VR-based exergaming is considered as the most advanced exergaming pattern in comparison to non-immersive VR, which enables player to be fully immersed into the virtual environment. Because such cutting-edge technology just turned to commercially available in the past few years, the health research on immersive VR exercise remains largely unexplored in various populations. Recently, Zeng et al. (2017) explored the acute effects of immersive VR exercise bike on physiological and psychological outcomes in comparison to traditional stationary exercise bike. The results revealed participants in the VR exercise bike group experienced higher levels of enjoyment and self-efficacy, and less perceived exertion, compared to traditional stationary exercise bike. The findings suggested immersive VR-based exercise could be a new trend in future for providing more engaging and enjoyable exercise experience. Also, the authors addressed the current lack of intervention in this field and suggested more studies are needed to consolidate the findings. In addition to the limited immersive VR study, there are many studies have been done on non-immersive VR exergaming among children and adolescents. Gao et al. (2015) conducted meta-analysis on the effects of exergames on children and adolescents’ physiological and psychological health-related outcomes. The findings indicated that exergames are effective and enjoyable for
motivating children and adolescents engaging in PA and experiencing positive psychological changes, such as mood, self-efficacy, and intrinsic motivation. It seems that the exergaming is an attractive exercise means to children and adolescents. Roure et al. (2015) further examined youth’s situational interest and PA levels in exergaming. Findings indicated high school students were more likely to engage MVPA when they felt the activity demanded greater attention, and higher LPA when they consider the activity only provided novelty. Situational interest has been defined as an activity’s appealing effect on an individual and emerges from an instant person-activity interaction in which the person recognizes a specific feature of this activity while being engaged in it (Hidi & Anderson, 1992). According to Hidi and Harackiewicz (2000), a highly interesting activity can immediately attract individual’s attention and provide positive feelings about the activity. The situational interest includes five constructs: novelty, challenge, attention demand, exploration intention, and instant enjoyment (Chen et al., 1999). Specifically, novelty is conceptualized as a gap between information known and unknown in an activity (i.e., information deficiency). According to Spielberger and Starr (1994), novelty functions to elicit individual’s participation in this activity. Challenge has been defined as the level of difficulty relative to one’s own ability and has been identified as a motivational factor that may predispose student’s engagement in an activity (Harter, 1978). Regarding attention demand and exploration intention, these constructs represent the stimulation generated by the person-activity interaction that create a perception of situational interest in the activity. According to Deci (1992), the power of the preceding two constructs increases the individual’s intrinsic motivation to engage in the activity.
Finally, instant enjoyment refers to individuals’ emotional engagement with an activity (Hedi & Anderson, 1992). Given the related literature review and available evidence, it is clear that exergames have great potential to promote situational interest and PA among children and adolescents. The immersive VR-based exergaming with higher levels of immersion and enjoyment, may have greater potential to promote sustained PA and experience higher level of situational interest. However, such investigations remain unexplored among college students.

**Virtual Reality on Cognitive Function**

In the past decade, VR technology has been widely used as an approach in the rehabilitation field. This emerging technology offers new rehabilitation options which can be tailored to suit specific clinical or research purposes (Rizzo et al., 2001; Tarnanas et al., 2013). The potential of virtual reality-based cognitive rehabilitation is currently being investigated, with focus on the treatment of cognitive processes such as attention, working memory, verbal and visual memory, and general cognitive functioning (Gamito et al., 2011; Kim, Chun, Kim, & Park, 2011; Man, Chung, & Lee, 2012; Manzoni et al., 2016; Optale et al., 2010, Sorita et al., 2013; Yip & Man, 2013; Zygouris et al., 2015). Recently, Liao and his colleague compared a 12-week VR-based physical and cognitive training to traditional physical and cognitive training among 34 older adults with mild cognitive impairment, with the objective being to improve dual-task gait performance (Liao et al., 2019). The findings indicated participants in the VR-based physical and cognitive training showed greater improvement on dual-task gait performance than traditional physical and cognitive training. Similarly, a 6-month VR-based Tai Chi
exercise intervention has been conducted among 60 older adults with cognitive impairment (Hsieh et al., 2018). The findings indicated that participants with cognitive impairment showed favorable improvement on cognitive and physical function over time compared with control group. Given the positive results reviewed above, the use of VR-based cognitive rehabilitation promises to continue to be a research area of interest. However, there is no available study investigating the effects of VR-based exercise on healthy population. Questions are remained, for example, will the VR-based exercise improve young adults’ cognitive function, such as the increased dual-task performance. Intervention is needed to address such interest.

In addition to clinic-based study and older population, few studies have investigated whether acute or chronic effects of immersive VR exercise on healthy young adults. Notably, several studies have examined the effects of cognitive benefits among children and adolescents. The feature of exergaming is combining PA and action video gaming, which has the potential to improve the youth’s cognitive function. One study compared the effects of playing a game that elicited both PA and cognitive engagement (i.e., a Wii exergame with action video game elements) to games that elicited PA or cognitive engagement (but not both) to watching an educational video (neither PA nor cognitive engagement). To measure cognitive function, including executive function, participants (primarily lean 6- to 10- year-olds) performed the Attention Network Test for Children (Rueda et al., 2004) immediately after each activity. It was found that playing an exergame selectively enhanced children’s executive function, regardless of whether the exergame had action video game elements. In addition, Staiano and colleagues (2012)
examined the effects of exergaming in a competitive versus cooperative fashion on executive function. Participants were (15-19 years old adolescents) randomly assigned to play Wii EA Sports Active in a cooperative or competitive fashion for 10 weeks or to a no treatment control condition. The results indicated adolescents in the competitive exergame condition showed improved executive function on both tasks compared to adolescents in either the cooperative exergame or control conditions.

To date, the limited experimental research suggests that exergaming can immediately enhance cognitive function in normally developing youth. It may be those certain types of exergames (e.g., ones that require competition) have stronger impact than others. However, much more research is needed.

**Virtual Reality on Depression**

The prevalence of anxiety and depression remain in a relatively high level in the United States (US). According to the report from the Anxiety and Depression Association of America (ADAA), 7 out of 10 U.S. adults have claimed to experience stress or anxiety at least at a moderate level on a daily basis. It is common to experience stress or anxiety due to various reasons in the daily lives, however, research has indicated a more prevalent incidents among college students (Mackenzie et al., 2011). In addition to anxiety and stress, depression can also impact college life to such an extent that in-depth research is necessary in order to help future students. About 1 out of 10 college students have been diagnosed with, or treated for, depression over the past year (Holm & Severinsson, 2012). However, only half of diagnosed depression adults received the treatment (Zeng et al, 2018).
Many treatments are available to treat anxiety and depression disorders, including medication, exercise, meditation, and cognitive behavioral therapy. In many cases, these treatments can be tailored to a client to help reduce symptomology of anxiety or depression. To date, the application of emerging technology in health promotion has generated substantial public interest. Among the emerging technologies that may potentially aid in the treatment of anxiety and depression, virtual reality (VR) is arguably the most exciting and technologically advanced. VR is a digital technology that artificially creates sensory experiences—including visual, auditory, touch, and scent stimuli—while allowing the user to manipulate objects within the virtual environment created (Pasco, 2013). Currently, there are two types of VR systems, one is immersive VR, the other one is non-immersive VR. Immersive VR operated by a VR headset, body motion sensor, and an interactive gaming console, which enables user to be merged into a completely virtual environment. With less degree of virtual stimulations, non-immersive VR uses interfaces such as flat screens with linked to keyboards, gamepads, and joysticks, which enables user to interact with the virtual condition without fully immersive condition. Over the past decade, VR applications were widely used for rehabilitation medicine (e.g., phobias, stroke, Parkinson’s disease, and developmental disabilities) and behavioral medicine (e.g., phobias, post-traumatic stress disorder, and autism). For example, as a means of treatment on phobias, VR-based psychological rehabilitation incorporates computer graphics, visual displays, and sensory inputs to create an immersive virtual environment capable of approximating the feeling of being in
the real-world (McCann et al., 2014). After immersing a patient in this virtual world, therapists can then introduce the anxiety-eliciting stimuli into the environment. The advantage of using virtual reality-based psychological rehabilitation is therapists’ ability to control the quality, intensity, duration, and frequency of exposure to the anxiety-eliciting stimuli (Emmelkamp, 2005). For instance, in a 12-month randomized controlled trial by Anderson and colleagues (2013), the effects of virtual reality exposure therapy on 97 participants’ social anxiety disorder were evaluated. These researchers found that patients who were exposed in the virtual world reported less peak anxiety and spoke longer at the post treatment speech indicating virtual reality exposure therapy might be effective for treating social fears. Further, Gaggioli and colleagues (2014) conducted a 5-week randomized controlled trial involving 121 teachers and nurses (i.e., all highly exposed to stress) to evaluate the effects of virtual reality for the management and prevention of psychological stress. These researchers found the virtual reality group to report significant reductions in chronic “trait” anxiety and a significantly increased coping and emotional support skills when compared to the wait-list group. Findings lead the authors to conclude that virtual reality protocol yields better effects than the traditionally accepted gold standard for psychological stress treatment (i.e., cognitive behavioral therapy). Previous meta-analyses have shown the effectiveness of virtual reality-based psychological rehabilitation on various mental disorders. For example, Powers and Emmelkamp (2008) conducted a meta-analytic review investigating the impact of virtual reality-based psychological rehabilitation on mental illnesses, with nine studies on specific phobias, two studies on social phobia, one study on panic disorder,
and one study on post-traumatic stress disorder. Researchers found that virtual reality-based psychological rehabilitation is highly effective in treating phobias in comparison to traditional psychological rehabilitation (e.g., relaxation and bibliotherapy).

Notably, VR-based treatments for different mental health conditions have observed improved mental health status and promising findings. Specifically, Chen et al. (2009) in a quasi-experiment compared VR-based exercise to traditional exercise on mood states among patients suffering from spinal-cord injury, which suggested a VR-based exercise was able to ease patients’ tension and induce calm. In addition to motivate people being physically active, recent studies have an agreement on that VR-based exercise also enhances overall positive psychological profile, such as the increased enjoyment and reduced tiredness (Plante et al, 2003). The advanced VR technology sheds the lights in the treatment of anxiety and depression. However, limit study is available, the randomized control trial is needed to investigate the effectiveness of immersive VR exercise on depression and anxiety among normal population.

An Overview of Motion Sickness on Virtual Reality

The applications of VR technology have been implemented across various domains, such as education, entertainment, physical activity promotion, physiological and psychological rehabilitation (Gao, 2017). However, number of reports have indicated that some individuals may have experiences in motion sickness by using the VR system (Boyd, 2014; Lewis, 2015; Lang, 2016). Specifically, in some cases, users may develop symptoms after or during the use of VR, such as eye strain, sweating, disorientation, nausea, fatigue, headache, vomiting and other related discomfort (LaViola, 2000).
Regarding this issue, early studies have been conducted to investigate the potential factors that cause motion sickness by using VR systems (Draper et al., 2001; Merhi et al., 2007). Specifically, Merhi and colleagues (2007) conducted controlled two experimental studies to examine the association between commercially-available VR console and motion sickness, and investigated the potential factors that may associate with the head-mounted VR-induced motion sickness. In the first experiment, participants were asked to play up to 50 minutes VR-based game with standing and sitting postures. The first experiment results concluded that some users may experience motion sickness by playing commercially-available VR console. Moreover, the incidence of motion sickness was higher in standing posture while playing VR-based game in comparison to sitting posture. In the second experiment, participants were also asked to play the VR-based game up to 50 minutes only in sitting condition, but with a different game compared with first experiment. Notably, there were obvious difference in movement patterns between two games. However, due to the extremely high incidence of motion sickness in the second experiment with only 1 participant did not report motion sickness. They were not able to test the difference between two games. Overall, the findings agreed the potential incidence of motion sickness among some individuals, also, the findings supported the postural instability theory of motion sickness (Riccio & Stoffregen, 1991).

The postural instability theory was developed by Riccio and Stoffregen (1991). The core concept of this theory argued that “the prolonged postural instability is the cause of motion sickness.” From the human behavioral perspective, one of primary behavioral goal in humans is to maintain postural stability in the environment. Along with this
concept, postural instability is determined by degree to which the process between perception of uncontrolled movements and adjusting or adapting action systems. When individuals in a condition and lack of pross between perception of uncontrolled movements and action systems, they are more likely to experience the motion sickness. There is a good and simple example to explain this concept (LaViola, 2000). Imagine two scenarios: walking on the concrete ground and walking on the icy ground. Usually, people will walk differently from concrete ground to slippery icy ground, whereas, if people walk on the icy ground as they do on concrete, they are going to fall easily. However, when this comes to the real life, when we walk on ice ground, we will naturally change our walking patterns to maintain the postural stability. That is saying when the environment changes uncertainly, postural instability will increase due to lack of postural control strategies. Thus, corresponding to the key concept of postural instability theory, the postural instability predicts motion sickness, and the severity of sick symptoms is influenced by the duration of stability. In other words, the longer duration of postural instability individuals experiencing, the more severe motion sickness symptoms they will have.

It seems that the environmental factors which lead to prolonged postural instability are linked to the incidence of motion sickness. According to the postural instability theory, there are several conditions that induce the long periods of postural instability, such as the condition of low-frequency vibration, the weighted lenses, the alteration between gravitoinertial force vector and surface of support, and changed specificity (Riccio & Stoffregen, 1991). The VR-induced motion sickness lies on the
category of altered specificity. In the VR-generated virtual environment, all the movements such as acceleration and rotation are based on the visual display, which are unrelated to the constraints on control of the body, thus, the postural control systems will not be processed. For example, if someone wears a head-mounted VR standing on the ground, but the VR-generated virtual world shows that he/she jumps from the top of the mountain. Instinctively, he/she will change movements from standing position, which may lead to the transition from a stable position to instable position.

In addition to the postural instability theory proposed concept and mechanisms, there may be other factors particularly contributing to the VR-induced motion sickness (Kolasinski, 1995; Pausch et al., 1992). First, the computer graphic technology and display resolution my contribute to the VR-induced motion sickness (LaViola, 2000). It has been a long way from non-immersive display to fully immersive virtual environment experiences. As mentioned earlier, the early generations of head-mounted VR systems have been mainly studied in the laboratory settings, which display resolution and computer graphic level were not that satisfying. Fortunately, as technology improves, the current head-mounted VR systems are getting more advanced configurations (e.g., higher display resolution and more sophisticated computer graphics), which enable the users to be presented in the virtual environment in a deeper degree. However, there is no perfection in technology. Although the current head-mounted VR systems display a vivid virtual environment, we can still easily distinct it from the real world. Yet, the incidence of motion sickness still exists among VR users. As the time goes by, may the future VR
technology completely simulate the real-world experience that make us hard to distinct between them?

Second, the VR system lagging issue may also contribute to the motion sickness (LaViola, 2000). The definition of lag in the VR systems refer to time between user executing an action and the action actually occurring in the virtual environment. In other words, after the user initiating an action, it takes time to process the action information and transferred to the visual display. For example, an VR user turns his/her head to watch a passing car in the virtual environment, if there is a unfavorable lag issue, the user need to wait the system’s processing and the image will not immediately show up in the visual display. Thus, such imaginary delay may lead to the incidence of motion sickness (Pausch et al., 1992).

Third, previous study also indicated that the flicker may also contribute to inducing the symptoms of motion sickness in VR (Harwood & Foley, 1987). Simply saying, in order to provide consistent visual content, the display needs to refresh and update the information constantly. That is the so-called flicker. The perception of flicker is based on the flicker fusion frequency threshold (Frank et al., 1984). Moreover, the perception of flicker may be also influenced by the field of view in the VR display. It is more likely to perceive flicker as the field of view increases, because human peripheral visual system is more sensitive to flicker than the fovea system (Boff & Lincoln, 1988). Since the key feature of immersive VR is to fill the user’s field of view with visual stimulation, in order to reduce the perception of flicker, a minimum 30 Hz display refresh
rate is needed. Fortunately, the current head-mounted VR systems are able to provide much higher refresh rate, which can reach to 60 Hz, 90Hz, 120 Hz, or even higher.

In addition to the technology concerns, individual factors may also contribute to the VR-induced motion sickness. The gender difference on motion sickness appears to be the most notable individual factor. It seems that women to be more susceptible to motion sickness than men (Biocca, 1992; Koslucher et al., 2015). Recently, Munafo, Diedrik, and Stofferegen (2017) have conducted two experiments examining whether the commercially available head-mounted VR system (Oculus Rift) induce the motion sickness and investigating the incidence of motion sickness regarding the gender difference. In addition, the study also tested the postural instability theory by comparing the standing body swing before and after the VR game playing. In detail, a total of 36 college students were recruited for the first experiment. The Simulator Sickness Questionnaire (SSQ) was administered for assessing the symptoms of motion sickness (Kennedy et al., 1993). The SSQ was measured before and after the VR gaming session. Following the weight and height measurement, participants were required to perform a visual task on a force plate. This task was also administered before and after the VR gaming session. Participants were asked to complete a 15-minute VR gaming session while in a sitting position. The results from the first experiment indicated that 22% participants have the incidence of motion sickness. Specifically, 11% of men and 44% of women were reported motion sickness. Notably, there was no statistically significant difference regarding the incidence of motion sickness between men and women. Also, the postural body swing did not different between men and women. Regarding the second
experiment, the researcher adopted the same procedure and measurements as the first experiment, except changed the VR game to a different one. The aim of the second experiment was to examine the difference of incidence of motion sickness between different VR games. In addition, the gender difference has been studied. The results revealed that 56% participants were reported motion sickness. Notably, there was significantly difference regarding the incidence of motion sickness, with 33% on men and 78% on women. The results is consistent with the previous studies’ findings, which indicate that women are more susceptible for motion sickness than men (boyd, 2014; Koslucher et al., 2015; LaViola, 2000; Merhi et al., 2007). Regarding the postural body swing, differences were observed between participants who reported motion sickness and those who did not. The results supported the postural instability theory’s assumption (Riccio & Stoffregen, 1991).

The human nature distinction between men and women may considered for explaining such difference on motion sickness. While there are no consistent findings for clearly explaining the underlying mechanism regarding the gender difference on motion sickness. The previous studies brought up a number of potential factors that may explain the gender difference on this issue, which considered the hormones, spatial information processing, human adaptation process (Golding, 2006; Koslucher et al., 2015; Parsons et al., 2004). However, those assumptions were either partially supporting the relations or there is a lack of study to further confirm the findings. In addition, some studies also indicated that the anthropometric differences between men and women may lead to different movement patterns, such as body swing postures (Koslucher et al., 2015; Hue
et al., 2007). Hue and colleagues (2007) conducted experiment to examine the effects of body weight in predicting balance stability. It turns out the body weight is a significant predictor for the postural body swings in men. Given the fact that men are usually weigh more than women, they suggested that there may have differences of body sway between men and women. Along with this finding, Koslucher and colleague (2015) conducted an experiment to examine relationships between visually induced motion sickness and anthropometric outcomes, from gender difference perspective. In detail, there were three aims for that study. First, examine the difference of linear visual oscillation induced motion sickness between men and women; second, examine the relationships between motion sickness and anthropometric properties in men and women; third, examine the relationship between motion sickness and symptom severity, from gender difference perspective. A total of 114 college students were recruited for this study. The participants’ height, weight, foot length, BMI, and the height of the body’s central mass were measured. Also, the SSQ was administered before and after the experiment. During the experiment session, the participants were asked to stand in a customized moving room. The moving room functions as visual stimulation where participants were exposed to the optical flow that oscillated along the line of sight. Participants were asked to complete 4 trials with 10 minutes in each trial. The results revealed the motion sickness incidence was 38% on women and 9% on men. The findings further confirmed that women are more susceptible to the linear oscillation induced motion sickness than men. Notably, the ratio of motion sickness incidence from their study was 4 to 1, which indicated a greater risk for having motion sickness under the visual linear oscillation
condition. However, there was no significant difference regarding the severity of motion sickness symptoms between men and women. Regarding the role of anthropometric factors, although there statistically significant correlations on some anthropometric outcomes (e.g., motion sickness incidence was negatively associated with the height of body’s central mass; motion sickness incidence was negatively associated with the foot length), however, effect sizes were relatively low. Thus, they suspect that the anthropometric outcomes may play a role to motion sickness.
Chapter Three: Methodology

Participants

The G*Power (G*Power; Brunsbüttel, Germany) was used to calculate the ideal sample size for achieving statistical significance. The power analysis indicated that 40 participants would be sufficient for detecting significant between-group difference on exercise motivation with 80% power. The significant level was at 0.05 and effect size (d) at 0.30. All participants were recruited from the University of Minnesota – Twin Cities for participating this 4-week VR-based exercise intervention. Inclusion criteria were (1) college students age from 18 to 35 years old who are currently enrolled in the university; (2) college students without diagnosed physical and/or mental disabilities; (3) willing to provide informed consent and complete the PA Readiness Questionnaire (PAR-Q); (4) willing to be randomized into an intervention or control group; (5) no self-reported motion sickness symptoms during immersive VR-based exercise. Conversely, exclusion criteria will be (1) < 18 or > 35 years old or not currently enrolled in the university; (2) having self-reported physical and/or mental disabilities; (3) contradictions to PA participation as determined by PAR-Q responses; (4) having motion sickness reaction when exercising under VR-based condition.

Randomization

To address the proposed study aims, a two-arm randomized control trial has been implemented, with participants randomized (Randomization sequence was created using Excel with a 1:1 group allocation) into two groups: (1) intervention group – participants were asked to exercise on an immersive VR-based exercise bike for one hour per session,
two times per week, for 4 weeks; (2) control group – participants were asked to maintain their usual activities. All participants completed assessments at baseline and 4 weeks including demographic, anthropometric, cardiovascular fitness, body composition, exercise motivation, mood states, and depressive symptoms. The physical activity levels were assessed at baseline and post-intervention.

**Immersive Virtual Reality Exercise Bike Session**

The commercially available VirZoom (Cambridge, MA, USA) VR exercise bike offers players a fully immersive virtual gaming environment via connection of the VirZoom bike to a PlayStation (Sony; Tokyo, Japan) VR system and an accompanying VR headset. Participants played two active games during the 60 minutes exercise session. The first game was entitled “Le Tour” which required players to race other virtual cyclists through a series of timing gates located on a scenic mountain road. During this cyclist racing game, there were other virtual cyclists in the game, and there were 15 gates in this costumed workout. Players were instructed to achieve different goals when passing a gate, such as keep fast pedaling with certain speed for 30 seconds, drafting behind the other riders for 60 seconds, passing certain number of riders, and so on. Notably, the game also features the customizable workout plan. For example, there were two modes (comfort mode and intense mode), where players can choose to pedal in light to moderate intensity or choose to race in moderate to vigorous intensity. In addition, workout duration is customizable. For this intervention, when participants played up to 30 minutes, the system will automatically switch to another game for 30 minutes. The second game, “Race Car”, required players to race other virtual race cars around a track
at high speeds. The goal of this game was trying to pass all the other virtual competitors, which requires the players to pedal as fast as possible while control the direction. There is a fun feature to be noted. The game automatically records the fastest player’s score whoever plays this game before, then, it will create a virtual ghost car in the racing game. Participants who play this game are able to see this ghost car (represents the fastest record), and they are encouraged to pass the car and create a new record in the game. If only let participants to play one game during the 4 weeks, they may get bored of the game which may potentially influence the intervention adherence. Thus, those two selected games with highly customizable workout plans and constant challenging goals may serve as motivators to encourage participants adhere to the intervention. The VirZoom VR exercise bike has been observed to provide moderate-to-vigorous physical activity (MVPA), therefore, the intervention would help participants meet the 150 minutes weekly MVPA recommendations (Liu, et al., 2019; Physical Activity Guidelines for Americans, 2018)
Control Group

Participants in the control group did not exercise on the traditional bike in the laboratory, instead, they were asked to maintain their usual activities, such as daily school routines. Notably, all participants were not allowed to participate in other PA intervention or programs during the 4-week intervention period, but they can maintain their usual exercise routines. All the measurements were identical to the intervention group, which took place at baseline and 4 weeks.

Several strategies have been implemented in order to ensure the intervention fidelity. In detail, first, participants in both groups have received detailed instructions regarding the use of study outcome-related surveys; second, investigator helped all participants to experience the immersive VR bike during the pre-intervention screening session, in addition, intervention participants received an additional tutorial session.
regarding how to exercise on the immersive VR bike prior to the intervention; third, intervention session log was used to track each participants’ exact exercise session date and time; Forth, an Excel spreadsheet was used to track the dates of all participants’ assessment (e.g., baseline and 4 weeks), which worked as a reminder to send out to participants not completing study-related assessments; Fifth, as all intervention sessions were based on one-one-one condition, thus, investigator has created separate schedules for each participant, and an email notification has been sent out prior to each exercise session for each participant encouraging the intervention adherence; Sixth, all participants received a $20 cash incentive after successfully completion of all study-related assessments (e.g., baseline and 4 weeks). Notably, all study-related surveys were distributed to participants using Qualtrics (Qualtrics; Provo, UT)—an online survey software. The “force response” function was applied to all survey-related questions to ensure survey completion rate.

Measurements

**Height, weight, and body composition**

Height was measured by a Seca stadiometer (Seca; Hamburg, Germany) to the nearest half-centimeter. Moreover, weight (kg) was measured with a Tanita BC-558 IRONMAN® Segmental Body Composition Monitor (Tanita; Tokyo, Japan). In detail, participants were asked to wear lightweight, athletic clothing and remove their shoes, socks, jewelry, and any personal items in their pockets prior to stepping onto the scale. While on the scale, the Tanita BC-558 IRONMAN® Segmental Body Composition Monitor simultaneously measures percent body fatness via bioelectrical impedance (i.e.,
a weak electrical current that flows through the body from which the voltage is measured in order to calculate resistance of the body, or percentage of fat mass) (Lukaski, Johnson, Bolonchuk, & Lykken, 1985)—a method of body composition measure observed valid in young adults (Aandstad, Holtberget, Hageberg, Holme, & Andersson, 2014) and observed to have low bias for measuring body composition compared to DXA in overweight and obese men (Pateyjohns, Brinkworth, Buckley, Noakes, & Clifton, 2006).

**Physical activity levels**

Participants’ free-living PA levels were assessed via International Physical Activity Questionnaire – Short Form (IPAQ). The survey was studied across 12 countries and showed a good reliability and validity internationally (Craig et al., 2003). The IPAQ short form assessed three specific types of activity: walking, moderate-intensity activities and vigorous-intensity activities. Participants were asked to recall the time spent in (minutes) walking, moderate-intensity physical activity, vigorous-intensity physical activity in the past 7 days. Sample question included “Think about all the vigorous activities that you did in the last 7 days. Vigorous physical activities refer to activities that take hard physical effort and make you breathe much harder than normal. Thank only about those physical activities that you did for at least 10 minutes at a time”.

Regarding the IPAQ scoring, the weekly physical activity volume was computed by weighing each type of activity by its energy requirements defined in METs to yield a score in MET-minutes. One MET was considered the energy expenditure during resting and one MET-minute was computed by multiplying the MET score of an activity by the minutes performed. Regarding the types of activities assessed in the IPAQ, walking was
considered 3.3 METs; moderate-intensity physical activity was considered 4.0 METs; and the vigorous-intensity physical activity was considered 8.0 METs. The weekly physical activity levels were calculated following the formulas: Walking MET-minutes/week = 3.3 * walking minutes * walking days; Moderate MET-minutes/week = 4.0 * moderate-intensity activity minutes * moderate days; Vigorous MET-minutes/week = 8.0 * vigorous-intensity activity minutes * vigorous-intensity days. Participants were asked to complete this survey at baseline and post-intervention follow-up. The mean weekly physical activity levels were calculated as the study outcomes.

**Cardiovascular fitness**

Cardiovascular fitness (CRF) was evaluated objectively using the Young Men’s Christian Academy (YMCA) 3-Minute Step Test (Golding, Meyers, & Sinning, 1998). In detail, participants were asked to step on and off of a 12-inch plyometric box for three minutes to the “beep” of a metronome set to 96 beats-per-minute, with each beep corresponding with one leg movement. Specifically, there were two beeps for the upward movement and two beeps for the downward movement, such that four beeps constitute a full “up-down” cycle. Immediately following the completion of the test, the principal investigator measured participants’ heart rate for 60 seconds via palpation of the radial artery on the underbelly of the left wrist. To assess changes in CRF over the 4 weeks period, the YMCA 3-minute Step Test was performed at baseline and 4 weeks. The mean difference of post-test heart rates was used as study outcome.

**Exercise Motivation**
The Behavioral Regulation in Exercise Questionnaire-2 (BREQ-2) was used to assess participants’ continuum of behavioral regulation in exercise context (Markland & Tobin, 2004; Mullan et al., 1997). The BREQ-2 has been shown to have a good reliability and construct validity for assessing exercise motivation among college student population (D’Abundo et al., 2014). The BREQ-2 is a 19-item survey with a 5-point Likert-type scale (1 = not true for me; 5 = very true for me). The scale was developed based on SDT and included five subscales assessing amotivation, external regulation, introjected regulation, identified regulation, and intrinsic regulation. Each subscale included a 4-item survey. The sample item for amotivation included “I don’t see why I should have to exercise”; the sample item for external regulation included “I exercise because other people say I should”; the sample item for introjected regulation included “I feel guilty when I don’t exercise”; the sample item for identified regulation included “I value the benefits of exercise”; and the sample item for intrinsic regulation included “I exercise because it’s fun”. Participants were asked to complete the survey at baseline and 4 weeks. The mean scores of each subscale were calculated as study outcomes. Notably, higher scores on intrinsic regulation and identified regulation indicated that participants had higher levels of self-determined motivation. Inversely, higher scores on external regulation, introjected regulation and amotivation indicated that participants had lower self-determined motivation for engaging in physical activity.

**Mood states**

Participants’ mood states were assessed by the Brunel Mood Scale (BRUMS). The BRUMS has 24-items arranged into six subscales: anger, confusion, depression,
fatigue, tension and vigor, each with four items. The research participant selects, from a numerical rating scale of zero to four (0 = not at all, 1 = a bit, 2 = moderate, 3 = enough; 4 = extremely), the option they believe best represents the situation at that time, using questions such as “How do you feel now?”, “How have you been feeling in the past week, including today?”, or “How have you been feeling?”. Participants will be asked to complete this survey at baseline and 4 weeks. The mean scores were calculated and used as study outcomes.

**Depressive symptoms**

Participants’ depression symptoms were assessed by the Beck Depression Inventory (BDI) (Beck et al., 1961). This is a 21-item, self-report rating inventory that measures characteristic attitudes and symptoms of depression. In detail, each item has four statements expressing respondents’ current psychological states, participants need to select one statement that most representing their states. Each statement corresponds to a value ranging from 0 to 3. The total depression score was calculated and used to assess the level of depression. Regarding the classification of depression, the depression score ranging from 1 to 10 was considered normal with no depressive disorder; depression score ranging from 17-20 was considered the borderline clinical depression; depression score over 40 was considered extreme depression. The sample 4-item statement will be like “I do not feel sad” (score 0 point), “I feel sad” (score 1 point), “I am sad all the time and I can’t snap out of it” (score 2 points), “I am so sad and unhappy that I can’t stand it” (score 3 points). There were 21 statements that describe the respondent’s psychological
status. Participants were asked to complete this survey at baseline and 4 weeks. Participants’ total scores were used for this study.

**Motion Sickness**

Participants were asked to complete a 2-item survey with 3-point Likert scale (1 = not at all; 3 = a lot) for assessing the symptoms of motion sickness. Two questions were included in the survey: (1) “when riding the VR bike, I feel sick to my stomach”; (2) “when riding the VR bike, I feel dizzy”. The survey was administered during the pre-intervention screening session, first exercise session at week 1, and last exercise session at week 4. The descriptive information was used to provide insights regarding the participation of a 4-week immersive VR-based exercise intervention.

**Procedures**

The approval of conducting human subjects research was obtained from Institutional Review Board and Sunrise Plan at the University of Minnesota Twin Cities. The recruitment was conducted during Covid-19 pandemic, all university courses were changed to online format in order to limit the in-person contact on campus. Thus, all participants were recruited via university email servers from different colleges (e.g., College of Education and Human Development students email servers). In detail, the digital flyers and recruitment information were sent out through various students email lists. In addition, the study recruitment information was also posted in the weekly department news. Students who interested in participating in this study contacted the investigator via email and scheduled for pre-intervention screening session.
Consider some people may experience motion sickness when exercising under an immersive VR condition, an additional screening session were conducted by the investigator (WL) to all enrolled participants and make sure they were comfortable for exercising on an immersive VR-based exercise bike. In detail, Prior to the start of the intervention, a screening session were conducted to determine whether the potential participants were capable of engaging a 4-week VR-based exercise intervention. During the screening session, the potential participants were asked to exercise on the VR-based stationary exercise bike for 15 minutes. Munafo et al. (2017) has indicated that the head-mounted VR game-induced motion sickness could occur as short as 15 minutes. Along with the suggestion, the potential participants were asked to exercise on the VR bike for 15 minutes. During the screening session, potential participants played two VR exergames. After completing the screening session, participants were asked to complete a 2-item survey with 3-point Likert scale (1 = not at all; 3 = a lot) for assessing the symptoms of motion sickness. Two questions were included in the survey: (1) “when riding the VR bike, I feel sick to my stomach,” and “when riding the VR bike, I feel dizzy.” As a result, potential participants who successfully complete the 15 minutes VR biking session and report no symptoms of motion sickness were officially recruited in the study.

During baseline assessment, participants were first completed a demographic survey that includes age, gender, and race/ethnicity. Participants’ physiological (e.g., height, weight, percentage of body fatness, and cardiovascular fitness), psychological (e.g., exercise motivation, mood states, and depressive symptoms), and past 7-day
physical activity were assessed via aforementioned instruments at baseline. Then, participants were randomly assigned to intervention or control group.

During the intervention session, participants were asked to wear the accelerometers on their right side of ankle. For the intervention group, participations exercised on an immersive VR-based exercise bike for one hour, twice per week, for 4 weeks. Participants in the control group were asked to maintain their usual routine after the baseline test for 4 weeks. Participants were scheduled separately coming to lab for the post-test after 4 weeks and all participants received the identical assessments in aforementioned physiological and psychological outcomes.

After 4 weeks from baseline, participants were asked to complete the International Physical Activity Questionnaire for assessing the 7-day physical activity following the completion of 4 weeks intervention.

**Statistical Analyses**

Data were analyzed using IBM-SPSS 27.0 (IBM Inc., Armonk, NY) in the following manner. First, descriptive statistics including means/standard deviations and frequencies for demographic information (e.g., age, race, height, weight, and percentage of body fatness) and physiological (e.g., body mass index, percentage of body fatness, and cardiovascular fitness) and psychological outcomes (e.g., motivation, mood states, and depressive symptoms) were analyzed. Also, the baseline group difference was assessed between intervention and control group to ensure the effectiveness of randomization. The independent t-test was used for objective outcomes (e.g., anthropometric measures) and chi square test was used for categorical outcomes (e.g.,
participants’ race/ethnicity, age, gender). Prior to hypothesis testing, the outlier analyses were performed for the reporting of descriptive statistics (i.e., means ± standard deviations) that calculated for all dependent variables at baseline, 4 weeks, and follow-up.

To address hypothesis 1, a two-way (time x group) repeated measures ANOVA was used to test difference regarding psychological outcomes changes between intervention and control group. The effect size was calculated as particle eta-squared ($\eta^2_p$) with 0.01, 0.06, and 0.14 indicating small, medium, and large effect sizes, respectively. Significance level was set to less equal 0.05.

To address hypothesis 2, a two-way (time x group) repeated measures ANOVA was used to test difference regarding physiological outcomes changes between intervention and control group.

To test hypothesis 3, a two-way (time x group) repeated measures ANOVA was used to test difference regarding physical activity changes between intervention and control group.
Chapter Four: Results

Participant Flow

The recruitment was conducted during Covid-19 pandemic, all university courses were changed to online format in order to limit the in-person contact on campus. Thus, all participants were recruited via university email servers from different colleges (e.g., College of Education and Human Development students email servers). In detail, the digital flyers were sent out through various students email lists. In addition, the study recruitment information was also posted in the weekly department news. Students who were interested in participating this study contacted the investigator via email. As a result, a total of 46 college students contacted investigator with the interest in study participation. A total of 40 college students came to the lab completed the pre-study screening session. The screening session included (1) introduction of study purpose and procedures; (2) completion of Physical Activity Readiness Questionnaire; (3) and experiencing 15-minute VR-based biking session. College students who completed screening session and reported no motion sickness during VR-based biking session were eligible for this study. As a result, a total of 38 college students were eligible for
participating in this study and provided online informed consent forms. Notably, there were 2 college students reported motion sickness during the 15-minute immersive VR bike session and excluded from the study participation. 38 eligible participants were then randomly assigned to immersive VR-based exercise intervention group or usual practice control group. Figure 3. included a CONSORT Flow Diagram of participant flow for this study. Overall, the retention rate was 94.73%, with two participants dropped out from the intervention group. Specifically, although all intervention sessions were conducted based on one-on-one condition and followed the Covid-19 precautions, two female participants expressed the concern of participating in in-person study during Covid-19 pandemic, one participant discontinued after the first session, and the other participant discontinued after the first week of intervention. In the end, a total of 36 (intervention group n = 17; control group n = 19) participants completed baseline, post-intervention, and follow-up assessments, and entered for the statistical analyses.
Baseline Participant Characteristics

The descriptive statistics of participants’ baseline demographic, physiological, and psychological outcomes by group were shown in Table 1. The Chi-Square test (testing mean group difference for categorical variables) and the independent t-test (testing mean group difference for continuous variables) indicated that there was no statistically significant difference regarding baseline demographic, physiological, and
psychological outcomes between intervention and control group at baseline. Regarding
the previous VR experience, 44.4% reported having VR experience before, and 55.6%
reported no previous VR experience. In addition, when answering “how good when
playing VR games,” 2.8% reported “extremely good,” 19.4% reported “somewhat good,”
75% reported “neither good nor bad,” and 2.8% reported “somewhat bad.” The Chi-
Square test of VR experience between two groups indicated there was no statistically
significant group difference at baseline.

Table 1. Baseline Group Comparisons for Study Outcomes.

<table>
<thead>
<tr>
<th></th>
<th>Intervention (n = 17)</th>
<th>Control (n = 19)</th>
<th>p-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gender</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>8 (47.1)</td>
<td>7 (36.8)</td>
<td>0.54</td>
</tr>
<tr>
<td>Female</td>
<td>9 (52.9)</td>
<td>12 (63.2)</td>
<td></td>
</tr>
<tr>
<td><strong>Race/Ethnicity</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>6 (35.3)</td>
<td>5 (26.3)</td>
<td></td>
</tr>
<tr>
<td>Asian</td>
<td>10 (58.8)</td>
<td>10 (52.6)</td>
<td>0.41</td>
</tr>
<tr>
<td>Other</td>
<td>1 (5.9)</td>
<td>4 (21.1)</td>
<td></td>
</tr>
<tr>
<td><strong>Age (year)</strong></td>
<td>22.82 (2.51)</td>
<td>24.84 (4.14)</td>
<td>0.09</td>
</tr>
<tr>
<td><strong>Height (cm)</strong></td>
<td>171.26 (7.21)</td>
<td>169.71 (7.35)</td>
<td>0.53</td>
</tr>
<tr>
<td><strong>Weight (kg)</strong></td>
<td>74.38 (16.49)</td>
<td>73.56 (14.75)</td>
<td>0.88</td>
</tr>
<tr>
<td><strong>BMI (kg/m^2)</strong></td>
<td>25.21 (4.36)</td>
<td>25.37 (3.69)</td>
<td>0.91</td>
</tr>
<tr>
<td><strong>%BF (%)</strong></td>
<td>26.11 (7.14)</td>
<td>27.65 (5.18)</td>
<td>0.46</td>
</tr>
<tr>
<td><strong>CRF (bpm)</strong></td>
<td>113 (22.10)</td>
<td>115.95 (16.64)</td>
<td>0.65</td>
</tr>
<tr>
<td><strong>PA (MET mins/wk)</strong></td>
<td>1152.06 (618.57)</td>
<td>1080.26 (935.04)</td>
<td>0.79</td>
</tr>
<tr>
<td><strong>SDT-Based Motivation</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amotivation</td>
<td>1.57 (0.64)</td>
<td>1.75 (0.64)</td>
<td>0.41</td>
</tr>
<tr>
<td>External Regulation</td>
<td>1.94 (0.71)</td>
<td>2.32 (0.86)</td>
<td>0.17</td>
</tr>
<tr>
<td>Introjected Regulation</td>
<td>3.33 (1.14)</td>
<td>2.86 (0.88)</td>
<td>0.17</td>
</tr>
<tr>
<td>Identified Regulation</td>
<td>4.00 (0.71)</td>
<td>3.74 (0.65)</td>
<td>0.25</td>
</tr>
<tr>
<td>Intrinsic Regulation</td>
<td>3.71 (0.94)</td>
<td>3.63 (0.86)</td>
<td>0.81</td>
</tr>
<tr>
<td><strong>Mood States</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anger</td>
<td>1.28 (0.57)</td>
<td>1.60 (1.09)</td>
<td>0.30</td>
</tr>
<tr>
<td>Confusion</td>
<td>1.53 (0.75)</td>
<td>1.67 (0.97)</td>
<td>0.63</td>
</tr>
<tr>
<td>Depression</td>
<td>1.41 (0.69)</td>
<td>1.62 (0.81)</td>
<td>0.42</td>
</tr>
<tr>
<td>Fatigue</td>
<td>2.00 (0.54)</td>
<td>2.09 (1.01)</td>
<td>0.74</td>
</tr>
<tr>
<td>Tension</td>
<td>1.85 (0.72)</td>
<td>1.84 (1.03)</td>
<td>0.97</td>
</tr>
<tr>
<td>Vigor</td>
<td>2.74 (0.50)</td>
<td>2.51 (0.74)</td>
<td>0.30</td>
</tr>
<tr>
<td><strong>Depression Score</strong></td>
<td>5.94 (5.68)</td>
<td>6.68 (6.25)</td>
<td>0.71</td>
</tr>
</tbody>
</table>

Note. All categorical variables are presented as frequency (n/%); All the continuous variables are presented as Mean and Standard Deviation; BMI, body mass index; %BF, percentage of body fatness; CRF, cardiovascular fitness; PA, physical activity.
Notably, although all recruited participants reported no motion sickness symptoms during screening session, some participants still reported having sort of symptoms of motion sickness. Overall, one female participant reported “a little bit sick to stomach when riding on VR bike” after the first session; 4 participants (2 female and 2 males) reported “a little bit dizzy when riding on VR bike”. After communication with the participants who reported mild symptoms of motion sickness, all of them decided to continue the rest of sessions. The detail description of motion sickness incidence by gender from baseline to 4 weeks has been presented in Table 2.

Table 2. Symptoms of Motion Sickness on Intervention Participants (n = 17; female 8).

<table>
<thead>
<tr>
<th>Symptom Description</th>
<th>Baseline</th>
<th>4 weeks</th>
</tr>
</thead>
<tbody>
<tr>
<td>I feel sick to stomach when riding on VR bike.</td>
<td>Male: 9</td>
<td>Male: 9</td>
</tr>
<tr>
<td>Not at all</td>
<td>Female: 7</td>
<td>Female: 7</td>
</tr>
<tr>
<td>A little</td>
<td>Male: 0</td>
<td>Male: 0</td>
</tr>
<tr>
<td>Female: 1</td>
<td>Female: 1</td>
<td></td>
</tr>
<tr>
<td>A lot</td>
<td>Male: 0</td>
<td>Male: 0</td>
</tr>
<tr>
<td>Female: 0</td>
<td>Female: 0</td>
<td></td>
</tr>
<tr>
<td>I feel dizzy when riding on VR bike.</td>
<td>Male: 7</td>
<td>Male: 9</td>
</tr>
<tr>
<td>Not at all</td>
<td>Female: 6</td>
<td>Female: 8</td>
</tr>
<tr>
<td>A little</td>
<td>Male: 2</td>
<td>Male: 0</td>
</tr>
<tr>
<td>Female: 2</td>
<td>Female: 0</td>
<td></td>
</tr>
<tr>
<td>A lot</td>
<td>Male: 0</td>
<td>Male: 0</td>
</tr>
<tr>
<td>Female: 0</td>
<td>Female: 0</td>
<td></td>
</tr>
</tbody>
</table>

Note. The values indicate the number of responses by gender.

Results for Study Aim 1: Examine the effects of a 4-week immersive VR-based exercise bike intervention on college students’ psychological outcomes in comparison with control group.

Self-Determination Theory-Based Exercise Regulations
The descriptive statistics for SDT-based exercise regulation by group at baseline and 4 weeks were presented in Table 4. Regarding the five subscales of SDT-based regulation, the two-way repeated ANOVA indicated significant main effect of time on amotivation \( (F(1,34) = 6.10, p = 0.02, \eta^2 = 0.15) \), external regulation \( (F(1,34) = 4.37, p = 0.04, \eta^2 = 0.11) \), identified regulation \( (F(1,34) = 6.55, p = 0.02, \eta^2 = 0.16) \), and intrinsic regulation \( (F(1,34) = 18.11, p < 0.001, \eta^2 = 0.35) \). Further, the significant “time * group” interaction was observed on identified regulation \( (F(1,34) = 6.55, p = 0.02, \eta^2 = 0.16) \) and intrinsic regulation \( (F(1,34) = 11.21, p = 0.02, \eta^2 = 0.25) \), indicating that intervention participants’ identified regulation and intrinsic regulation were significantly increased after 4 weeks intervention as compared to the control group.

Table 4. Descriptive statistics for self-determination theory-based exercise regulation by group.

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>4 weeks</th>
<th>( p )-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Amotivation</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intervention</td>
<td>1.57 (0.64)</td>
<td>1.07 (0.15)</td>
<td>0.05</td>
</tr>
<tr>
<td>Control</td>
<td>1.75 (0.64)</td>
<td>1.61 (0.89)</td>
<td></td>
</tr>
<tr>
<td><strong>External Regulation</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intervention</td>
<td>1.94 (0.71)</td>
<td>1.76 (0.56)</td>
<td>0.21</td>
</tr>
<tr>
<td>Control</td>
<td>2.32 (0.86)</td>
<td>1.99 (0.91)</td>
<td></td>
</tr>
<tr>
<td><strong>Introjected Regulation</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intervention</td>
<td>3.33 (1.14)</td>
<td>3.67 (0.99)</td>
<td>0.06</td>
</tr>
<tr>
<td>Control</td>
<td>2.86 (0.88)</td>
<td>3.05 (0.79)</td>
<td></td>
</tr>
<tr>
<td><strong>Identified Regulation</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intervention</td>
<td>4.00 (0.71)</td>
<td>4.59 (0.33)</td>
<td>0.02*</td>
</tr>
<tr>
<td>Control</td>
<td>3.74 (0.65)</td>
<td>3.74 (0.61)</td>
<td></td>
</tr>
<tr>
<td><strong>Intrinsic Regulation</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intervention</td>
<td>3.71 (0.94)</td>
<td>4.81 (0.26)</td>
<td>0.02*</td>
</tr>
<tr>
<td>Control</td>
<td>3.63 (0.86)</td>
<td>3.76 (0.61)</td>
<td></td>
</tr>
</tbody>
</table>

Note: *, significant level was 0.05.

The descriptive statistics for mood states has been presented in Table 5. Regarding the six subscales of mood states, the two-way repeated measures ANOVA indicated significant main effect of time on Anger \( (F(1,34) = 4.54, p = 0.04, \eta^2 = 0.12) \), fatigue \( (F(1,34) = 5.35, p = 0.03, \eta^2 = 0.14) \), and vigor \( (F(1,34) = 50.79, p < 0.001, \eta^2 = 0.60) \). Further, the significant “time * group” interaction was observed on confusion \( (F(1,34) = 6.72, p = 0.01, \eta^2 = 0.17) \), fatigue \( (F(1,34) = 6.46, p = 0.02, \eta^2 = 0.16) \),
tension \( F(1,34) = 10.44, p = 0.003, \eta_p^2 = 0.24 \), and vigor \( F(1,34) = 7.22, p = 0.01, \eta_p^2 = 0.18 \). In detail, intervention participants’ level of confusion has decreased 0.38 after 4 weeks, whereas control participants’ level of confusion has increased 0.17; intervention participants’ level of fatigue has decreased 0.56 and control participants’ level of fatigue has increased 0.03 after 4 weeks; intervention participants’ level of tension has decreased 0.5 and control participants’ level of tension has increased 0.16 after 4 weeks; intervention participants’ level of vigor has increased 1.27 and control participants’ level of vigor has increased 0.58 after 4 weeks.

### Table 5. Descriptive Statistics for Mood States by Group.

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>4 weeks</th>
<th>p-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Anger</strong></td>
<td>Intervention</td>
<td>1.28 (0.57)</td>
<td>1.01 (0.06)</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>1.59 (1.09)</td>
<td>1.51 (0.95)</td>
</tr>
<tr>
<td><strong>Confusion</strong></td>
<td>Intervention</td>
<td>1.53 (0.75)</td>
<td>1.15 (0.18)</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>1.67 (0.97)</td>
<td>1.84 (0.97)</td>
</tr>
<tr>
<td><strong>Depression</strong></td>
<td>Intervention</td>
<td>1.41 (0.69)</td>
<td>1.01 (0.06)</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>1.62 (0.81)</td>
<td>1.63 (0.87)</td>
</tr>
<tr>
<td><strong>Fatigue</strong></td>
<td>Intervention</td>
<td>2.00 (0.54)</td>
<td>1.44 (0.40)</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>2.09 (1.01)</td>
<td>2.12 (1.01)</td>
</tr>
<tr>
<td><strong>Tension</strong></td>
<td>Intervention</td>
<td>1.85 (0.72)</td>
<td>1.35 (0.52)</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>1.84 (1.03)</td>
<td>2.00 (1.11)</td>
</tr>
<tr>
<td><strong>Vigor</strong></td>
<td>Intervention</td>
<td>2.74 (0.50)</td>
<td>4.01 (0.50)</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>2.51 (0.74)</td>
<td>3.09 (0.88)</td>
</tr>
</tbody>
</table>

Note: *, significant level was 0.05.

The descriptive statistics for total depression score by group from baseline to 4 weeks has been presented in Table 6. Regarding the depressive symptoms, the mixed model ANOVA revealed a significant “time * group” interaction on the mean scores of depression symptom assessment \( F(1,34) = 5.53, p = 0.03, \eta_p^2 = 0.14 \). Specifically, intervention participants total depression score has increased 2.7 whereas control participants’ total depression score has increased 0.53 after 4 weeks.

### Table 6. Descriptive Statistics for Depressive Symptoms by Group.
Results for Study Aim 2: Examine the effects of a 4-week immersive VR-based exercise bike intervention on college students’ physiological outcomes in comparison with control group.

Physiological Outcomes (BMI, %BF, and CRF)

The descriptive statistics for BMI, %BF, and CRF by group at baseline and 4 weeks was presented in Table 3. The results of two-way repeated measures ANOVA (“time” as the within-subject factor and “group” as the between-subject factor) indicated that there was a significant main effects of time on CRF ($F(1,34) = 20.65, p < 0.001, \eta_p^2 = 0.38$). However, there was no significant main effect of time on BMI ($F(1,34) = 1.48, p = 0.23, \eta_p^2 = 0.04$) and %BF ($F(1,34) = 3.07, p = 0.09, \eta_p^2 = 0.08$). In addition, significant “time * group” interaction was observed on %BF ($F(1,34) = 17.26, p < 0.001, \eta_p^2 = 0.34$) and CRF ($F(1,34) = 30.05, p < 0.001, \eta_p^2 = 0.47$). The results indicated that intervention participants’ %BF and CRF had significant improvement after the 4 weeks intervention. Overall, intervention participants’ %BF has decreased 1.6% from baseline to 4 weeks, whereas control group participants’ %BF has increased 0.88% after 4 weeks. In addition, intervention participants’ CRF improved from 113 bpm at baseline to 96.12 bpm at 4 weeks, however, the control participants’ CRF decreased from 115 bpm at baseline to 117.53 bpm at 4 weeks. There was no significant interaction regarding the changes on BMI from baseline to 4 weeks.

<table>
<thead>
<tr>
<th>Depression Score</th>
<th>Intervention</th>
<th>4 weeks</th>
<th></th>
<th>Control</th>
<th>4 weeks</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>5.94 (5.68)</td>
<td>3.24 (4.28)</td>
<td>0.03*</td>
<td>6.68 (6.25)</td>
<td>7.21 (6.75)</td>
<td></td>
</tr>
</tbody>
</table>

Note: *, significant level was 0.05.
Table 3. Descriptive Statistics for Physiological Outcomes by Group.

<table>
<thead>
<tr>
<th></th>
<th>Group</th>
<th>Baseline</th>
<th>4 weeks</th>
<th>p-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BMI (m/kg^2)</strong></td>
<td>Intervention</td>
<td>25.21 (4.36)</td>
<td>25.00 (4.05)</td>
<td>0.55</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>25.52 (3.71)</td>
<td>24.87 (5.11)</td>
<td></td>
</tr>
<tr>
<td><strong>%BF (%)</strong></td>
<td>Intervention</td>
<td>26.11 (7.14)</td>
<td>24.51 (6.98)</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>27.28 (5.09)</td>
<td>28.16 (4.60)</td>
<td></td>
</tr>
<tr>
<td><strong>CRF (bpm)</strong></td>
<td>Intervention</td>
<td>113 (22.10)</td>
<td>96.12 (16.48)</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>115.19 (16.64)</td>
<td>117.53 (16.56)</td>
<td></td>
</tr>
</tbody>
</table>

Note. BMI, body mass index; %BF, percentage of body fatness; CRF, cardiovascular fitness.

Results for Study Aim 3: Examine the effects of a 4-week immersive VR-based exercise intervention on college students’ physical activity in comparison with control group.

The descriptive statistics for PA by group between baseline and 4 weeks were shown in Table 5. The two-way repeated measures ANOVA indicated a significant main effect of time on PA ($F(1,34) = 15.84, p < 0.001, \eta^2_p = 0.34$). Further, the significant “time * group” interaction was observed ($F(1,34) = 17.35, p < 0.001, \eta^2_p = 0.36$). The tests of between-subjects effects indicated a significant group difference on PA after 4 weeks intervention ($F(1,34) = 5.91, p = 0.02, \eta^2_p = 0.16$), indicating that intervention participants reported significant higher level of PA as compared to control group after 4 weeks. In detail, Intervention group’s PA has increased 1075.12 MET-minutes/week after 4 weeks, whereas control group’s PA has decreased 24.44 MET-minutes/week after 4 weeks.
Chapter Five: Discussion

Summary of Findings

The study was designed to examine the effectiveness of an immersive virtual reality exercise bike intervention for promoting physical activity and health-related physiological and psychological outcomes among college students over 4 weeks. Specifically, intervention participants participated a total of eight 60-minute immersive virtual reality bike exercise sessions for 4 weeks, on the other hand, the control group participants maintained their usual routine. Intervention participants’ weekly physical activity levels, health-related physiological outcomes (e.g., body mass index, percentage of body fatness, and cardiovascular fitness) and psychological outcomes (e.g., self-determination theory-based exercise regulation, mood states, and level of depressive symptoms) were compared to the control group after 4 weeks. It was hypothesized that intervention participants would have significant improvement on psychological and physiological improvement in comparison with control group after 4 weeks. Overall, the results partially support the hypotheses. Specifically, intervention participants’ percentage of body fatness and cardiovascular fitness level improved significantly after 4 weeks immersive virtual reality exercise intervention as compared to the control group. In addition, intervention participants’ intrinsic regulation and identified regulation (relatively higher level of self-determination) toward exercise or physical activity, and overall mood states (e.g., vigor, confusion, fatigue, and tension) had significant improvement after 4 weeks as compared to the control group. Regarding depressive symptoms, although both groups demonstrated normal total depression score that
indicating normal status without depressive disorder, intervention participants’ total depression score had significant improvement as compared to control group after 4 weeks virtual reality-based exercise intervention. Lastly, hypothesis 3 was met. Intervention participants’ physical activity levels had significant improvement after 4 weeks as compared to control group.

**Virtual Reality Exercise on Psychological Outcomes**

Congruent with the study hypothesis 1, intervention participants’ exercise motivation, mood states, and level of depressive symptoms had significant improvement over the 4 weeks intervention. Significant time x group interactions were observed on self-determination-based intrinsic regulation, identified regulation, mood states, and depressive symptoms. Such findings provide solid evidence that participating in a 4-week virtual reality exercise intervention is effective for inducing greater exercise motivation and improving overall mood states, also, may reduce depressive symptoms.

**Virtual Reality Exercise on Exercise Motivation**

According to the self-determination theory (Ryan & Deci, 2000), exercise/physical activity behaviors that driven by the higher level of self-determination (intrinsic and identified regulation) are more likely to be maintained in a longer duration. Consistent with our previous observational studies, which compared the acute effects of immersive virtual reality bike on college students’ exercise motivation and found that participating in 20 minutes may have a greater impact on intrinsic motivation as compared to exercise on a traditional bike, suggesting that the virtual reality exercise may offer an interesting and fun means for promoting physical activity among young adults
(Liu et al., 2019; Zeng et al., 2017). Regarding the virtual reality-based exercise, the fun nature of game-type exercise may be one of the factors that leads to the increase intrinsic motivation. A recent meta-analysis examining the effectiveness of virtual reality exercise on individuals’ psychological and physiological outcomes concluded that participation in virtual reality-based exercise programs can lead to greater enjoyment (Qian et al., 2020).

Importantly, the novel features of immersive virtual reality exercise provided participants a greater sense of immersion during the virtual environment and constant feedbacks under the game flow, which makes it unique beyond conventional exercise. Broadly, the immersive virtual reality offers participants a greater sense of presence. In detail, the concept of presence has been defined by Slater and Wilbur (1997), which describe it as the subjective feeling of “being there” in the virtual environment. The fully immersive virtual reality exercise system is well capable of providing participants an inclusive, extensive, surrounding, and vivid illusion of reality, which lead to greater sense of being in the virtual environment. Previous study has indicated that the stronger an individual experiences the feeling of being in the virtual reality environment, the more likely he or she will report behaving to that in the real world (Bowman & McMahan, 2007). Corresponding to the present study, 55.6% of participants reported no virtual reality playing experience prior to participating in this study, which means that exercise under a fully immersive were considered a new experience among those college students. Such new experience may drive participants’ attention and interest, thereby, inducing greater self-motivation for engaging such virtual reality-based exercise. As the intervention participants’ intrinsic and identified regulation improved with a greater sense
of presence under virtual reality exercise, the exercise behaviors may be transferred to the real world after the intervention. Indeed, after the 4 weeks intervention, the researcher conducted a 7-day post-intervention follow-up assessment of free-living physical activity in all participants. The significant effects of immersive virtual reality exercise intervention on promoting physical activity levels have been observed. Specifically, intervention participants’ weekly physical activity levels had significantly increase as compared to the control group. Intervention participants’ weekly physical activity level has increased 1075.12 MET minutes per week as compared to the baseline. It is worth noting that the weekly physical activity levels were assessed based on self-reported questionnaire. Due to the nature limitation of self-report assessment, the physical activity level may be overestimated. As the accelerometers have been widely used in the physical activity research field, it is highly recommended to assess physical activity levels using objective means.

In addition to the benefits of greater immersion, the enjoyable game flow and constant feedbacks during immersive virtual reality exercise may also account for the improvement of intrinsic motivation. Specifically, participants played two competition-based games (car racing and cyclist racing) during each 60 minutes exercise session. Both games provide various tasks depend on the progression of game playing and virtual avatars competing with the participants. A recent review examining the effects of virtual reality on motivation, enjoyment, and engagement during exercise among healthy population found that the virtual competitive avatars and agents were appeared to be the most influential factors impacting on exercise motivation and engagement (Mouatt et al.,
2020). Notably, the study also indicated the types of virtual avatars in the virtual reality environment may result in different findings regarding the change of motivation during the exercise. Specifically, the study distinguished the virtual avatars into competitive and cooperation avatars. For example, the competitive avatars challenge the player to increase the speed during exercise in order to win the game. Whereas, when players exposed to the cooperation avatars such as virtual trainer proving positive feedbacks did not result in motivation changes as compared to the competitive avatars. Corresponding to the current study, both virtual reality games were highly competitive. For example, during the cyclist racing game, participants need to pass as many as possible virtual riders during each mini session in the game in order to collect the most points. The system will adjust the virtual avatars’ speed based on participants’ performance in previous mini session (e.g., the virtual avatars’ speed will increase if the player collects all points during previous mini session). Such constant challenging tasks and gaming interactions may drive participants to be more self-motivated engaging in the exercise session. Moreover, participants were scheduled separately for each session and all participants take turns to exercise in one immersive virtual reality exercise bike. The game was able to save the records of highest points collected during each game, based on the observation of investigator, most of participants were trying to break the records that achieved by others, and this could also be one of the factors that driving participants’ intrinsic motivation.

Overall, the current findings support that participating in an immersive virtual reality exercise intervention can promote greater intrinsic motivation and identified regulation, and the increased exercise motivation during the intervention may transferred
to the real-life physical activity. Consistent with the previous study (Mouatt et al., 2020), the highly immersive virtual reality exercise may promote greater motivation and engagement towards exercise, the selection of virtual reality system (immersive vs. non-immersive) and program (virtual competitors vs. virtual cooperation avatars) appeared to be important to observe the changes in motivation during exercise. It is recommended that future virtual reality-based exercise study should adopt highly immersive virtual reality system and include the programs with competition component for promoting favorable motivational changes among college students.

**Virtual Reality Exercise on Mood States**

Intervention participants’ overall mood states had significant improvement from baseline to post-intervention. Specifically, significant reduction in feeling of confusion, fatigue, tension, and increase in vigor were observed over time. Regarding the between-group difference on mood states, intervention participants’ feeling of vigor had significant improvement after 4 weeks as compared to the control group. Vigor refers to the sense of being lively, energetic, active, and alert (Brandt et al., 2016). The findings of this study were in line with the previous empirical studies, which suggested the combination of virtual reality and exercise may lead to favorable changes in mood states (Gao et al., 2020; Plante, Aldridge, Bogden, et al., 2003; Plante, Aldridge, Su, et al., 2003; Qian et al., 2020). Plante and colleagues (2003) conducted a cross-sectional study examining the psychological benefits of virtual reality-based exercise among 154 college students. Participants were randomly assigned to one of four conditions for 20 minutes: (1) walking around campus; (2) walking on a treadmill and wearing a VR head-mounted
display; (3) walking on a treadmill without VR; or (4) experiencing a virtual walk by VR without actual walking. The increased perception of vigor and related mood benefits were observed immediately after the virtual reality exercise session. Although there is a paucity of literature studying the effects of immersive virtual reality exercise on healthy population, the effects of non-immersive virtual reality exercise (also refers to exergame or active video game) on positive mood states has been well studied (Daley, 2009; Foley & Maddison, 2010; Gao et al., 2015; Staiano & Calvert, 2011). Consistent findings indicated that non-immersive virtual reality may have beneficial effects on psychological well-being, such as mood and enjoyment. The level of immersive during virtual reality-based exercise has been considered as an important mechanism impacting individuals’ mood states when experience virtual reality. Previous studies have shown that higher level of immersion increases satisfaction of the exergaming experience (Nunez & Blake, 2006), and is a strong predictor of game enjoyment (Horvath & Lombard, 2010; Shafer et al., 2011). Despite findings in that non-immersive virtual reality-based exergaming, the fully immersive virtual reality technology offers a deeper level of immersion where player can be fully immersed into the virtual environment, and this may lead to greater positive feelings under this condition. Our previous cross-sectional study examining the acute effects of immersive virtual reality exercise on college students’ psychological outcomes found significant positive feelings such as overall mood states and enjoyment when exercising under a fully immersive virtual reality bike in comparison with the traditional bike and non-immersive virtual reality bike. However, because there is no follow-up assessment of mood states after intervention, whether the improved mood
states can be sustained for extend periods remain unclear. Future study may include a follow-up with longer duration examining the positive effects on mood among this population.

Virtual Reality Exercise on Depression

Regarding the effects of immersive virtual reality-based exercise on depression, the current study observed significant reduction in the level of depressive symptoms from baseline to 4 weeks in the intervention group. However, the changes were not significant different between intervention and control group. Not surprisingly, because the enrolled participants were healthy college students, which indicate they were generally in a healthy state (both mentally and physically). According to the manual of Beck’s Depression Inventory II (Beck, A.T., Steer & R.A., & Brown, G.K., 1996), the inventory is scored by summing the ratings for 21 items (each item scale ranging from 0 to 3). The total score between 1 to 10 is considered normal. The participants’ depression scores were normal at baseline, with intervention participants scored average 5.94 and control scored 6.68. Notably, the intervention participants’ depression score decreased after 4 weeks intervention (3.24) and control participants’ depression score slightly increased to 7.21, but the overall scores at post-intervention were still considered normal.

Although participants showed no depression symptoms, the decreased depression score in the intervention group may provide additional insights regarding the use of immersive virtual reality-based exercise as a means for treating depression. Recently, one study adopted the virtual reality games paired with exercise and examined the effects of a virtual reality exergame on depressive young adults (Lin et al., 2020). The findings of
this study indicated such virtual reality-based exergame may help increase physical activity and decrease symptoms of anxiety and depression. Clinical study suggested that virtual reality can help to create a virtual environment that modulates the triggers that lead to an individual’s anxiety or depression (Maples-Keller et al., 2017). In addition, Zeng et al. (2017) conducted a review regarding the effectiveness of virtual reality exercise on anxiety and depression. Among five reviewed studies, four studies reported significant improvements in anxiety and depression symptoms after the virtual reality exercise. However, the researcher also pointed out the limited studies on this topic were no sufficient to confirm the effectiveness on treating anxiety and depression.

As mood states are related to the depression, recall to the current study on mood, college students participated a 4-week immersive virtual reality-based exercise intervention reported significant reduction in tension and fatigue and increase in vigor, however, there was no significant changes in control group. As discussed earlier, the highly immersive and interaction during virtual reality exercise were able to positively influence college students’ mood while eliciting physical activity. The improved mood states in the intervention participants may also facilitate the improvement in the depression score. It appears that the immersive virtual reality exercise can help to reduce the negative feelings. Given the participants of current study were overall healthy college students, future studies may consider recruiting college students with depressive disorder in order to further examine the effectiveness in treating depression.

Virtual Reality Exercise on Physiological Outcomes
The findings of this study indicated that participating in a 4-week immersive virtual reality-based exercise bike intervention are effective for improving college students’ cardiovascular fitness level and reducing percentage of body fatness. To the best of the investigator’s knowledge, this is the first study that examined the effects of an immersive virtual reality-based exercise intervention on healthy college students’ cardiovascular fitness and body composition. According to the Physical Activity Guidelines for Americans, it is recommended that adults should participate at least 150 minutes moderate-intensity physical activity or 75 minutes vigorous physical activity each week to obtain health benefits, such as reduced risk factor of cardiovascular disease (Piercy et al., 2018). Corresponding to the present study, intervention participants were asked to come to lab exercising on the virtual reality exercise bike 60 minutes per session, twice per week, for 4 weeks. Our immersive virtual reality exercise bike was previously observed to provide moderate-to-vigorous intensity physical activity (Liu et al., 2019; Zeng et al., 2017). Notably, participants were wearing the accelerometer during each exercise session to validate the exercise intensity. The analyses of accelerometer-determined intensity during each 60-minute session indicated that participants spent 89.68% of time on moderate-to-vigorous physical activity per exercise session. Notably, 78% of time was contributed to vigorous intensity physical activity. As all participants successfully completed all 8 sessions for 4 weeks, which indicated that participants performed at least 120 minutes of moderate-to-vigorous physical activity each week. Notably, there is no exercise or physical activity restriction in addition to the intervention sessions, thus, participants may accumulate more physical activities during the week. The
relationship between physical activity and cardiovascular fitness have been widely studied, which indicated the positive relationship between physical activity and cardiovascular fitness level. One recent systematic review investigating the correlates and determinants of cardiovascular fitness in adults has further concluded the positive impacts of physical activity on cardiovascular fitness (Zeiher et al., 2019). It is worth noting that during each 60-minute exercise session, there is a large amount of time was devoted to vigorous physical activity. Because the virtual reality exercise session included two competition-type games (Car Racing and Cyclist), which require participants to pedaling fast in order to win the game. For example, during the “Cyclist” game, in order to collect points, participants need to pedal beyond certain speed to pass each gate with limited time (usually 60 seconds), otherwise, participants may fail to obtain the points. Based on this gaming mechanism, the investigator observed that most of participants were highly motivated and thus performed more vigorous physical activity during the game playing. As intervention participants spent relatively more time in vigorous physical activity during each session, this may account for the significant improvement on cardiovascular fitness level after 4 weeks immersive virtual reality exercise intervention. One study synthesized epidemiological studies and clinical trials comparing the cardioprotective benefits of vigorous versus moderate intensity physical activity while controlling for total energy expenditure (Swain & Franklin, 2006). The findings of this study indicated that vigorous intensity tended to have greater impact on cardioprotective benefits as compared to the moderate intensity physical activity when spending the same energy expenditure. In addition, findings from previous study
indicated that vigorous intensity appeared to be more effective on improving aerobic capacity as compared to the moderate intensity physical activity (Swain & Franklin, 2002; Wenger & Bell, 1986). Corresponding to this finding, epidemiology studies suggested that each 1-MET increases in aerobic exercise capacity may reduce 8-17% of risk in cardiovascular disease and all-cause mortality among adults (Blair et al., 1995; Gulati et al., 2003; Myers et al., 2002).

Regarding the effects of virtual reality exercise on body composition, there was significant improvement on percentage of body fatness from baseline to post-intervention in the intervention participants. Specifically, intervention participants’ average percentage of body fatness reduced 1.6% after 4 weeks, whereas the control group participants’ average percentage of body fatness increase 0.88%. Regarding the improvement on percentage of body fatness, one recent study examining the effects of a 4-week sports virtual reality training program on body composition also found a significant reduction in body fatness from baseline to post-test (Lee & Kim, 2018). Participants of this study exercised in the virtual reality training program 3 days per week, 20 to 30 minutes per day, for 4 weeks. The percentage of body fatness reduced 0.98% from pre- and post-test. Notably, there was no control group for this study, thus, the effectiveness of this study needs randomized control trials to further conclude the findings. Also, the virtual reality system was not fully immersive environment, instead, they used a huge flat screen to stimulate the virtual environment, which offers less immersion as compared to the fully immersive virtual reality system (wearing a headset). Corresponding to the present study, the significant reduction on percentage of body
fatness was observed in intervention participants. However, one randomized control trial examined the effects an 8-week virtual reality exercise program on hemodialysis patients’ body composition and found no significant group difference on the ratio of body fatness after 8 weeks intervention, yet the intervention participants’ percentage of body fatness decreased 0.8%. They indicated that the short duration and low intensity of exercise session may account for the non-significant changes. Recent meta-analysis summarized the findings regarding the effects of exercise intervention on weight, body mass index, and body fatness in overweight and obese individuals (Lee & Lee, 2021). The study emphasized the types of exercise and duration of intervention were important factors for improving weight loss, reducing body mass index and accumulated visceral fat. They suggested the exercise intervention dose should consist of moderate-to-vigorous physical activity at least 50 minutes per session 4 times per week for 22 weeks in order to observe the favorable changes. Although the present study duration was 4 weeks, the most time of each exercise session was contributed to the vigorous intensity, which has a greater impact on reducing percentage of body fatness. Overall, given the promising findings on physiological outcomes, future study may consider using immersive VR-based exercise as an approach for treating young adults with obesity.

**Virtual Reality Exercise on Physical Activity**

The hypothesis 3 was supported. The intervention participants had significant increase in physical activity during the post-intervention 7-day follow-up as compared to the control group. Specifically, intervention participants’ weekly physical activity significantly increased 1075.12 MET minute/week as compared to baseline. The current
study adopted self-determination theory as the guiding theory for the implementation of the intervention and the previous discussion has confirmed the effectiveness of a 4-week immersive virtual reality-based exercise intervention in improving the college students’ exercise motivation, especially in the intrinsic and identified regulation. Physical activity interventions that grounded by the self-determination theory suggesting the important role of higher level of self-determination in promoting sustained physical activity/exercise behaviors, such as intrinsic and identified regulation (Teixeira et al., 2012). Specifically, Thøgersen-Ntoumani and Ntoumanis (2006) examining the relationships between the self-determined regulations (e.g., intrinsic motivation, identified regulation, external regulation, and amotivation) and exercise-related behaviors suggested that intrinsic and identified regulation were significant predictors for promoting and maintaining sustained exercise behaviors. Moreover, one study reviewed three large-scale self-determination theory-based physical activity interventions and found consistent evidence supporting the autonomous regulation (intrinsic and identified regulation) lead to persistence of physical activity participation (Fortier et al., 2012). Notably, there is a discussion regarding whether the sustained physical activity behaviors were influenced by intrinsic motivation or identified regulation. Specifically, one study examining the relationship between exercise motivational regulations and physical activity patterns among college students indicated that identified regulation appeared to have a stronger effect influencing the physical activity behaviors than intrinsic motivation (Daley & Duda, 2006). However, two long-term exercise intervention indicated that the intrinsic motivation was the key determinants for long-term exercise engagement
(Edmunds et al., 2006; Silva et al., 2011). Because there is a lack of longitudinal or experimental studies to explore the potential different effects between intrinsic and identified regulation, it is suggested that to foster both regulations to optimize the promotion in physical activity behaviors (Teixeira et al., 2012). Corresponding to the current study, the increased physical activity during follow-up may explain by the improved intrinsic motivation and identified regulation during the 4 weeks intervention. Notably, the follow-up assessment of physical activity took place one week later after the 4 weeks intervention, thus, the effects of immersive virtual reality-based exercise intervention in promoting free-living physical activity remains inconclusive. However, findings of current study indicated that participating a 4-week immersive virtual reality exercise may have a strong short impact in promoting physical activity levels among college students.

**Study Strengths**

To the best of investigator’s knowledge, this is the first randomized control trial that examine the effects of an immersive virtual reality-based exercise on health-related physiological and psychological outcomes among healthy college students. As limited cross-sectional and expletory studies have indicated the promising influence of virtual reality on health-related outcomes, the current study provided the initial experimental evidence in the field for future intervention programs that aim to promote physical activity and health-related outcomes in college population. In addition, this is the first study examined the effects of immersive virtual reality exercise on body composition and cardiovascular fitness among college students. The promising physiological changes
support the feasibility of immersive virtual reality exercise in reducing percentage of body fatness and improving cardiovascular fitness. Moreover, this is the first study that adopted self-determination theory guiding the intervention, which provided the opportunity to understand the underlying psychological mechanism of using immersive virtual reality in promoting physical activity and health-related outcomes.

**Study Limitations**

The limitations of current study must be acknowledged when interpreting the study findings. First, the participants’ racial backgrounds may limit the generalizability of findings. Specifically, most of participants were either White (30.6%) or Asian (55.6%), with very few participants in other race/ethnicity (13.9%). Because the university was closed due to the Covid-19 pandemic and college students only taking online course at home, it was very difficult to recruit participants under this circumstance as the intervention requires participants to come to laboratory for exercise session and assessment. Future studies with more diverse racial backgrounds are needed to increase the generalizability of findings.

Second, the 7-day physical activity was assessed by the self-reported questionnaire. The major limitation of self-report measures is that participants may overestimate or underestimate the time spent in different types of physical activities. Moreover, the recall bias may lead to the inaccurate estimation of physical activity. The proposed intervention protocol was to use the accelerometers for assessing the 7-day physical activity, however, the investigator must revise the plan in order to reduce face-to-face interactions under Covid-19 pandemic and responding to the university research
policy. As accelerometers have been widely used in various physical activity studies, future studies are highly encouraged to adopt objective measures for assessing physical activity.

Third, the findings of current study were based on the college students who do not have motion sickness under the immersive virtual reality environment. Notably, during the pre-intervention screening session, only 2 out of 40 college students reported having motion sickness within 15 minutes virtual reality experience. Given the complex factors of motion sickness (e.g., posture instability, genetic factor, etc.), there is no solution to treat the motion sickness to date. Future studies using immersive virtual reality should acknowledge this issue and carefully interpreting the findings.

Forth, the investigator did not recruit enough study sample as plan, which may limit the statistical power to detect the difference. The plan study sample was 40 participants, in fact, 36 participants were recruited and completed the intervention. Again, it was very difficult to recruit participants during the Covid-19 pandemic and related university closure, the investigator made every effort in recruiting participants. Future studies with large sample size are needed.

Fifth, the findings of current study may be influenced by potential confounding factor such as dietary behavior. The investigator only required all participants not to participate other physical activity programs during the 4 weeks intervention period, but did not restrict the dietary behaviors, as this is another important component impacting health-related outcomes. For better understanding the intervention effects, future studies
need careful consideration of all potential confounding factors that may impact study outcomes.

Seventh, there may have a placebo effect, as the control group participants did not receive any treatment but just maintain their usual routine. The original study plan was to let control group participants exercise on a traditional bike, however, the investigator must revise the plan in order to reduce face-to-face interactions under Covid-19 pandemic and responding to the university research policy. In order to further examine the effectiveness of virtual reality-based exercise intervention, future studies are highly encouraged to include control group with comparable treatment.
Chapter Six: Conclusion

In summary, the findings of current study suggest that a 4-week immersive virtual reality-based exercise intervention is effective in promoting college students’ intrinsic motivation and identified regulation toward exercise, overall mood states, body composition, cardiovascular fitness, and physical activity levels. It is suggested that virtual reality exercise could be a fun and motivating means for promoting young adults’ physical activity and health-related physiological and psychological outcomes. Future studies with diverse samples, longer intervention duration, and objective measure of physical activity are warranted to further examine the long-term effects of immersive virtual reality exercise on health-related outcomes.
Biography


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https://doi.org/10.1186/1479-5868-9-78


https://doi.org/10.1177/1359105307084318


Appendix A. Intervention Pictures
Appendix B. Approval from IRB and Sunrise Plan

UNIVERSITY OF MINNESOTA

Twin Cities Campus

Human Research Protection Program
Office of the Vice President for Research
Room 350-2
McNamara Alumni Center
200 Oak Street S.E.
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612-626-5654
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APPROVAL OF NEW STUDY

September 28, 2020

Dear Zan Gao:

IMPORTANT: All human research conducted at the University of Minnesota must adhere to the IRB guidance and requirements, Office of the Vice President for Research guidance, and the Medical School/Office of Academic Clinical Affairs Sunrise Implementation Plan in response to the COVID-19 pandemic. Non-medical school investigators should contact their Associate Dean for Research for information on the "sunrise" process.

Even with IRB approval, in-person research visits may not take place without documented approval by either the Medical School/OACA sunrise process or the Associate Dean for Research sunrise process. These reviews are intended to protect the health of all research participants and the broader University/Fairview communities during the COVID-19 pandemic. Researchers must inform the IRB of
their approved sunrise plans. The IRB will document the approval status on ETHOS via a comment in the study history section. Please note that IRB approved COVID-19 related research is exempt from the sunrise requirements.

All researchers should review the guidance for the IRB, the medical school and their own departments as guidance is updated frequently.

On 9/14/2020, the IRB reviewed the following submission:

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<th>Type of Review:</th>
<th>Initial Study</th>
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<tr>
<td>Title of Study:</td>
<td>Effects of Virtual Reality Exercise on Promoting Physical Activity and Health among College Students: A 4-week Randomized Control Trial</td>
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<tr>
<td>Investigator:</td>
<td>Zan Gao</td>
</tr>
<tr>
<td>IRB ID:</td>
<td>STUDY00010580</td>
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<tr>
<td>Sponsored Funding:</td>
<td>None</td>
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<td>Grant ID/Con Number:</td>
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<td>Fund Management Outside University:</td>
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<td>IND, IDE, or HDE:</td>
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<tr>
<td>Documents Reviewed with this Submission:</td>
<td>*Physical Activity Readiness Questionnaire.pdf, Category: Other;</td>
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The IRB determined that the criteria for approval have been met and that this study involves no greater than minimal risk.

This research includes a Non-Significant Risk Device. As used in the research, the investigational device does not meet the criteria for a Significant Risk Device as outlined in "CHECKLIST: Non-Significant Risk Device (HRP-418)." Because of this determination, the Sponsor of the research is considered to have an abbreviated IDE.

The IRB approved the study from 9/28/2020 to 9/13/2021 inclusive. You will be sent a reminder from ETHOS to submit a Continuing Review submission for this study. You must submit your Continuing Review no later than 30 days prior to the last day of approval in order for your study to be reviewed and approved for another Continuing Review period. If Continuing Review approval is not granted before 9/13/2021, approval of this protocol expires immediately after that date.
To: Zan Gao, PhD  
From: J. Michael Oakes, PhD, Associate Vice President for Research  
Date: 5 February 2021  
Re: Face to Face Research Sunrise Plan

Conditional on your application attestations and the stipulations listed below, the Office of the Vice President for Research (OVRP) approves your face-to-face (F2F) human participant research COVID-19 protection plan (hereinafter "Plan") for your study "Effects of Virtual Reality Exercise on Promoting Physical Activity and Health among College Students: A 4-week Randomized Control Trial." Note well that COVID-19 safety procedures are designed to minimize the likelihood of infection, but do not a guarantee that you, a member of your staff, a research participant, or a community member will not get sick with COVID-19. We urge extra caution and care for those at higher risk of poor outcomes, such as immunocompromised persons, those over 60, persons with obesity, those with any heart or lung condition, and so forth. Your next, and presumably final approval, step is to work with your Associate Dean for Research to submit this letter to the IRB for formal acknowledgement. Thank you for your commitment to the health and safety of research participants, research staff, and our larger community.

Stipulations:

1. You may not begin any F2F human participant research until the IRB formally acknowledges your sunrise request; notification will be sent through ETHOS.

2. This approval does not supercede or alter any IRB approvals, requirements, restrictions, or regulations, nor does permit any deviation from the study's approved IRB protocol. This approval is limited to COVID-19 risk mitigation plans only. Any changes to the protocol must be approved by the IRB; failure to do so may result in a finding of non-compliance.

3. All F2F research participants must receive the attached COVID-19 information sheet at least 24 hours prior
to any and all F2F research interactions. Provided the participant is able to effectively receive it, emailing the sheet is acceptable. If the study is subject to HIPAA regulations, please contact your Associate Dean for Research for coordination with HIPCO.

4. This approval is not a return to work authorization. Unless the PI and study staff have already been deemed *essential*, you must work with your college's Associate Dean for Research to complete a "return to work authorization" request. An approved return to work authorization is necessary before beginning any F2F research activity. Only study staff approved to return to work may do so under this authorization.

5. It is the responsibility of the study PI to abide by and enforce the study's approved Plan. The Plan must be shared with all study staff.

6. It is the responsibility of the study PI to immediately alert her/his Associate Dean for Research of any deviations from the approved Plan and/or any new information that may affect the Plan or COVID-19 risks.

7. Whenever possible all research interactions with participants and/or staff must be conducted remotely (e.g., Zoom).

8. The study PI is responsible for ensuring that staff involved in all F2F interactions have a body temperature of <100F and have no other COVID symptoms. This information, however, should not be recorded or documented. Employees who report to work are attesting that they do not have a temperature >100.4F or any other COVID symptoms. The University's Human Resource website has information on scenario planning for potentially sick employees. See https://humanresources.umn.edu/covid-19/sunrise-plan-return-campus/workplace-info

9. The PI is responsible for logging when staff are working in and engaging participants in shared spaces and providing a mechanism for check-in/check-out. A Google document available to all employees may be useful.

10. The Plan and associated research protocols may be subject to a periodic review to assess the effectiveness of COVID-19 protections.
11. Per University policy, masks are required, except under explicit limited conditions. Participants in research studies should be informed that they must wear masks when participating in studies. Use of clinical-grade PPE may be limited given needs of clinical care settings, yet N95 respirators may be required in certain F2F circumstances. Visit UMarket for PPE needs.

12. For cleaning and disinfecting purposes, please coordinate with Facilities Management regarding supplies and service. See the FM Enhanced Cleaning and Expectations for additional details.

13. This support and approval may be modified or terminated by OVPR or the Office of the President at any time if warranted by future developments or circumstances. For the most up-to-date information on the University’s COVID-19 response, please visit the Campus Public Health Officer website.
Appendix C. Study Recruitment Information

Participation in regular physical activity is vital to a healthy lifestyle. As a college student, however, engaging in a healthy lifestyle can be difficult due to school and work pressures in addition to the increased responsibility brought about by making nutrition and physical activity choices independently for the first time. Luckily, we live in an age of technology wherein virtual reality provides an opportunity for increased physical activity participation. Yet, the effectiveness of virtual reality as a tool for improving health outcomes among college students is largely unstudied.

The purpose of this study is to evaluate the long-term effects of virtual reality-based exercise on college students’ physiological and psychological health outcomes.

You will receive $20 incentive gift card upon completion of the study. Think this study is for you? See the participant requirements below.

**Participant requirements:**

- 18-35 years-old, currently enrolled in the university
- No motion sickness when playing virtual reality-based game or exercise
- Possess no diagnosed severe physical or mental disorder (e.g., cystic fibrosis, multiple sclerosis, schizophrenia, bipolar disorder and major depressive disorder)

Participants will be requested to come into the University of Minnesota’s Physical Activity Epidemiology Laboratory for a total of 8 sessions fully immersive virtual reality biking exercise, each session will last 60 minutes, with 2 days per week, for 4 weeks.

**Interested? Please contact:**

Wenxi Liu  
University of Minnesota  
Room 310 Williamson hall  
231 Pillsbury Drive SE, Minneapolis, MN 55455  
Phone: 210-819-9278  
Email: liux4443@umn.edu
Virtual Reality Bike Exercise Study

Wenxi Liu <liux4443@umn.edu>
to CEHD-ANNOUNCEMENTS

Hello,

My name is Wenxi Liu, Ph.D. candidate in the School of Kinesiology. Below are the details for participating in my dissertation study. I have also attached the study recruitment flyer. Thank you!

Study Title: "Effects of Virtual Reality Exercise on Promoting Physical Activity and Health among College Students: A 4-Week Randomized Control Trial." This study is approved by IRB (Study ID: 00010580).

Volunteers are needed for a study at the University of Minnesota that is investigating the long-term effects of virtual reality (VR) -based exercise on college students' physiological and psychological outcomes. Participants will be randomly assigned to the intervention or control group. Intervention Group Participants will be scheduled to exercise on a fully immersive VR bike for a total of 8 sessions, one hour per session, twice per week, for 4 weeks. All the exercise sessions will be conducted based on the "one-on-one" condition (participants will be scheduled separately). Control group participants will maintain their usual activities for 4 weeks. Participants will get a $20 gift card at the completion of the study.
*To be eligible for participation you must*:

- Currently enrolled university students age 18-35 years old
- No motion sickness when playing VR games or exercise
- Possess no diagnosed severe physical or mental disorder
- Be able/willing to exercise on the VR bike twice per week for 4 weeks.

If you are interested in participating, please contact *Wenxi Liu* via email: liux4443@umn.edu

**Wenxi Liu, M.S.**
Ph.D. Candidate/Research Assistant
School of Kinesiology, University of Minnesota - Twin Cities
Physical Activity Epidemiology Laboratory
Email: liux4443@umn.edu
Phone: 210-819-9278
COVID-19 and Research Participation

The University of Minnesota and the research team are committed to your care and safety. This document provides you with important information about COVID-19 (Coronavirus Disease 2019), ways your choice to participate in research might change, and information to help you decide whether research participation is right for you at this time.

It is important to know that research participation may include increased travel outside of your home and exposure to others that may increase your exposure to COVID-19. **You do not have to participate in research now or at any time if you do not feel comfortable doing so. Research participation is always voluntary; you may stop participation at any time.**

**What are researchers doing to minimize your risks?**
Researchers will screen participants for symptoms and for contact with people that have or had COVID-19. They will also minimize the number of in-person research visits and appropriately disinfect research visit spaces before and after use.

Researchers have been asked to follow all University of Minnesota COVID-19 safety guidelines, which include:

- Properly wash their hands
- Maintain physical distance
- Wear a face covering (mask)
- Check their temperature each morning and

- Tell their supervisor or HR representative if they have a fever or any COVID-19 symptoms
- Stay home if they feel sick

**How is COVID-19 spread?**
COVID-19 is a respiratory illness in people caused by a new virus that can be spread:

- From person to person, such as when an infected person coughs or sneezes
- By touching a surface or object (such as a doorknob or counter surface) that has the virus on it, then touching their mouth, nose or eyes
- When people are in close contact with one another (within about 6 feet), especially indoors
- By some people without symptoms

**Can COVID-19 be prevented?**
There currently is no vaccine to prevent COVID-19 and the following is important for everyone:

- Wash your hands often
- Avoid close contact with people who are sick
- Wear a mask when around others
- Cover coughs and sneezes
- Monitor your own health for COVID-19 symptoms

If you decide to attend in-person research visits, you will be asked to do these things. You will also be asked questions to screen for symptoms before you arrive and to limit additional people who will attend the research appointment with you.
Appendix D. Informed Consent

**Title of Research Study:** Effects of Virtual Reality Exercise on Promoting Physical Activity and Health among College Students: A 4-week Randomized Control Trial

**Investigator Team Contact Information:** Zan Gao
For questions about research appointments, the research study, research results, or other concerns, call the study team at:

<table>
<thead>
<tr>
<th>Investigator Name: Zan Gao</th>
<th>Student Investigator Name: Wenxi Liu</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investigator Departmental Affiliation: School of Kinesiology</td>
<td>Phone Number: 210-819-9278</td>
</tr>
<tr>
<td>Phone Number: 612-626-4639</td>
<td>Email Address: <a href="mailto:liux4443@umn.edu">liux4443@umn.edu</a></td>
</tr>
<tr>
<td>Email Address: <a href="mailto:gaoz@umn.edu">gaoz@umn.edu</a></td>
<td></td>
</tr>
</tbody>
</table>

**Supported By:** This research is supported by Physical Activity Epidemiology Laboratory ________.

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**Key Information About This Research Study**

The following is a short summary to help you decide whether or not to be a part of this research study. More detailed information is listed later on in this form.

**What is research?**

- The goal of research is to learn new things in order to help people in the future. Investigators learn things by following the same plan with a number of participants, so they do not usually make changes to the plan for individual research participants. You, as an individual, may or may not be helped by volunteering for a research study.

- The purpose of this research is to examine the effectiveness of a 4-week immersive-virtual reality (VR) exercise bike intervention on college students’ physiological outcomes (physical activity levels, cardiovascular fitness, and body composition) and psychological outcomes (situational motivation, situational interest, mood states, and depressive symptoms).

**Why am I being invited to take part in this research study?**

We are asking you to take part in this research study because you met the inclusion criteria for participation: 1) 18-35 years old; 2) Possess no diagnosed severe physical or mental disorder; 3) no self-reported motion sickness when playing VR games (e.g., disorientation, dizzy, fatigue, and stomach discomfort).

**What should I know about a research study?**

- Our research staff will explain this research study to you.

- Whether or not you take part is up to you.
You can choose not to take part.

- You can agree to take part and later change your mind.
- Your decision will not be held against you.
- You can ask all the questions you want before you decide.

**Why is this research being done?**
The fact that more than 80% of adults fail to meet the guidelines for both aerobic and muscle-strengthening activities, while the experience of VR is most interesting and appealing to young people. Regrettably, present evidence regarding the use of commercially-available immersive VR headsets and compatible VR exercise apparatus in the promotion of individuals’ physiological and psychological health outcomes is lacking. To this end, we will conduct an immersive VR-based exercise intervention exploring the long-term effects of VR-based exercises promoting PA and health-related outcomes among young adults.

**How long will the research last?**
We expect that you will be in this research study for 4 weeks.

**What will I need to do to participate?**
You will be asked to engage in a total of 8 VR-based exercise sessions within 4 weeks. You will be asked to come to exercise twice per week.

More detailed information about the study procedures can be found under “What happens if I say yes, I want to be in this research?”

**Is there any way that being in this study could be bad for me?**
This is no notable health risks regarding the participation of this study. More detailed information about the risks of this study can be found under “What are the risks of this study? Is there any way being in this study could be bad for me? (Detailed Risks)”

**Will being in this study help me in any way?**
More detailed information about the benefits of this study can be found under “Will being in this study help me in any way? (Detailed Benefits)”

**What happens if I do not want to be in this research?**
There are no known alternatives, other than deciding not to participate in this research study.

**Detailed Information About This Research Study**
The following is more detailed information about this study in addition to the information listed above.

**How many people will be studied?**
We expect about 40 people here will be in this research study.
What happens if I say “Yes, I want to be in this research”?

If you agree to participate in this study, we will randomly assign you to one of the groups:

- VirZoom virtual reality (VR) exercise bike (intervention group)
- Maintain your usual activities (control group)

Participants will be asked to do the following in addition to engaging in exercise:

- **Anthropometric measurements:** Participant’s height and weight measurements will be taken within the University of Minnesota’s Physical Activity Epidemiology Laboratory prior to engaging in the 4-week VR exercise intervention.

- **Physical activity levels:** Each participant will be assigned an accelerometer to wear during each 60-minute exercise session. Prior to the start of the intervention, we will ask you to wear an accelerometer for one week for measuring your physical activity levels. In addition, we will ask you to wear the accelerometer for another week at the completion of 4-week intervention.

- **Cardiovascular fitness levels:** we will ask you to step on and off of a 12-inch plyometric box for 3 minutes to the “beep” of a metronome set to 96 beats-per-minute, with each beep corresponding with one leg movement. Immediately following the completion of the test, the principal investigator will measure participants’ heart rate for 60 seconds via palpation of the radial artery on the underbelly of the left wrist.

- **Psychological measurements:** we will ask you to complete a series of questionnaires regarding motivation, interest, and mood states to this type of physical activity at baseline and 4 weeks.

What happens if I say “Yes”, but I change my mind later?

You can leave the research study at any time and no one will be upset by your decision. Choosing not to be in this study or to stop being in this study will not result in any penalty to you or loss of benefit to which you are entitled. This means that your choice not to be in this study will not negatively affect your right to any present or future medical care, your academic standing as a student, or your present or future employment.

What are the risks of being in this study? Is there any way being in this study could be bad for me? (Detailed Risks)

The study has the following risks:

1. Delayed onset muscle soreness occurring several hours to a couple of days after physical activity engagement.

2. Given the study’s potential to increase your physical activity participation a possibility exists
for the development of symptoms such as muscular strains/sprains, shortness of breath, joint pain, cramping, fatigue, fainting, and dizziness.

(3) Although very unlikely, mental distress caused by the administration of assessments of physical activity-related psychosocial constructs is possible.

(4) There is a potential risk for unidentified heart issues during exercise that may impact you.

**Will it cost me anything to participate in this research study?**
There will be no costs to you as a result of taking part in this study other than the time spent participating. Taking part in this study is voluntary.

**Will being in this study help me in any way? (Detailed Benefits)**
During the participation of this study, your weekly time spending in physical activity may increase, also, this study offers you an opportunity to exercise under a fully immersive virtual environment, and you may find it enjoyable to exercise while playing virtual reality games.

**What happens to the information collected for the research?**
The records of this study will be kept private. Your record for the study may, however, be reviewed by designated departments at the University with appropriate regulatory oversight. We will not include any information in publications or presentations that will make it possible to identify you. To these extents, confidentiality is not absolute. Study data will be encrypted according to current University policy for protection of confidentiality.

**Will I receive research test results?**
The investigator(s) will not contact you or share your individual test results. However, the summary of the research findings may be available upon request.

**Will anyone besides the study team be at my consent meeting?**
No. There will be only the study team at your consent meeting.

**Whom do I contact if I have questions, concerns or feedback about my experience?**
This research has been reviewed and approved by an IRB within the Human Research Protections Program (HRPP). To share feedback privately with the HRPP about your research experience, call the Research Participants’ Advocate Line at 612-625-1650 (Toll Free: 1-888-224-8636) or go to z.umn.edu/participants. You are encouraged to contact the HRPP if:

- Your questions, concerns, or complaints are not being answered by the research team.
- You cannot reach the research team.
- You want to talk to someone besides the research team.
- You have questions about your rights as a research participant.
Will I have a chance to provide feedback after the study is over?
The HRPP may ask you to complete a survey that asks about your experience as a research participant. You do not have to complete the survey if you do not want to. If you do choose to complete the survey, your responses will be anonymous.

If you are not asked to complete a survey, but you would like to share feedback, please contact the study team or the HRPP. See the “Investigator Contact Information” of this form for study team contact information and “Whom do I contact if I have questions, concerns or feedback about my experience?” of this form for HRPP contact information.

What happens if I am injured while participating in this research?
In the event that this research activity results in an injury, treatment will be available, including first aid, emergency treatment and follow-up care as needed. Care for such injuries will be billed in the ordinary manner, to you or your insurance company. If you think that you have suffered a research related injury let the study physicians know right away.

Will I be compensated for my participation?
If you agree to take part in this research study, we will pay you $20.00 for your time and effort.

Your signature documents your permission to take part in this research. You will be provided a copy of this signed document.

_______________________________________________      __________________
Signature of Participant                                                                    Date

_______________________________________________
Printed Name of Participant

_______________________________________________      __________________
Signature of Person Obtaining Consent                                        Date

______________________________________________________
Printed Name of Person Obtaining Consent
Appendix E. Study-Related Surveys

Physical Activity Readiness Questionnaire (PAR-Q)

Name: ____________
Date: ____________

Please answer the following questions by checking “Yes” or “No”.

<table>
<thead>
<tr>
<th>Questions</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Has your doctor ever said that you have a heart condition and that you should only perform physical activity recommended by a doctor?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Do you feel pain in your chest when you perform physical activity?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. In the past month, have you had chest pain when you were not performing any physical activity?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Do you lose your balance because of dizziness or do you ever lose consciousness?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Do you have a bone or joint problem that could be made worse by a change in your physical activity?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Is your doctor currently prescribing any medication for your blood pressure or for a heart condition?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Do you know of any other reason why you should not engage in physical activity?</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

If you have answered “Yes” to one or more of the above questions, consult your physician before engaging in physical activity. Tell your physician which questions you answered “Yes” to. After a medical evaluation, seek advice from your physician on what type of activity is suitable for your current condition.
INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE

We are interested in finding out about the kinds of physical activities that people do as part of their everyday lives. The questions will ask you about the time you spent being physically active in the last 7 days. Please answer each question even if you do not consider yourself to be an active person. Please think about the activities you do at work, as part of your house and yard work, to get from place to place, and in your spare time for recreation, exercise or sport.

Think about all the vigorous activities that you did in the last 7 days. Vigorous physical activities refer to activities that take hard physical effort and make you breathe much harder than normal. Think only about those physical activities that you did for at least 10 minutes at a time.

1. During the last 7 days, on how many days did you do vigorous physical activities like heavy lifting, digging, aerobics, or fast bicycling?

_____ days per week

☐ No vigorous physical activities  ➔ Skip to question 3

2. How much time did you usually spend doing vigorous physical activities on one of those days?

_____ hours per day

_____ minutes per day

☐ Don’t know/Not sure

Think about all the moderate activities that you did in the last 7 days. Moderate activities refer to activities that take moderate physical effort and make you breathe somewhat harder than normal. Think only about those physical activities that you did for at least 10 minutes at a time.

3. During the last 7 days, on how many days did you do moderate physical activities like carrying light loads, bicycling at a regular pace, or doubles tennis? Do not include walking.

_____ days per week
4. How much time did you usually spend doing moderate physical activities on one of those days?
   _____ hours per day
   _____ minutes per day
   □ Don’t know/Not sure

Think about the time you spent walking in the last 7 days. This includes at work and at home, walking to travel from place to place, and any other walking that you have done solely for recreation, sport, exercise, or leisure.

5. During the last 7 days, on how many days did you walk for at least 10 minutes at a time?
   _____ days per week
   □ No walking  ➤ Skip to question 7

6. How much time did you usually spend walking on one of those days?
   _____ hours per day
   _____ minutes per day
   □ Don’t know/Not sure

The last question is about the time you spent sitting on weekdays during the last 7 days. Include time spent at work, at home, while doing course work and during leisure time. This may include time spent sitting at a desk, visiting friends, reading, or sitting or lying down to watch television.

7. During the last 7 days, how much time did you spend sitting on a week day?
   _____ hours per day
   _____ minutes per day
EXERCISE REGULATIONS QUESTIONNAIRE (BREQ-2)

WHY DO YOU ENGAGE IN EXERCISE?

We are interested in the reasons underlying peoples’ decisions to engage, or not engage in physical exercise. Using the scale below, please indicate to what extent each of the following items is true for you. Please note that there are no right or wrong answers and no trick questions. We simply want to know how you personally feel about exercise. Your responses will be held in confidence and only used for our research purposes.

1. I exercise because other people say I should
   0 1 2 3 4

2. I feel guilty when I don’t exercise
   0 1 2 3 4

3. I value the benefits of exercise
   0 1 2 3 4

4. I exercise because it’s fun
   0 1 2 3 4

5. I don’t see why I should have to exercise
   0 1 2 3 4

6. I take part in exercise because my friends/family/partner say I should
   0 1 2 3 4

7. I feel ashamed when I miss an exercise session
   0 1 2 3 4

8. It’s important to me to exercise regularly
   0 1 2 3 4

9. I can’t see why I should bother exercising
   0 1 2 3 4

10. I enjoy my exercise sessions
    0 1 2 3 4

11. I exercise because others will not be pleased with me if I don’t
    0 1 2 3 4
<table>
<thead>
<tr>
<th></th>
<th>Question</th>
<th>Score</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>I think it is important to make the effort to exercise regularly</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>15</td>
<td>I find exercise a pleasurable activity</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>16</td>
<td>I feel under pressure from my friends/family to exercise</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>17</td>
<td>I get restless if I don’t exercise regularly</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>18</td>
<td>I get pleasure and satisfaction from participating in exercise</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>19</td>
<td>I think exercising is a waste of time</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

**Beck’s Depression Inventory**
Please circle the scores that best describe you right now.

1. 0 I do not feel sad
    1 I feel sad
    2 I am sad all the time and I can’t snap out of it
    3 I am so sad and unhappy that I can’t stand it

2. 0 I am not particularly discouraged about the future
    1 I feel discouraged about the future
    2 I feel I have nothing to look forward to
    3 I feel the future is hopeless and that things cannot improve

3. 0 I do not feel like a failure
    1 I feel I have failed more than average person
    2 As I look back on my life, all I can see is a lot of failures
    3 I feel I am a complete failure as a person

4. 0 I get as much satisfaction out of things as I used to
    1 I don’t enjoy things the way I used to
    2 I don’t get real satisfaction out of anything anymore
    3 I am dissatisfied or bored with everything

5. 0 I don’t feel particularly guilty
    1 I feel guilty a good part of time
    2 I feel quite guilty most of time
    3 I feel guilty all of the time

6. 0 I don’t feel I am being punished
    1 I feel I may be punished
    2 I expect to be punished
    3 I feel I am being punished

7. 0 I don’t feel disappointment in myself
    1 I am disappointed with myself
    2 I am disgusted with myself
    3 I hate myself

8. 0 I don’t feel I am any worse than anybody else
    1 I am critical of myself for my weakness or mistakes
    2 I blame myself all the time for my faults
    3 I blame myself for everything bad that happens

9. 0 I don’t have any thoughts of killing myself
1. I have thoughts of killing myself, but I would not carry them out
2. I would like to kill myself
3. I would kill myself if I had the chance

10. 0 I don’t cry any more than usual
1. I cry more now than I used to
2. I cry all the time now
3. I used to be cry, but now I can’t cry even though I want to

11. 0 I am no more irritated by things than I ever was
1. I am slightly more irritated now than usual
2. I am quite annoyed or irritated a good deal of the time
3. I feel irritated all the time

12. 0 I have not lost interest in other people
1. I am less interested in other people than I used to be
2. I have lost most of my interest in other people
3. I have lost all of my interest in other people

13. 0 I make decisions about as well as I ever could
1. I put off making decisions more than I used to
2. I have greater difficulty in making decisions more than I used to
3. I can’t make decisions at all anytime

14. 0 I don’t feel that I look worse than I used to
1. I am worried that I am looking old or unattractive
2. I feel there are permanent changes in my appearance that make me look attractive
3. I believe that I look ugly

15. 0 I can work about as well as before
1. It takes an extra effort to get started at doing something
2. I have to push myself very hard to do anything
3. I can’t do any work at all

16. 0 I can sleep as well as usual
1. I don’t sleep as well as I used to
2. I wake up 1-2 hours earlier than usual and find it hard to get back to sleep
3. I wake up several hours earlier than I used to and cannot get back to sleep

17. 0 I don’t get more tired than usual
1. I get tired more easily than I used to
2. I get tired from doing almost anything
3. I am too tired to do anything
18. 0  My appetite is no worse than usual
     1  My appetite is not as good as it used to be
     2  My appetite is much worse now
     3  I have no appetite at all anymore

19. 0  I haven’t lost much weight, if any, lately
     1  I have lost more than five pounds
     2  I have lost more than ten pounds
     3  I have lost more than fifteen pounds

20. 0  I am no more worried about my health than usual
     1  I am worried about my physical problems like aches, pains, upset stomach
     2  I am very worried about physical problems and it’s hard to think of much else
     3  I am so worried about my physical problems that I cannot think of anything else

21. 0  I have not noticed any recent change in my interest in sex
     1  I am less interested in sex than I used to be
     2  I have almost no interest in sex
     3  I have lost interest in sex completely

Please add up all the scores from the 21 questions.

Total Score ________________