THE EFFECTS OF EXERCISE ON BDNF, MOOD, AND SLEEP QUALITY

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Abstract

Neurogenesis is the growth and regeneration of new or damaged neurons in the brain. This process is partially controlled by BDNF, which increases with exercise in rodents. Exercise improves recovery and decreases risk of developing neurodegenerative diseases. BDNF has only recently become easy to measure in humans, and rodent studies show both immediate and long term gains due to exercise. Exercise increases many different aspects of psychological well-being across a wide range of populations. However, these effects are less commonly studied in healthy, young adult populations. While exercise commonly improves mood, there is a possible mediating effect of sleep quality. This study intended to recreate these common effects in a population rarely represented in similar research while examining relationships between these effects. Participants included nine healthy college students who partook in a four-week running program running at least twice per week for 20 minutes each time. Questionnaires were filled out on the first and last days of the study, and saliva was collected to measure changes in BDNF. Significant improvements were found in sleep quality, negative affect, and general life satisfaction. Slight non-significant change was observed in long-term positive affect, and no change was observed in BDNF or immediate effects on mood. Results suggest that running is an effective way of improving sleep quality and long-term psychological well-being. However, there is no support that BDNF is a contributing factor to the positive effects of exercise on psychological well-being. Suggestions for further research are discussed.
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Background

A vast amount of literature over the years has examined how exercise affects the brain. Many studies examine the effects of exercise on emotion, well-being and physiological traits, and yet this field of research remains largely open. The proposed study will examine whether aerobic exercise, in the form of running on a track, results in improvements in subjective well-being, or changes in putative biological mediators of these effects of exercise. This study is a conceptual replication of previously demonstrated effects that is designed to assess the potential of exercise to meaningfully improve subjective well-being among healthy young adults.

“Adult neurogenesis” refers to the birth of new neurons in the brains of adult mammals (Kempermann, 2006). Before the 1960’s it was generally believed that no new neurons were born in the human brain after the age of about 12 (Kempermann, 2006). This postnatal neurogenesis is vastly different from adult neurogenesis in that it is occurring in the still-developing brain. Adult neurogenesis is unique and important because it is occurring in parts of the brain that have otherwise stopped development. Since then, neurogenesis has been observed in several brain areas, including the hippocampus (Altman, 1962) and the olfactory bulb (Kaplan & Hinds, 1977). Early research on neurogenesis was largely ignored until the identification in the early 1990’s of neuronal stem cells (the cells from which new neurons are derived) and of natural molecules in the brain that could increase or inhibit neurogenesis (Kilpatrick & Bartlett, 1993).

Neurogenesis is controlled and stimulated by neurotrophins, mainly brain-derived
neurotrophic factor (BDNF). Therefore, the current study will examine changes in BDNF in saliva before and after running. If BDNF expression were found to increase as a result of physical exercise, that would be indirect evidence that running increased neurogenesis in these research participants. The resulting new neurons and regeneration of damaged ones (another property of BDNF) could account for improvements in behavioral functioning.

One obstacle to examining and confirming effects of exercise is that ethical constraints on the use of human subjects can complicate investigation of underlying molecular mechanisms. On the most basic of levels, for research results to be meaningful, they must be replicable and generalizable to people other than the study participants. Children and the elderly have been studied in detail to determine the potential of exercise to improve the course of developmental or neurodegenerative disorders such as autism or dementia, but the age range between these groups, and the population of normally functioning brains (as opposed to disordered populations), has received less attention in research. Animal studies have proved to be very useful, but they are often focused on one narrow phenomenon and may not provide good models for some proposed exercise effects such as effects on mood or subjective well-being. These potential benefits of exercise on ‘higher level’ cognition and mood may one day form the basis of a first line therapy for depression, anxiety, and other common psychological disorders. For many reasons, exercise is extremely beneficial to physical health and fitness. However, because of these trends in early research, many of the reported findings about the relationship of exercise to neurogenesis, behavior change, and psychological change, cannot be
confidently generalized to healthy young adults.

The current study was primarily interested in whether exercise improves mood (subjective wellbeing) in healthy young people, and, if so, whether BDNF was an essential mediator of that effect. Participants were healthy college students not currently following a routine exercise program. The experimental intervention was a 4-week running program in which participants ran for 20 minutes at least twice per week. Salivary BDNF was measured before and immediately after running on the first and last days of the running program. Mood and sleep quality (examined as another potential mediator, along with BDNF, of the effect of exercise on mood) were measured before and after the 4-week program.
Background and Neurogenesis

Exercise affects many observable aspects of health and development. It improves
general health, including protection against neurodegenerative diseases, brain structure,
cognitive function, weight control, and physical fitness (e.g., Davis et al., 2011; Hamer &
Chida, 2009; Kramer & Erickson, 2007; Van der Borght, Havekes, Bos, Eggen, & Van
der Zee, 2007). Mood and psychological health are greatly influenced by exercise as well
(e.g., Thayer, Newman, & McClain, 1994). Exercise has both immediate and long-term
effects, and protects against psychological disorders such as Major Depressive Disorder
(e.g., Karege et al., 2002; Mata, Thompson, & Gotlib, 2010). Many biological
mechanisms and modifiers of these effects have been discovered as well, including
BDNF and sleep quality (e.g., Buman, Hekler, Bliwise, & King, 2011; McMorris, 2009).
Research clearly shows that exercise has important effects on psychological health, but
the mechanisms of exercise effects on psychological states have only recently begun to
be elucidated.

Most neurons in the brain are unable to grow back or be replaced if they die
(Gage, Kempermann, Palmer, Peterson, & Ray, 1998), but in several brain areas,
including the dentate gyrus and hippocampus, new neurons are born throughout adult life
in a process that is referred to as adult neurogenesis (Gage, 2000). This process is
controlled and stimulated by chemicals called neurotrophins, mainly nerve growth factor
and BDNF. BDNF it is a diffusible signaling molecule that is synthesized in the brain and
in several peripheral tissues including skeletal muscle and the salivary glands. Its
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synthesis is increased by acute exercise (Marais, Stein, & Daniels, 2009). BDNF is bound by the TrkB receptor, a membrane-bound metabotropic neurotransmitter receptor expressed widely in the brain (Huang & Reichardt, 2001; Vaynman, Ying, & Gomez-Pinilla, 2004). The neurogenic and synaptogenic effects of BDNF signaling have been under investigation for more than 10 years, although the cellular mechanisms of these effects are not yet fully known (Huang & Reichardt, 2001; Johnson & Mitchell, 2003).

The hippocampus begins to shrink in later stages of adulthood, resulting in impaired memory and sometimes neurodegenerative diseases (Erickson et al., 2011). Aerobic exercise training results in an increase of volume in the anterior hippocampus by two percent, effectively reversing the age-related degeneration of this structure in late adulthood by 1-2 years (Erickson et al., 2011). Similar structural and functional improvements in the brain due to physical activity at young ages (Chaddock et al., 2010a; Chaddock et al., 2010b) have huge educational implications to increase public health and awareness. Structural improvements in the brain due to the biological mechanisms of exercise could be a key to reducing the risk of developing neurodegenerative diseases.

Rodents have proved to be extremely important in laboratory experimentation in the field of neurogenesis because of the ability to examine them on a molecular level and control for variables that are difficult to control for in human studies. Laboratory rats and mice voluntarily engage in exercise when provided access to a running wheel in their cage. Running in rodents produces an immediate increase in neurogenesis, and neurogenesis levels remain elevated as long as exercise habits continue (Kerr & Swain, 2011; Rhodes et al., 2003; van Praag, 2008). Running also directly increases BDNF, and
the upregulation of BDNF due to exercise is linked to neurogenesis (Fabel et al., 2003; Trejo et al., 2001; Vaynman et al., 2004). New neurons play a role in important functions of the hippocampus, including regulation of addiction, stress, and emotions (Luu et al., 2012). With more control and greater insight into the mechanisms behind the changes, these results from rodent studies give us a unique approach to understanding neurocognitive plasticity of humans.

Long-term potentiation (a major cellular mechanism underlying learning and memory) was tested in groups of mice (van Praag, Christie, Sejnowski, & Gage, 1999), showing that exercise regulated synaptic plasticity and increased the number of maturing neurons, as well as led to improvements in memory acquisition, retention, and reversal learning (Van der Borght et al., 2007; van Praag et al., 1999). Exercise also enhances learning in aged mice (van Praag, Shubert, Zhao, & Gage, 2005), showing that these benefits can be observed at later stages in life. These improvements to cognition, especially in aged mice, are an example of how exercise may protect against the degeneration of neurons in aging humans, and neurogenesis may be an important underlying biological factor contributing to these improvements.

**Exercise Effects on General Health**

Evidence is sufficient to recommend exercise as a routine part of daily life (CDC, 2011). Cardiovascular exercise, which can be defined as large muscle movement over a sustained period of time keeping your heart rate to at least 50% of its maximum level (HealthStatus, 2013), lengthens life span (Reimers, Knapp, & Reimers, 2012), decreases risk of heart disease (Myers, 2003) and many other diseases (CDC, 2011), and slows the
progression of physical and cognitive decline with aging (Hamer & Chida, 2009). Many
general benefits of exercise have been known to medicine for decades, yet the research is
rarely focused on why these relationships exist and how they relate to more recently
recognized benefits of exercise (Kramer, Erickson, & McAuley, 2008).

Exercise Effects on Mood and Life Satisfaction

Several methods have been used to examine how exercise influences
psychological health, showing improvements after exercise to self-reported scales
measuring different aspects of mood or mood disorders (Hillman, Erickson, & Kramer,
2008; Johansson et al., 2011; Mata et al., 2010; Pimonow, 2010; Van der Borght et al.,
2007). Depression is unfortunately very common among college students (Furr,
Westefeld, McConnel, & Jenkins, 2001). Reasons can include social problems,
hopelessness, academic problems, difficulties adjusting, and interactive factors (Furr et
al., 2001). Genetic factors play a role in BDNF expression (Karege et al., 2002), and
physical activity protects against depressive symptoms in carriers of an allele linked to
Major Depressive Disorder (Mata et al., 2010). This combination of biology and
psychology contributes to our understanding of how exercise can protect the brain from
mental illness, as well as reduce existing symptoms related to these disorders.

The negative impact of stressors and stressful life events on health are negatively
correlated with levels of exercise (Brown & Siegel, 1988), suggesting that life stress may
be partially subdued by physical exercise. Psychological resilience has been reviewed in
quite a bit of detail with regards to exercise (Fletcher & Sarkar, 2013). Adversity and
positive adaptation to stressful events are two common aspects of psychological
resilience. The American Psychological Association (APA) gives ten ways to build psychological resilience. One of these ten ways is to exercise regularly (APA, 2013), indicating that exercise plays an acknowledged role in encouraging positive outcomes when faced with challenges and stressful events.

The hypothalamic-pituitary-adrenal (HPA) axis is a set of processes among the hypothalamus, the anterior pituitary, and the adrenal gland that make up an important part of the neuroendocrine system that regulates many bodily processes, including mood, and controls the body’s reaction to stress. The HPA axis starts by releasing corticotropin-releasing hormone (CRH) from the hypothalamus, and multiple factors, two of which are stress and physical activity, influence this release. The HPA axis adapts to intense physical training (e.g., athletes training for an ultramarathon), attenuating the cortisol response to stress (Wittert, Livesey, Espiner, & Donald, 1996). Implications from this research suggest that exercise training could be used to improve mood and alleviate and protect against symptoms of depression, stress, and anxiety (Strong, 2012).

Exercise has been reported in the past as the most effective behavior to regulate mood, raise energy, and reduce tension (Thayer et al., 1994). However, not all of the literature has found positive relationships between exercise and mood, with evidence suggesting that mood increases after low-intensity exercise, but actually decreases after high-intensity exercise (Steptoe & Cox, 1988). Recent research is much more consistent showing that aerobic exercise, as well as other forms of exercise, enhance mood and reduce anxiety (e.g., Caldwell, Emery, Harrison, & Greeson, 2011; Johansson, Hassmen, & Jouper, 2011; Kim & Leem, 2014), although methodological limitations may still
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preclude the consistency of conclusions (Stonerock, Hoffman, Smith, & Blumenthal, 2015). Many studies have small samples collected through convenience sampling, select subjects based on preexisting disorders, or admit to possible placebo effects. This prevents fair representation of populations and limits replicability of results.

The difficulty of beginning a new exercise routine can result in negative feelings such as discouragement and lack of motivation, and people sometimes associate these negative feelings with exercise itself. However, these negative feelings dissipate after establishing a routine (Ruby, Dunn, Perrino, Gillis, & Viel, 2011). Exercise effects on mood are significantly correlated with motivation to exercise in the future (Bryan, Hutchison, Seals, & Allen, 2007), essentially creating a positive feedback loop. Environment and company may be confounding variables when reporting mood change (Plante et al., 2007), but mood is consistently elevated through successive weeks of exercise (Steinberg et al., 1998). In agreement with all other topics discussed, regular maintenance of an exercise routine seems to be an incredibly effective way to promote greater psychological and physical health.

Therapists are more likely to discuss exercise with their clients if they exercise themselves (McEntee & Halgin, 1996). An estimated 10% of all mental health professionals recommend exercise (Walsh, 2011), and those 10% are the ones that keep up an exercise routine of their own. With the current literature and the direction of the field, it is surprising that more mental health professionals do not recommend exercise to patients, let alone exercise themselves, as it is an extremely cost-effective and efficient way to improve multiple aspects of mental health (Walsh, 2011). If aerobic exercise can
act as a protective buffer against depressive symptoms and other mood disorders, then successfully promoting this approach widely and early in life could improve epidemiological trends in these disorders.

Life satisfaction is one’s subjective assessment of all positive and negative aspects in their life to arrive at a conclusive representation of their satisfaction with their life as a whole (WHOQLAG, 1998). Physical activity improves life satisfaction in older adults (Elavsky et al., 2005; McAuley et al., 2006) and certain disabled or otherwise unhealthy populations (Motl, McAuley, Snook, & Gliattoni, 2009; Zanuso, Balducci, & Jimenez, 2009), but this relationship is less commonly studied in young adults and healthy populations. While a positive relationship still exists in young adults (Maher et al., 2013), the immediate effect after single bouts of exercise is studied more often than long-term effects (Miller, Bartholomew, & Springer, 2005; Raedeke, 2007).

College students in particular have an increased risk of a reduction in life satisfaction and an increase in life stressors (Gall, Evans, & Bellerose, 2000). Physical activity may protect college students against the harmful effects of these stressors and improve life satisfaction and psychological well-being (Bray & Born, 2004; Maher et al., 2013). Since life satisfaction is an assessment of positive and negative aspects of one’s life, it can provide a broad examination of exercise effects on affective states and how these states affect life satisfaction over the course of this study.

Accumulating evidence supports the notion that exercise has a profound effect on mood and well-being. However, there are flaws with the generalizability within this body of literature. Little research on the subject has been conducted with young adults
(Hillman et al., 2008) or healthy populations. In addition, differences in length, duration, and intensity of exercise are all possible confounding variables. Finally, there is a clear distinction between immediate effects and long-term effects in research, and little research examines both within the same population.

**Sleep Quality**

One important factor pertaining to health is sleep, including both the amount and quality of sleep. Certain amounts of sleep are necessary to optimize cognitive functioning, as well as improve emotional and physical functioning (Gruber, 2013). Specifically, sleep deprivation can impair specific aspects of brain functioning and well-being (LeDuc, Caldwell, & Ruyak, 2000). Consistent exercise does, however, improve sleep quality (Buman et al., 2011), and that improvement is sustained at least six months while exercise habits continue (Alfaris et al., 2015).

Exercise leads to improvements in both sleep quality and duration in patients with chronic sleep disorders (Passos et al., 2012), as well as improvements to quality of life and mood (Alfaris et al., 2015; Reid et al., 2010). Again, many effects of exercise on sleep quality are presented in specific disordered or otherwise abnormal populations. Insufficient sleep and poor sleep quality are overwhelmingly present in college students, and affected students reported lower physical and psychological health (Lund, Reider, Whiting, & Prichard, 2010). Exercise classes for college students resulted in an increase to sleep quality and mood, and a reduction in perceived stress (Caldwell et al., 2011), indicating that sleep quality may be an important variable affected by exercise, and a possible mediator in the effects of exercise on different aspects of psychological well-
Statement of the Problem

Aerobic exercise has been repeatedly shown to have beneficial effects on aspects of psychological well-being including mood. The current study aimed to demonstrate that effect in a group of healthy college students participating in a campus running club. The primary goal of the study was to evaluate whether or not a recreational running program in healthy young adults results in gains in well-being. If results supported the hypotheses, that would support the wider implementation of this program format as a strategy for promoting psychological well-being. College students provided a representation of young adults that could help extend the consistency of findings to a broader range of the population, although limited sample size precluded this generalizability.

Looking beyond representative samples and discrepancies in consistent findings, much of the research done in humans has only examined one or two aspects of psychological well-being. Further and more detailed examination, especially with relation to BDNF and neurogenesis, is mainly conducted in rodents or other species of non-human animals. The integration of a variety of measures of human participants provided more clear insight as to which aspects of well-being are affected by exercise.

While the primary purpose of this study was to examine the effects of exercise on well-being in college students, it was also to test the hypothesis that exercise increases circulating levels of BDNF in the saliva, both immediately and over the course of a month. Neurotransmitters and other biological signaling molecules affected by exercise
play a large role in the affective states and mood of an individual (Greenwood et al., 2003; Dishman, 1997; Strong, 2012). Relating exercise to these biomarkers is an important step in understanding how to apply this science for therapeutic goals. Since neurogenesis is virtually impossible to directly examine in humans, other methods, such as BDNF levels, which can be measured from blood or saliva, must be relied upon to study molecular mechanisms of exercise effects in people.

One very important limitation to research examining well-being and exercise in humans is the range of ages represented. With much of the research only examining the relationship in children or aging adults, a huge portion of the population is rarely represented. This study aimed to fill a portion of that gap to better determine if these findings hold throughout the human lifespan. If exercise does indeed improve well-being, we would still see this effect with college students and young adults.

It is commonly known that college students often do not get the recommended amount of sleep. Due to a variety of factors such as parties, stress, exams, and independence, it is not uncommon for college students to have unhealthy sleeping habits. Poor sleep or sleep deprivation can lead to a decline in well-being (Gruber, 2013). By supporting research that exercise improves sleep quality (Buman et al., 2011) and has an improving effect on well-being and mood, it would support the further implication that sleep quality may in part mediate the effect of exercise on mood.
Research Hypotheses and Rationale

Hypothesis 1

It was expected that aerobic exercise would increase circulating levels of BDNF in the saliva.

Hypothesis 1A. BDNF levels would be significantly elevated immediately after twenty minutes of running.

Hypothesis 1B. Pre-run levels of BDNF taken during the final meeting, after 4 weeks of the running program, would be significantly higher than pre-run levels of BDNF from the first session.

Rationale for Hypothesis 1

BDNF expression increases due to voluntary physical activity (e.g., Cotman & Berchtold, 2002). This increased expression was found to moderate psychological factors and mood (Karege et al., 2002), increasing motivation to exercise more (Bryan et al., 2007). Since BDNF promotes neuronal growth, regeneration, and neurogenesis (Johnson & Mitchell, 2003), this biomarker is supported as an indirect indication of neurogenesis in the human brain as a result of running. Running results in immediate increases to neurogenesis, and this increase is maintained as long as the running behavior continues (Kerr & Swain, 2011), indicating that BDNF may show both immediate and long-term effects.

Hypothesis 2

Exercise would significantly improve mood among a sample of healthy college students.
Hypothesis 2A. Participants would report significant change in the positive direction on the Subjective Exercise Experience Scale (SEES) from before to immediately after running for twenty minutes.

Hypothesis 2B. Participants’ scores on the NIH Toolbox positive affect scale of the psychological well-being subdomain would be significantly higher on the final day of testing, after 4 weeks of the running program, compared to the first measurement made before the running program began.

Hypothesis 2C. Participants’ scores on the NIH Toolbox sadness scale of the negative affect subdomain would be significantly lower on the final day it was measured compared to the first day it was measured.

Rationale for Hypothesis 2

Physical activity increases positive aspects and decreases negative aspects of mood (Johansson et al., 2011; Ruby et al., 2011; Thayer et al., 1994). Mood is also consistently increased, even over much longer experimental periods (Steinberg et al., 1998), showing that it is not only an acute effect. The current study will hopefully reinforce these findings, as literature on the longevity of these effects is limited. Increased positive aspects of mood can lead to greater motivation to exercise (Bryan et al., 2007), which could then lead to better adherence to a schedule, and finally, improve both psychological and physical health. The SEES was used because it was specifically designed to measure immediate changes in mood in physical activity settings (McAuley & Courneya, 1994), and the NIH Toolbox measured long-term effects.

Hypothesis 3
Running would improve general life satisfaction.

**Rationale for Hypothesis 3**

While less commonly studied with young, healthy populations, exercise improves quality of life and life satisfaction (Maher et al., 2013). Exercise improves positive aspects and decreases negative aspects of mood. Life satisfaction is partially determined by the consistency of these aspects over a period of time. The NIH Toolbox measure for life satisfaction examines a 30 day period, which is approximately the length of the intervention. Increasing positive aspects of mood and decreasing negative aspects of mood should result in an improvement to general life satisfaction.

**Hypothesis 4**

Exercise would improve sleep quality.

**Rationale for Hypothesis 4**

Sleep deprivation hinders cognitive functioning and affect aspects of psychological well-being (Gruber, 2013; LeDuc et al., 2000). Exercise improves sleep quality (Buman et al., 2011), protecting individuals who would otherwise be poor sleepers from the harmful effects of poor sleep. Poor sleep quality is common among college students (Lund et al., 2010), and an exercise routine can provide a fairly simple way to alleviate the negative symptoms of sleep deprivation and poor sleep quality.
Method

Participants

Participants were undergraduate students attending Humboldt State University ranging in age from 18-24 ($N = 9$, 5 male). Only five of the participants were present for the final meeting, so long-term effects had an even further reduced sample size. While three had had prior experience with running, all nine participants were not involved in any sort of exercise program at least 30 days prior to participating in the study. This information served as evidence to suggest the program as an actual increase in exercise habits for all participants.

An a priori power analysis for each hypothesis was run, indicating that 20-30 participants would be sufficient to detect significant change between most variables, due to relatively large expected effect sizes ($d > .8$). However, expected concentrations of BDNF suggested a higher number of participants (estimated around 50) would be necessary. Time constraints prevented the ability of continued testing, and analyses were ran with the data that had been collected.

Multiple recruitment strategies were used. An announcement for the study was set up on the psychology department research pool webpage, announcements were made in various psychology and kinesiology classes, and fliers were passed out in classes and posted on billboards around campus. Participants were also recruited from a student running club on campus. All recruitment strategies emphasized that no running experience was necessary, and beginners were encouraged to join. It was also made clear that participation in the study was completely voluntary.
Instrumentation

A consent form specifically detailing the purpose, procedure, timeline, risks, benefits, and researcher contact information was given to each potential participant to sign. A release of liability form was also given and signed before basic demographic information was collected. These demographics included age and sex, but no identifying information that could be used to selectively publicize results.

Health and exercise history questionnaire. A Health and Exercise History Questionnaire (HEHQ; Hansen, Stevens, & Coast, 2001) was administered (see Appendix A). This was used as a screening measure to ensure that the participants were prepared for physical exercise and had no known health problems that could have become an issue during testing. The HEHQ also asked if participants had experienced any traumatic or exhilarating events in recent memory to ensure that emotional life events did not affect the data.

Human BDNF sandwich ELISA kit. BDNF was measured in the saliva through a BDNF sandwich ELISA immunoassay kit. Measurement of BDNF from saliva is a relatively newer technique, but has been validated in a recent methodological study (Mandel, Ozdener, & Utermohlen, 2011). The salivary immunoassay kit was easy to use with simple collection and data analysis. The Human BDNF sandwich ELISA kit sold by Millipore (catalog number CYT306) was used.

Subjective exercise experience scale. Immediate effects of exercise on mood were measured with the Subjective Exercise Experiences Scale (SEES; see Appendix E). The SEES measures positive well-being, psychological distress, and fatigue. It is a 12-
item scale where each item is scored on a scale ranging from 1 (not at all) to 7 (very much so). Significant correlations were found between the SEES and the Positive and Negative Affect Schedule (PANAS) in regards to positive well-being and psychological distress. The PANAS, as well as the Profile on Mood States (POMS) are popular instruments measuring constructs of mood. However, these measures may have limited use in physical activity settings and rely heavily on negative emotions, whereas the SEES measures more positive emotions (Gill & Williams, 2008). The decision to use the SEES was ultimately based on the fact that it was specifically designed to measure immediate effects of exercise on mood (McAuley & Courneya, 1994), one of the main effects hypothesized in the present study.

NIH toolbox. To measure long-term effects of exercise on mood, the National Institutes of Health Toolbox for the Assessment of Neurological and Behavioral Function, or NIH Toolbox for short, was used. This relatively new and comprehensive kit for measuring functioning was specifically designed to measure four major components of human functioning: motor abilities, emotion, sensation, and cognition across a diverse range of study designs and settings (National Institutes of Health & Northwestern University, 2012). Within the emotion domain, scales from two subdomains were used: psychological well-being and negative affect. The general life satisfaction (see Appendix D) and positive affect (see Appendix B) measures were used from the psychological well-being subdomain. The sadness (see Appendix C) measure was used from the negative affect subdomain. All three measures are 10- to 34-item scales with each item scored on a 5-7 point Likert-type scale. The NIH Toolbox emotion measures focus on
feelings over the past seven days or thirty days, in contrast to immediate effects of exercise on mood.

**Pittsburgh sleep quality index.** Sleep quality was measured with the Pittsburgh Sleep Quality Index (PSQI). This self-reported 24 question measure asks questions about sleep latency, disturbance, duration, efficiency, and other subconstructs of sleep quality. Detailed scoring instructions were provided with the measure and followed to obtain one final score between zero and 21. A score of five or below indicates good sleep, while a score above five is associated with poor sleep quality.

**Running Program**

Running sessions were conducted twice per week at the same time of day on the track at the Humboldt State University football field. The experiment lasted 4 weeks for a total of 8 running sessions. In one instance, the meeting was rescheduled due to rain for later in the week. Sessions were held outside because mood is often increased more when exercising outdoors as opposed to indoors (Plante et al., 2007). All running sessions were held during hours in which the gym was open, so a first aid responder was available should they be needed. Additionally, a first aid kit was available on site in the case of an injury. Participants were told to continue their daily routines outside of these meetings to ensure that these sessions serve as an increase in exercise, regardless of previous activity level.

**Procedure**

This study was conducted as a true pre-test/post-test within subjects experiment, although the sample size was small, reducing interpretability. Once participants were
recruited, they were told the location and day/time to meet for the first session, where they were informed of the purpose of the study and filled out the consent and liability forms as well as the HEHQ screening assessment. On the questionnaire packet with the rest of the measures, each participant was assigned a packet identification number and the researchers recorded the number. This number was used to keep all materials together for each individual throughout the course of the study.

At this time, participants filled out the questionnaire packets containing the PSQI and all three measures from the NIH Toolbox emotion battery to establish baseline levels of well-being and sleep quality. Upon completion of the questionnaires, the first saliva sample was collected. Once all of the pre-intervention baseline data had been collected, participants were taken out to the track while a research assistant took the saliva samples to a freezer for storage. Participants then filled out the first iteration of the SEES and prepared to run. A timer was started and participants began to run. The second saliva sample tubes and SEES forms were then prepared with ID numbers by the researcher. Once the 20 minutes had expired, participants were told to get a quick drink of water and cool down. A new timer was started so that saliva samples would not be collected within 10 minutes of drinking water, as per guidelines of the BDNF assay kit. After cooling down, runners filled out the post-run SEES, and collected a second sample of saliva after the ten minutes had passed.

Participants were then encouraged to exercise outside of meetings to an amount that was consistent with what they were doing before beginning participation in the experiment, though none of them reported consistent exercise leading up to the study.
They were also told to keep track of how much they exercised outside of the experiment meetings. The group continued to meet two times per week for one half hour per session. The first and final sessions were extended to one hour so that the questionnaire packets could be administered and saliva samples could be collected.

During the subsequent half-hour sessions, the group met on the track at Humboldt State University and was reminded of where to get water or first aid. Participants ran for 20 minutes until they were told to stop by the researcher. The final session was identical to the first session, minus the consent, liability, and screening assessment forms. All biological samples were immediately taken to a freezer to be stored at -80 degrees Celsius until they were ready to be analyzed. Mood and BDNF were measured before and after exercise on the first and last day of the 4-week course, allowing both short and long term effects of exercise to be evaluated.

Safety being the number one concern, it was left up to the participant to determine how fast they ran and when they needed to walk for a break. However, they were encouraged to run the entire time and to run as hard as they felt comfortable doing. Participants were also shown the Ratings of Perceived Exertion (RPE) scale and given a measurable level of exertion to strive for throughout the run. However, this was mainly for self-monitoring, and levels of exertion were not recorded.

Upon completion of the study, participants were thanked for their participation and their participation was recorded for extra credit if they were enrolled in psychology courses that allowed extra credit for participating in research.

Data Analyses
Salivary BDNF was measured by following the instruction manual for the sandwich ELISA kit. By following the kit, samples and standards with known concentrations of BDNF were collected alongside BDNF in wells of a microplate and read by a Biotek ELx800 absorbance microplate reader. A spreadsheet was generated of absorbance levels at 450 nm. Linear regression analysis was used with the known concentrations of the BDNF standard to generate a standard curve to obtain concentration levels of BDNF in each sample from the light absorbance reading. These concentration levels were then compared using paired samples $t$-tests to determine whether or not BDNF levels were significantly higher immediately after running or whether baseline levels of BDNF were higher by the end of the study than they were at the beginning of the study.

Scores on the SEES were separated into the three provided subconstructs and added up to obtain a sum score for each construct. Results were then analyzed with paired samples $t$-test to determine the short-term effects of the 20-minute run on mood. The 34-question positive affect measure and the 27-question sadness measure were analyzed by averaging the summation of responses and compared with paired samples $t$-tests. The measure of general life satisfaction was analyzed by summing the total responses and compared with another paired sample $t$-test.

Detailed instructions for scoring were provided with the PSQI, and those instructions were followed closely. Once final scores were obtained, a paired samples $t$-test was conducted to determine the effect of the intervention on sleep quality. A multiple regression analysis would have been run to determine if sleep quality had a mediating...
effect on the relationship between exercise and mood; however, the sample size was too small and there was no variability in the number of times participants exercised.

Paired samples $t$-tests were chosen over repeated measures ANOVA because no test required more than two comparison times. Cohen's $d$ statistics were then measured for estimates of effect sizes. Results ranged from medium to very large.
Results

Effects on BDNF

The first two tests related to the immediate and long-term effects of exercise on BDNF concentration (pg/ml) in the saliva. Very small differences in concentration were observed in either immediate or long-term relationships. In contrast to hypothesis 1, there was no change in BDNF concentration from a single run ($t(7) = 1.14, p = .293, d = 0.402$) or four weeks of consistent exercise ($t(4) = -1.59, p = .186, d = -0.713$). Because these data did not fit assumptions of normality and variances were unequal from pretest to posttest, nonparametric tests were run as well. Wilcoxon signed rank tests also resulted in a failure to reject the null hypotheses for both short ($Z = 1.26, p = .208$) and long-term ($Z = 1.21, p = .225$) effects. As indicated by the power analysis, a much larger sample size would have been required to observe any significant change. As such, the present results indicate that exercise did not lead to any significant change in salivary BDNF concentration. Results from paired samples t-tests are found in Table 1.

Immediate and Long-Term Effects on Mood

Mood was examined with three separate tests, as mentioned in hypothesis 2. The first paired samples t-test was designed to examine an immediate change in mood after running for twenty minutes. Inconsistent with hypothesis 2A, there was no significant change between scores before ($M = 19.00, SD = 3.43$) and after ($M = 21.33, SD = 5.96$) a single session of running for the psychological well-being subconstruct ($t(8) = 1.61, p = .147, d = 0.535$). No change was observed between the psychological distress ($t(8) = -.206, p = .842, d = 0.069$) or fatigue ($t(8) = 1.18, p = .273, d = 0.392$) subconstructs.
Table 1

*Paired Samples t-tests of BDNF, Mood, and Sleep Quality*

<table>
<thead>
<tr>
<th>Variable</th>
<th>Before</th>
<th>After</th>
<th>t</th>
<th>df</th>
<th>p</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Immediate BDNF</td>
<td>-28.77</td>
<td>-18.38</td>
<td>1.14</td>
<td>7</td>
<td>.293</td>
<td>0.402</td>
</tr>
<tr>
<td>Long-term BDNF</td>
<td>-27.43</td>
<td>-33.30</td>
<td>-1.59</td>
<td>4</td>
<td>.186</td>
<td>-0.713</td>
</tr>
<tr>
<td>Immediate Effects on Mood</td>
<td>19.00</td>
<td>21.33</td>
<td>1.61</td>
<td>8</td>
<td>.147</td>
<td>0.535</td>
</tr>
<tr>
<td>Positive Affect</td>
<td>4.14</td>
<td>4.39</td>
<td>2.53</td>
<td>4</td>
<td>.065</td>
<td>1.131</td>
</tr>
<tr>
<td>Negative Affect</td>
<td>1.74</td>
<td>1.37</td>
<td>5.42</td>
<td>4</td>
<td>.006</td>
<td>2.425</td>
</tr>
<tr>
<td>General Life Satisfaction</td>
<td>47.80</td>
<td>52.20</td>
<td>4.09</td>
<td>4</td>
<td>.015</td>
<td>1.827</td>
</tr>
<tr>
<td>Sleep Quality</td>
<td>5.40</td>
<td>3.20</td>
<td>3.77</td>
<td>4</td>
<td>.020</td>
<td>1.687</td>
</tr>
</tbody>
</table>

*Note.* Negative BDNF concentrations obtained through regression analysis of light absorbance compared to a known BDNF standard concentration.
either. To account for unequal variances, nonparametric tests were run with these data, and a Wilcoxon signed rank test indicated a failure to reject the null hypothesis as well ($Z = 1.36, p = .176$), suggesting no immediate change in mood due to exercise. Descriptive statistics, including mean and standard deviation of each group, are found in Table 1.

The second test examined effects of the entire intervention on positive affect, concurrent with hypothesis 2B. In partial support of this hypothesis, averaged scores of positive affect were slightly elevated after the intervention ($M = 4.39, SD = 0.49$) compared to before the intervention ($M = 4.14, SD = 0.63$), but not significantly ($t(4) = 2.53, p = .065, d = 1.131$). While change of positive affect in the present sample was non-significant, it is noteworthy that each participant reported a positive change of some magnitude. The smallest increase was from 4.82 to 4.88, however most of the scores were improved by at least 0.20. Another interesting point to note is that the four participants who did not show up for the final meeting were the four with the lowest starting scores for positive affect.

Hypothesis 2C indicated an expected decrease in negative affect due to a long-term exercise program. Scores on the sadness scale were significantly lower at the end of the study ($M = 1.37, SD = 0.20$) than they were at the beginning ($M = 1.74, SD = 0.34$) of the study ($t(4) = 5.42, p = .006, d = 2.425$), supporting hypothesis 2C. Each participant noted a decrease in negative affect, and these results do not seem to be skewed by one score dropping substantially. The two smallest decreases were from the two smallest starting scores, so there wasn’t as much room to improve. The other three all reduced in negative affect by a similar margin. Similar to positive affect, three of the four
participants who did not make the final meeting had the three highest pre-test scores for this construct. These results indicate that exercise did not produce an immediate effect on mood; however, a much more noticeable change occurred when exercise habits are sustained over a longer period of time.

**Effects on General Life Satisfaction**

Another measured construct of psychological well-being was general life satisfaction. Participants reported significantly higher ratings of life satisfaction after the intervention ($M = 52.20, SD = 4.15$) than before ($M = 47.80, SD = 5.12$) the intervention ($t(4) = 4.09, p = .015, d = 1.827$). A Wilcoxon signed rank test was run to account for possible variance here as well, and the results still indicated a rejection of the null hypothesis ($Z = 2.04, p = .041$). This suggests that general life satisfaction is improved by consistent exercise, supporting hypothesis 3. The strength of which life satisfaction was improved is also supported by the results of an increase to positive affect (though non-significant) and a decrease to negative affect, as this is one definition of general life satisfaction. Also similar to positive and negative affect, each participant reported an increase to life satisfaction over the course of the study. While one participant only reported a small increase (47 to 49), the rest improved by a larger margin. Again, the four lowest pre-test scores corresponded to the four who did not complete the program.

**Effects on Sleep Quality**

Sleep quality was totaled on a scale of 0-21, with scores five or below indicating good sleep quality and scores above five indicating poor sleep quality. Sleep quality score at the end of the study ($M = 3.20, SD = 0.45$) was significantly lower than at the
beginning of the study ($M = 5.40, SD = 1.34$), indicating that there was an improvement in sleep ($t(4) = 3.77, p = .020, d = 1.687$). This is consistent with hypothesis 4, although sleep quality as a mediator was unable to be tested. However, correlations were examined to determine if there is some sort of relationships between the variables involved in mediation. The previously reported results show that exercise had a long-term effect on both mood ($t(4) = 5.42, p = .006$) and sleep quality ($t(4) = 3.77, p = .020$) individually; the first two steps in determining mediation. When accounting for exercise, sleep quality was still related to mood ($r = .917, p = .029$), further suggesting that mediation might indeed be involved.

It is also interesting to note that three of the five participants who completed both sleep quality surveys crossed the threshold from poor to good sleep quality over the course of the study. The other two began the program with scores of 4 and improved to having scores of 3. As with all measures of long-term mood effects, the four respondents who did not complete the final questionnaire packets had the four worst starting sleep quality scores. Table 1 summarizes the results discussed in this section.
Discussion

The current study aimed to examine the effect of a specific exercise regime on different measures of psychological well-being, BDNF, and sleep quality. While some key methodological limitations prevent all the findings reported from being generalizable, there are still some important contributions to the current body of literature. The importance of results, significant or non-significant, will be discussed along with limitations of the present study and suggestions for future research.

A comprehensive interpretation of results suggests that consistent exercise, sustained over a period of time, improves psychological well-being and sleep quality. Mood does not increase immediately as a result of exercise, and there is not enough evidence to support the notion that exercise has a significant effect on levels of salivary BDNF. However, the lack of support from the current study speaks more to the limitations present than it does to the relationship between the variables. Effect sizes were all medium or better. The three significant results showed large to very large effect sizes, indicating that these results have substantive meaning as well as statistical significance. While certain hypotheses achieved stronger support than others, this study did help to broaden the relationships to a portion of the population that is rarely represented in similar research. Similarly, it was able to examine both short- and long-term effects within the same sample.

Observing no change in BDNF levels was somewhat surprising given the consistent findings supporting the relationship in the literature. Showing an immediate or long-term increase in salivary BDNF due to exercise would have provided valuable
insight as to the possible biological mechanisms contributing to gains in other measures of brain and behavioral functioning. However, a lack of support from the current results does not mean that salivary levels of BDNF cannot be elevated after running in humans, as this was the analysis most impacted by technical and methodological limitations, which are discussed in detail in the limitations section. Additionally, the concentrations found do not vary greatly from previous research examining salivary BDNF. While salivary concentrations typically range from 35pg/ml to 60pg/ml (Saruta, Fujino, To, & Tsukinoki, 2012), there is a considerable amount of individual variability (Mandel et al., 2011), indicating that the measurement was likely still done correctly.

By finding support that regular exercise for one month improves psychological well-being, specifically by decreasing negative affect and increasing general life satisfaction, there are many implications to clinical and educational settings. If running for 20 minutes two times per week for four weeks is enough to produce significant improvement in these aspects of well-being, educators, clinicians, and many others can recommend simple, cheap, and effective programs that do not require much time or effort. While these findings were significant, it is important to keep in mind the low sample size and the difficulty to generalize these findings to the entire college student population, as only a tiny portion was represented. Additionally, while positive affect was not significantly changed, there were improvements in each participant’s score, indicating that a longer intervention or a larger sample size may have produced significant results. Regardless, significant findings to two constructs of mood and well-being in such a small sample may indicate that the effect size may be quite large if it is actually real.
No short-term change was observed in mood. One possible reason for this includes the short time between the two administrations of the SEES. While it is designed to measure immediate changes in mood while accounting for fatigue, the test was given twice in a 30-minute period, and the 20-minute run may not have provided adequate time for a change in mood to take effect. Another possible contributing factor is the number of questions in the psychological well-being construct of the measure, as it may have not been broad enough to get a sufficient grasp on the degree of change in the construct.

The results from analyses on sleep quality were possibly the most interesting. Sixty percent of the respondents began the study with a score that qualified them as having poor sleep quality, and finished the study with good sleep quality. The rest of the respondents began the study with good sleep quality, and improved even more. These findings not only support the growing body of literature on sleep quality, but also offer some valuable insight on just how important sleep quality and exercise may be in improving healthy psychological functioning. The possibility of mediating effects of sleep quality remains a question to study further, as there is already evidence suggesting the impact of sleep quality on mood and cognitive functioning. Additionally, sleep quality was correlated with mood even when exercise is accounted for, showing that there is a relationship to be examined further. If sleep quality is a key mediator in the relationship between exercise and well-being, this knowledge could be exploited to design more effective mood interventions.

One of the most interesting results was the scores of participants who did not finish the running program. In every significant relationship, the four worst scores
(lowest life satisfaction, highest negative affect, and poorest sleep quality) belonged to the four who did not complete the study. With positive affect, only one participant who did complete the study scored in between the four who did not, while everybody else began the experiment with higher positive affect. It is interesting that the four who could theoretically benefit the most from these hypothesized effects of exercise are the ones who did not continue to exercise. This information could be useful when designing programs to help people exercise, as motivation to continue may be more important to those who can benefit the most. It also presents the idea that maybe those who aren’t happy see exercise as more of a task, making them less happy so they stop. Either way, this information is valuable in determining who can benefit the most from exercise effects on psychological well-being and how to motivate people to continue to exercise.

This study expanded previous findings to a broader range of the general population, as not much related research had been done on healthy college students. If educators were able to extend the beneficial facts of exercise to include benefits to mood and psychological well-being, many more people may decide to exercise on a regular basis. Discovering biological processes behind these changes could have had major implications for pharmaceutical companies, and further research is suggested to continue examining these relationships.

Limitations and Strengths

There were a number of limitations to this study. Most importantly, the sample size was very small, resulting in a lack of generalizability and the probability of committing a type II error high. The most likely reason for this is the difficulty of getting
college students to commit to a four-week program amidst their busy schedules. Additionally, there was a high attrition rate, reducing the already low sample size even lower for long-term effects.

It is also possible that the timing of this study played a critical role in both the attrition rate and the number of people who agreed to participate in the first place. The study began late in the semester, with the final week falling on the last week of classes. It is expected that the extra stress of finishing classes and preparing for finals factored into some people deciding they could not continue participating in the study. With summer vacation approaching, people are also less likely to be looking for a new club to join or study to get involved in.

The timing of the study may have had another impact to the interpretability of results. The last four weeks of a semester in school can produce some confounding variables. The individual variability in class schedule could partially account for individual differences stress levels, sleeping habits, mood, and many other variables of this nature. For example, if one student had an easy finals week, he/she may report better life satisfaction or mood than a student who has to prepare for five difficult finals. Similarly, a student’s relative workload towards the end of the semester can play a large role in the amount of sleep he/she gets or the disturbance in his/her sleep. However, it would be expected that the end of the semester would produce greater stress, lowered mood, and poorer sleep quality in students. Considering that the results indicate the opposite effects, it is unlikely that changes in scores were due to the four-week period that this study was conducted.
One important methodological limitation is the possibility that the scope of the study was too large. Instead of trying to get as much information about as many different constructs as possible, a more narrowed focus on specific primary hypotheses could have been beneficial. Since neurogenesis was a large conceptual driver in conducting this study, it may have been better to focus on just the effects of running on BDNF and not include the mood and sleep quality components. It would be helpful to demonstrate effects of one hypothesis before examining the relationship on multiple effects working together.

With regards to sleep quality as a mediating variable, the hypothesis could not be properly examined with the study’s current design. The design focused on whether or not participants exercised a certain number of times rather than obtaining an easily quantifiable number of times exercised. Because that variable was obtained in categorical responses and the sample size was so low, there was no variability in the independent variable, making a regression analysis impossible to interpret.

One technical limitation to the study was with the collection and storage of saliva samples. According to the assay kit used to analyze BDNF concentration, saliva samples are supposed to be analyzed immediately after collection for best results. However, freezer storage is recommended if samples are unable to be analyzed immediately. While all guidelines were followed with regards to the freezing and storing of samples, it is possible that this played into not finding a change in BDNF concentration. One example of this is the recommended avoidance of repeated freeze-thaw cycles. The first attempt at preparing thawed samples was ruined by a researcher error in overdiluting the thawed
samples. Since the original samples had already been replaced in the freezer, they were refrozen, leading to a repeated freeze-thaw cycle to gather new thawed samples for analysis.

As this was our first time running a new assay kit, there is a possibility of small researcher errors, leading to a reduced probability of finding accurate results. The specific kit being used was originally made for detecting BDNF in blood samples, though since the discovery of BDNF in saliva, has been validated to work with any biological sample. However, salivary concentrations of BDNF are often low (35-60 pg/ml), especially relative to concentrations in the blood (>200 pg/ml; Saruta et al., 2012). The concentrations of BDNF are obtained by comparing light absorption ratings of samples to light absorption ratings of known concentrations of BDNF through a linear regression equation. The assay kit detection range is relatively high (15-1000 pg/ml) and the known concentrations used to create the regression equation span the entire detection range, causing the total range of detectable concentrations in samples to fall within the lower ten percent of the regression line. Because of this, the linear regression equation produced some negative results, reducing interpretability and possibly accuracy of results.

While many limitations to this study admittedly exist, there are several strengths as well, and the results found should not be disregarded. Certain populations receive much more attention in related research, and this study examined a population that is rarely represented. The broad scope of this study was mentioned as a limitation, but it serves as a key strength as well. By finding multiple significant relationships in one study, we get a closer look at the scope of the effects of exercise, and what may be more
or less affected by it. A large scope also provides information on possible biological or behavioral mechanisms of these effects. The late-semester timing of the study may serve as a strength as well. Finding a significant decrease in negative affect and increase in life satisfaction and sleep quality would logically be the opposite expected effect that ending a semester would have on well-being. It is possible that conducting this study in the middle or beginning of the semester may produce even more significant effects.

**Recommendations for Future Research**

This study leaves many recommendations for future research. Firstly, further study is recommended on the effects of exercise on salivary BDNF. While this effect is largely supported in rodent studies, it is still relatively new in human research, and its effects may be critical to understanding the biological reasons exercise affects so many aspects of brain functioning. If research shows consistent support for this relationship, it would then open the door for examining BDNF as a biological mediator of the effects of exercise. It is also recommended that further effects of sleep quality as a mediator is examined. There is strong support that exercise improves sleep quality and psychological well-being, and sleep quality improves psychological well-being. There is not as much support showing the relationship of all three together. Finally, it is important to continue research on both short- and long-term effects of exercise on mood, as more and more support could lead to simple, cheap, and effective clinical and educational tools for treatment of negative mood symptoms.

**Conclusion**

Ever growing support for the beneficial effects of exercise add to the existing
body of literature recommending exercise as a part of everyday life. Although much is already known, there is plenty more to learn, and continued research is always necessary to expand the limits of what is known. Exercise may have a larger impact on well-being when sustained over a long period of time compared to a single session. Additionally, sleep quality plays an important role in the health of an individual, and exercise clearly improves sleep quality. Whether sleep quality mediates the relationship between exercise and well-being is still a question. More research is required before BDNF is determined to be an important biological mechanism behind these effects, but evidence is more than sufficient to recommend regular exercise to healthy young adults.
EFFECTS OF EXERCISE ON BDNF AND WELL-BEING

References


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Neuroscience, 126, 381-391. doi: 10.1037/a0028252


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Steinberg, H., Nicholls, B. R., Skyes, E. A., LeBoutillie, N., Ramlakhan, N., Moss, T. P.,
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*European Psychologist, 3,* 271-280. doi: 10.1027/1016-9040.3.4.271


### Data Collection Sheet

**NAME:** __________________________________________  **DATE:** __________________

**HEIGHT:** _______ in.  **WEIGHT:** _______ lbs.  **AGE:** ________  **PHYSICIANS**

**NAME:** __________________________________________  **PHONE:** ____________

### PHYSICAL ACTIVITY READINESS QUESTIONNAIRE (PAR-Q)

<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.*
On the next few pages, we will ask you questions about your thoughts, feelings and behaviors. Read each question carefully and answer as well as you can. There is no right or wrong answer, only what is true for you and describes your thoughts, feelings, and behaviors. Some questions may seem like ones you have already answered. This is on purpose. Please think about each question by itself and choose the answer that shows how you behave or what you really feel or believe.

**In the past 7 days:**

<table>
<thead>
<tr>
<th></th>
<th>Not at all</th>
<th>A little bit</th>
<th>Somewhat</th>
<th>Quite a bit</th>
<th>Very much</th>
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<tbody>
<tr>
<td>I felt cheerful.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I felt attentive.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I felt relaxed.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
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<tr>
<td>I felt delighted.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I felt inspired.</td>
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<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
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<td>2</td>
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<td>4</td>
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</tr>
<tr>
<td>I felt happy.</td>
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<td>2</td>
<td>3</td>
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<td>5</td>
</tr>
<tr>
<td>I felt joyful.</td>
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<td>4</td>
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<tr>
<td>I felt excited.</td>
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<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
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<tr>
<td>I felt proud.</td>
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<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
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<tr>
<td>I felt lively.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
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<tr>
<td>I felt at ease.</td>
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<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
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<tr>
<td>I felt enthusiastic.</td>
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<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I felt determined.</td>
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<td>2</td>
<td>3</td>
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<td>5</td>
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<tr>
<td>I felt interested.</td>
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<td>2</td>
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<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I felt confident.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I felt able to concentrate.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I was thinking creatively.</td>
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<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I liked myself.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>My future looked good.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>------------------------------------------</td>
<td>---</td>
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<td>---</td>
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<td>---</td>
</tr>
<tr>
<td>I smiled and laughed a lot.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
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</tr>
<tr>
<td>I felt peaceful.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I was able to reach down deep into myself for comfort.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I felt a sense of harmony within myself.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I generally enjoyed the things I did.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I felt lighthearted.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I felt satisfied.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I felt good-natured.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I felt useful.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I felt optimistic.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I felt interested in other people.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I felt understood.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I felt grateful.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I felt content.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>
### Appendix C

**In the past 7 days:**

<table>
<thead>
<tr>
<th></th>
<th>Never</th>
<th>Rarely</th>
<th>Sometimes</th>
<th>Often</th>
<th>Always</th>
</tr>
</thead>
<tbody>
<tr>
<td>I felt worthless.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I felt that I had nothing to look forward to.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I felt helpless.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I withdrew from other people.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I felt that nothing could cheer me up.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I felt that I was not as good as other people.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I felt sad.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I felt that I wanted to give up on everything.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I felt that I was to blame for things.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I felt like a failure.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I had trouble feeling close to people.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I felt disappointed in myself.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I felt that I was not needed.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I felt lonely.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I felt depressed.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I had trouble making decisions.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Feeling</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>------------------------------------------------------------------------</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>I felt discouraged about the future.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I found that things in my life were overwhelming.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I felt unhappy.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I felt I had no reason for living.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I felt ignored by people.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I felt upset for no reason.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I felt that nothing was interesting.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I felt pessimistic.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I felt that my life was empty.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I felt guilty.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I felt emotionally exhausted.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>
For the next set of questions, please indicate how much you agree or disagree with each statement.

1. In most ways, my life is close to perfect.
   | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
   | Strongly disagree | Disagree | Slightly disagree | Neither agree nor disagree | Slightly agree | Agree | Strongly agree |

2. If I could live my life over, I would change almost nothing.
   | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
   | Strongly disagree | Disagree | Slightly disagree | Neither agree nor disagree | Slightly agree | Agree | Strongly agree |

3. I am satisfied with my life.
   | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
   | Strongly disagree | Disagree | Slightly disagree | Neither agree nor disagree | Slightly agree | Agree | Strongly agree |

4. So far I have gotten the important things I want in life.
   | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
   | Strongly disagree | Disagree | Slightly disagree | Neither agree nor disagree | Slightly agree | Agree | Strongly agree |

5. My life situation is excellent.
   | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
   | Strongly disagree | Disagree | Slightly disagree | Neither agree nor disagree | Slightly agree | Agree | Strongly agree |

6. My life is going well.
   | 1 | 2 | 3 | 4 | 5 |
   | Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |

7. My life is just right.
   | 1 | 2 | 3 | 4 | 5 |
   | Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |

8. I wish I had a different kind of life.
   | 1 | 2 | 3 | 4 | 5 |
   | Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |
9. I have a good life.
   1   2   3   4   5
   Strongly disagree  Disagree  Neither agree nor disagree  Agree  Strongly agree

10. I have what I want in life.
    1   2   3   4   5
   Strongly disagree  Disagree  Neither agree nor disagree  Agree  Strongly agree
Appendix E

How Do You Feel?

This inventory contains a number of items designed to reflect how you feel at this particular moment in time (i.e., Right Now). Please circle the number on each item that indicates HOW YOU FEEL RIGHT NOW.

I FEEL:

1. Great
   not at all
   1  2  3  4  5  6  7
   moderately very much so

2. Awful
   not at all
   1  2  3  4  5  6  7
   moderately very much so

3. Drained
   not at all
   1  2  3  4  5  6  7
   moderately very much so

4. Positive
   not at all
   1  2  3  4  5  6  7
   moderately very much so

5. Crummy
   not at all
   1  2  3  4  5  6  7
   moderately very much so

6. Exhausted
   not at all
   1  2  3  4  5  6  7
   moderately very much so

7. Strong
   not at all
   1  2  3  4  5  6  7
   moderately very much so

8. Discouraged
   not at all
   1  2  3  4  5  6  7
   moderately very much so

9. Fatigued
   not at all
   1  2  3  4  5  6  7
   moderately very much so

10. Terrific
    not at all
    1  2  3  4  5  6  7
    moderately very much so
<table>
<thead>
<tr>
<th></th>
<th>Miserable</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>not at all</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>11</td>
<td>moderately</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>very much so</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tired</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>not at all</td>
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<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
</tr>
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<td></td>
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</tr>
<tr>
<td></td>
<td>very much so</td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>