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Original Research

Pilot Study of Endurance Runners and Brain Responses Associated with Delay Discounting

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ABSTRACT

International Journal of Exercise Science 10(5): 690-701, 2017. High levels of endurance training have been associated with potentially negative health outcomes and addictive-like symptoms such as exercise in the presence of injury and higher levels of impulsivity. This pilot study examined the relationships among self-report measures of addictive symptoms related to exercise and behavioral and neural measures of impulsivity in endurance runners. We hypothesized endurance runners would have increased preference for immediate rewards and greater activation of cognitive control regions when making decisions involving delayed rewards. Twenty endurance runners (at least 20 miles/week) were recruited to undergo measures of self-report exercise addiction symptoms, impulsive decision-making (delay discounting) and functional magnetic resonance imaging (fMRI). During behavioral and fMRI examinations, participants chose between a small hypothetical amount of money given immediately ($0 – 100) compared to a larger hypothetical amount of money ($100) given after a delay (2-12 weeks). On half of the trials participants were instructed that if they chose the delayed reward they would not be able to exercise during the delay period. Eighteen participants were included in the analysis. Results indicated that 94% of endurance runners reported high levels of exercise addiction symptoms, and 44% were "at-risk" for exercise addiction. In addition, endurance runners demonstrated increased preference for immediately available compared to delayed rewards ($p < 0.001$) and greater recruitment of cognitive control regions (dorsomedial prefrontal cortex and anterior cingulate) when making decisions involving rewards when exercise was delayed ($p < 0.05$). Together, these results indicate that endurance runners not only report addictive symptoms related to exercise, but also demonstrate addictive-like behaviors.

KEY WORDS: Impulsivity, delay-discounting, endurance training, running, monetary reward, cognitive control, brain imaging

INTRODUCTION

Exercise is generally considered to be healthy however only 51% of United States adults meet the physical activity guidelines that recommend 150 minutes of moderate intensity aerobic exercise per week (1, 24). On the other hand, endurance athletes sometimes show addictive-like symptoms involving exercise (6, 11, 18). These symptoms include, continuing to exercise despite negative outcomes, including physiological and psychosocial consequences. Symptoms can include addictive-like withdrawal from exercise and the inability to regulate exercise levels when they exceed healthy ranges (5, 20). Exercise addiction can be defined based on the same criteria used to define other addictive behaviors including, tolerance, withdrawal, lack of control, reduction in other rewarding activities, and continuance despite negative outcomes (20). For example, runners who 1) find they need to run more to experience the same positive psychological effects (e.g. runners high), 2) experience depression or irritability when unable to run, 3) find that running time interferes with other responsibilities (e.g. work, family, etc), or 4) exercise despite physical injury may have an addictive-like relationship with exercise. Measures of exercise addiction quantify the number and/or type of addictive symptoms in order to identify individuals who may be "at-risk" for exercise addiction (33). There is also some evidence from animal and human studies that females may be at higher risk for developing exercise addiction, however this is not consistent across all studies (14).

Impulsivity is a multidimensional personality characteristic that can lead to maladaptive decision-making and is a contributing factor to addictive behaviors (7, 12). Impulsivity can be measured behaviorally with an experimental paradigm known as delay discounting, which assesses how people weigh immediate rewards versus long-term consequences. Addictive populations (e.g. individuals who smoke cigarettes, gamble, use cocaine, engage in risky sexual behaviors, overeat, etc.) show a greater preference for smaller, immediately available rewards over larger, delayed rewards (6, 11, 18). This preference for immediately available rewards has been suggested as a potential behavioral marker of addiction (7). Moreover, addictive populations discount their drug of choice (e.g. cocaine, cigarettes, food) at steeper rates than money (8, 10, 21, 31) demonstrating a preference for what is perceived as a positive immediate outcome of the drug of choice over long-term potentially negative outcomes. Unlike exercise addiction, some studies show greater discounting for males compared to females (17, 29). Gender differences in discounting may be related to the specific discounting task used or population examined. For instance gender differences are present when using real-money but not when using hypothetical rewards (29) or present in addictive populations (i.e. smokers) but not in controls (17).

Neuroimaging studies of delay discounting show activation in cognitive-control regions, such as the dorsolateral, dorsomedial prefrontal cortices (dlPFC, dmPFC) including the dorsal anterior cingulate cortex (dACC), when participants make decisions involving delayed rewards, and activation in reward regions, such as the ventral striatum, when participants make decisions involving immediately available rewards (27, 34). In addition, the ACC activation is more robust in studies where the decision to choose the delayed reward requires

more effortful (e.g. participants must exert more effort in a motor task, or do a cognitively demanding task) (23). Other brain regions involved in delay discounting include regions of the temporal cortex which appear to be related to higher levels of impulsivity and may reflect the incorporation of affective processes in decision-making (13).

In summary, high levels of engagement in exercise have been linked to addictive-like symptoms regarding their relationship with exercise. Studies in other addictive populations demonstrate increased levels of impulsivity indexed by a preference for small, immediately available rewards over larger delayed rewards, yet little is known about the relationship between exercise addiction and behavioral and neuroimaging measures of impulsivity.

The purpose of this pilot study was to explore whether or not endurance runners (greater than 20 miles per week) (19**)** demonstrate addictive like behaviors in terms of behavioral and brain responses during a delay discounting task and if these responses were exacerbated in endurance runners "at-risk" for exercise addiction. In order to tailor the discounting task to endurance runners and index addictive symptoms, we examined discounting behavior and brain responses when participants were instructed that choosing the larger delayed reward over the smaller immediately available reward would mean that they would not be allowed to exercise during the delay period (Ex-) or would be allowed to exercise as usual during the delay period (Ex+). Based on previous studies in other addictive populations we hypothesized that endurance runners would have increased preference for immediately available rewards and greater activation of cognitive control regions when making decisions involving delayed rewards and that this would be greater when participants were told that exercise would be withheld during the delay.

METHODS

Participants

Endurance runners were recruited from local running stores and from the community. Inclusion criteria included: being between 20-60 years of age and running at least 20 miles per week (19). Exclusion criteria included the following: any known cardiovascular disease, diagnosis of cancer and/or receiving chemotherapy or radiation therapy, ischemic cardiovascular event or coronary artery bypass surgery less than 3 months ago, claustrophobia, magnetic resonance imaging (MRI) contraindications, pregnancy, diagnosis of a neurologic or psychiatric disorder (including eating disorder), and currently taking psychotropic medication. All participants provided written informed consent, and the study protocol was approved by the University of Kansas Medical Center Human Subjects Committee. Participants completed two appointments during the study. The first appointment consisted of consent, completing self-report measures of exercise addiction and heart rate variability measures. The second appointment included a practice delay discounting task and the MRI session.

Protocol

The Exercise Addiction Inventory (EAI) was used to assess addictive-like symptoms (33). The EAI is a valid assessment of attitudes and beliefs about exercise. Individuals respond to six items, such as "Exercise is the most important thing in my life", on a 5-point Likert-type scale. Individuals with mean scores between 13 and 23 are considered to have symptoms of exercise addiction, and scores greater than or equal to 24 are considered "at-risk" of exercise addiction. The internal reliability of the EAI is 0.84 (Cronbach's alpha) (33).

The delay discounting task was performed in and out of scanner. During the delay discounting task, participants made a series of hypothetical choices about whether they preferred a smaller amount of money given immediately ($0 – 100) or a larger amount of money ($100) given after a delay of 2, 4, 6, or 12-weeks. On half of the trials participants were told that they would not be able to exercise during the delay (Figure 1). The reward values were based on previous delay discounting studies in addictive populations (28). Hypothetical delay discounting scenarios have been used in previous studies and show no difference in terms of behavioral responses (16).

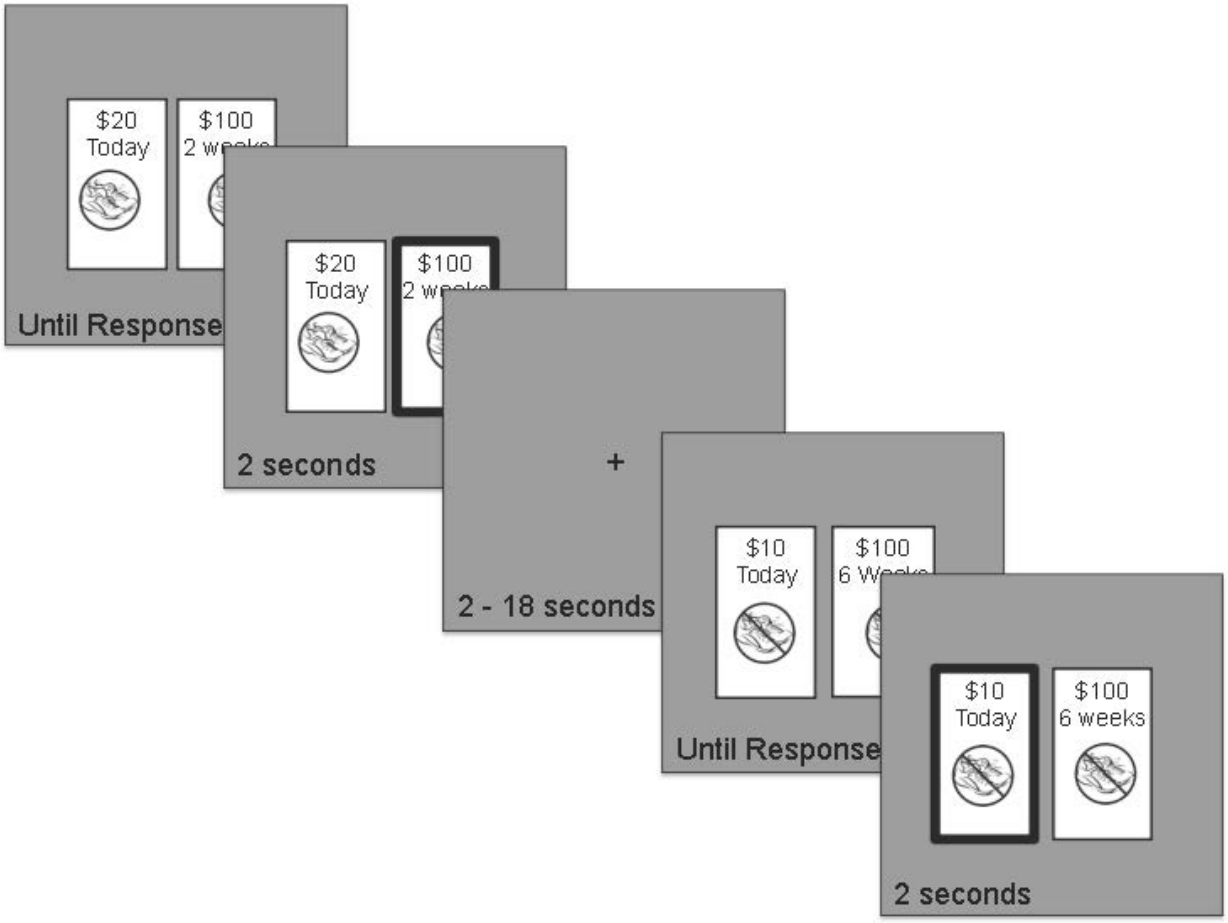

Figure 1. Example of the delay discounting task in the scanner. Ex+ was exercise as usual during the delay condition, and Ex- was not exercise during the delay condition. Ex+ trials were indicated with running shoes and Ex- trials were indicated with crossed out running shoes.

Participants completed a practice delay discounting task outside the scanner. The practice task introduced participants to the task and provided behavioral data (i.e. indifference points) used to tailor the task to each participant based on his/her preference for immediate and delay rewards. Indifference points were obtained Ex+ and Ex- conditions. In order to estimate each participant's indifference point, participants were presented with eight questions to narrow in to the subject's indifference point by a third for each question (22, 35). Indifference points were calculated prior to the fMRI to create an equal number of trials where the participant would be expected to choose the immediate and the delayed reward. Participants then completed the delay-discounting task in the scanner. Participants completed six rounds of 24 monetary and exercise decision-making trials (144 total trials). Each round was about seven minutes long (see Figure 1 for specific timings). Optimal timing of trials was estimated using Analysis of Functional Neuroimage (AFNI) stimulus timing program (make_random_timing.py).

Scanning was performed at the University of Kansas Medical Center's Hoglund Brain Imaging Center on a 3-Tesla Siemens Skyra scanner. T1-weighted 3D MPRAGE anatomic images were obtained (TR/TE 23/2ms, flip angle 9°, FOV = 256mm, matrix = 256 x 176, slice thickness = 1 mm). Gradient echo blood oxygen level dependent (BOLD) scans were acquired in 35 contiguous slices at a 40° angle to the AC/PC line (TR/TE = 2000/25ms, flip angle = 90°, matrix = 80 x 80, slice thickness = 3 mms, in-plane resolution = 2.9 mms). All functional scans were acquired at a 40° angle to the AC-PC line to optimize OFC signal by minimizing susceptibility artifact.

Statistical Analysis

T-tests were performed in IBM Statistical Product and Service Solutions (SPSS) Statistics, version 21.0, (SPSS IBM, New York, U.S.A.) to determine differences in impulsive decision-making between Ex+ and Ex- conditions. Discounting rates were calculated using the following formula: $V = A/(1+kD)$ where V is the indifference point, A is the amount of the reward, D is the value of the time delay, and k is a parameter that reflects how V decreases as D increases (25). After calculating k-values the area under the curve (AUC) was calculated as a measure of impulsivity (32). Higher levels of impulsivity are associated with lower AUC and steeper discounting rates. Dependent t-tests were performed to examine differences in discounting rates for Ex+ and Ex- conditions between participants considered "at-risk" for exercise addiction (i.e. scores greater than 24) and those who were not "at risk".

Data pre-processing and statistical analyses were performed in AFNI (Medical College of Wisconsin). Preprocessing steps included motion correction, alignment, spatial smoothing and spatial normalization. Time points during which participants moved more than 0.3 mm in any direction within a TR (2000 ms) were censored (i.e. removed from the analysis). The images were spatially smoothed with a 4 mm FWHM Gaussian blur. Data were resampled to a 2.5 x 2.5 x 2.5 resolution. Participants' anatomical and functional scans were spatially normalized to Talairach stereotaxic space using AFNI's automated algorithm. Statistical contrasts were conducted using multiple regression analysis with motion parameters included as nuisance regressors. Regressors representing the experimental conditions (Ex+, Ex-) for the decision

making phase of each trial were modeled with a hemodynamic response filter and entered into the multiple-regression analysis using a random-effects model. Duration modulation regression in AFNI was used so that the decision phase included the time from the presentation of the cue until the participant responded.

Whole-brain voxelwise t-tests were conducted to identify task related activation during Ex+ compared to Ex- conditions. Activations were corrected for multiple comparisons based on Monte Carlo simulations using AFNI's 3dClustSim. This resulted in a cluster size of at least 53 voxels ($p_{corrected} < .05$; $p_{voxelwise} < .01$). Percent signal change was extracted for regions showing significant differences between Ex+ compared to Ex- conditions and t-tests were performed to examine differences in brain activation between participants considered "at-risk" for exercise addiction (i.e. scores greater than 24) and those who were not "at risk".

RESULTS

Twenty runners (8 female) were enrolled Participant characteristics are reported in Table 1. Two participants were excluded from the behavioral delay discounting and functional (MRI) analysis due to excessive motion during the MRI. Overall, 94% (n=17) of participants showed exercise addiction symptoms with scores between 13 and 23 on the Exercise Addiction Inventory (Mean = 22.33, SD = 3.91, Minimum = 11, Maximum = 28). Moreover, 44% (n=8) of the participants had scores greater than 24 indicating that they were "at-risk" for exercise addiction.

Table 1.

Variable	Mean (SD)	Range
Age (years)	40.35 (8.35)	27 – 55
Weekly mileage	33.28 (8.61)	20 – 55
EAI Score	22.33 (3.91)	11 - 28

Overall, participants showed increased discounting for Ex- trials (AUC = 0.10, SD = 0.20) compared to Ex+ trials (AUC = .49, SD = 0.26; $t(17) = 3.83$; $p < 0.001$). No significant differences were found for discounting rates between participants "at-risk" for exercise addiction and those who were not considered "at risk" based on Exercise Addiction Inventory scores.

The dmPFC (x, y, z = 9, 16, 44) significantly activated more during the Ex+ condition (Figure 2) compared to the Ex- condition. Similarly the rostral anterior cingulate cortex (ACC, x, y, z = 9, 24, 1) extending into the MPFC deactivated during the Ex+ compared to Ex- condition (Figure 2). However, the right superior temporal gyrus (STG, x, y, z = 66, -31, 11) activated more during the Ex- compared to the Ex+ condition. Widespread bi-lateral activation was found in attention and visual processing regions that were greater during the Ex+ compared to Ex- condition.

A trend was found suggesting that participants "at risk" for exercise addiction may show less differentiation between the Ex+ and Ex- conditions in terms of brain activation in the ACC ($p = 0.09$). No significant differences in brain activation of the dmPFC ($p = 0.38$) were found between participants "at risk" compared to those not "at risk" for exercise addiction.

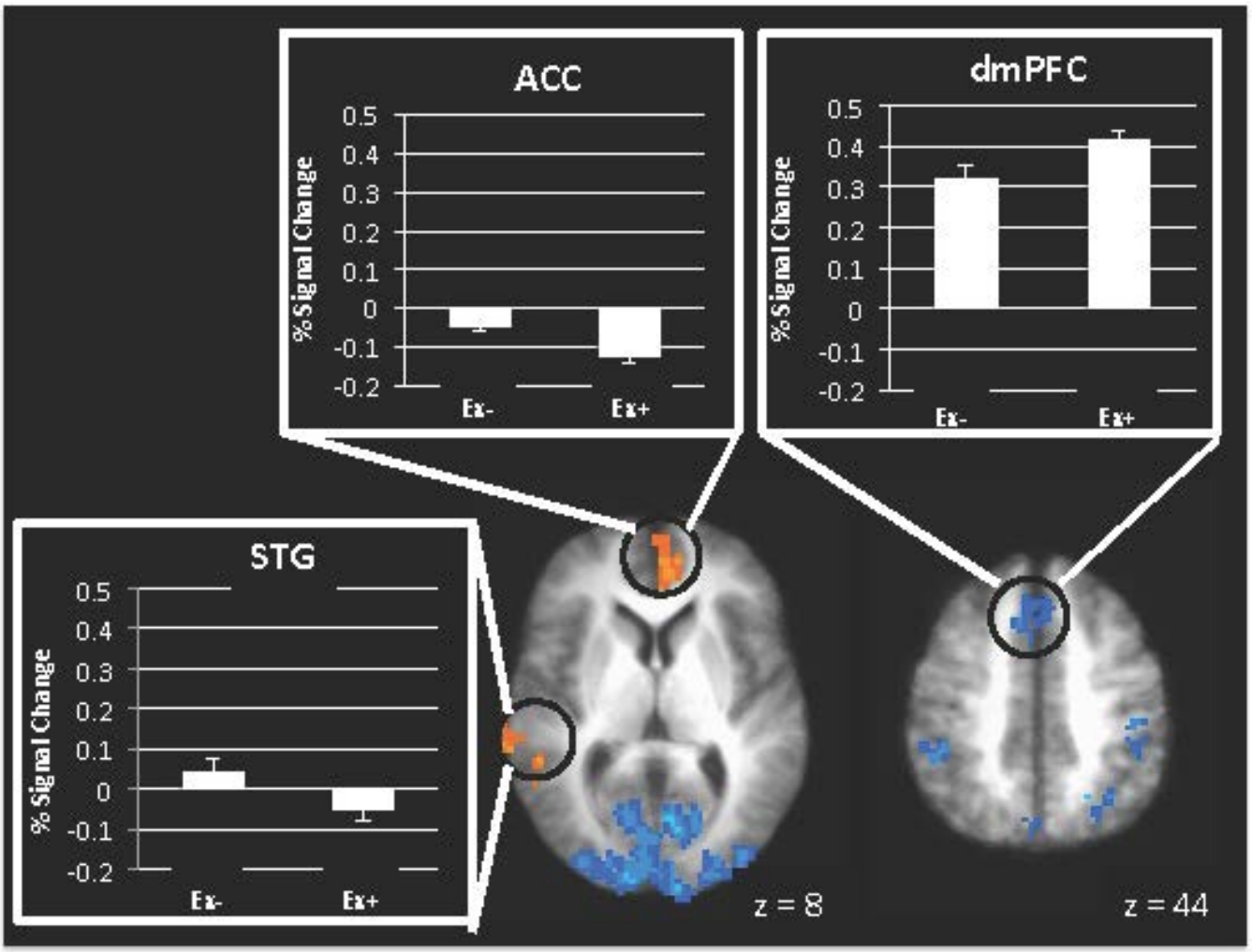

Figure 2. Activation maps showing pattern of activation in the ACC, dMPFC, STG as well as, parietal regions and occipital regions when participants made decisions during the Ex- compared to Ex+ condition.

DISCUSSION

Endurance exercise might be considered an addictive-like behavior, particularly when exercise is continued in the face of injury and stress (5, 20). In the current sample almost all of the participants self-reported some level of addictive-like symptoms concerning exercise (e.g. placing high importance on exercise, experiencing withdrawal like symptoms) and almost half of the participants had scores that indicated they may be "at-risk" for exercise addiction. The delay discounting behavioral and brain results suggested that this sample of endurance runners displayed a decreased ability to wait for larger rewards and decreased recruitment of cognitive control regions when scenarios suggested that exercise must be delayed while

waiting for the rewards compared to scenarios allowed exercise during the delay period. However, no significant differences were found between individuals "at risk" for exercise addiction and those not "at risk" bases on scores on the Exercise Addiction Inventory.

The behavioral results showed greater discounting of delayed monetary rewards when participants must forgo exercise while waiting for the reward. These results are similar to those found in addictive populations where subjects show increased discounting when making decisions about their drug of choice (8, 10, 21, 31) and support the use of delay discounting as a potential behavioral marker for addictive behaviors (7). These results combined with the scores on the Exercise Addiction Inventory support the notion that endurance athletes demonstrate addictive-like symptoms that could lead to exercising despite negative consequences (5, 20). Specifically endurance runners in our study showed steep discounting when waiting for a larger reward was linked to not exercising for 2 – 12 weeks suggesting that endurance athletes may place greater value on exercise than other types of rewards. Discounting rates did not differ between those "at risk" for exercise addiction and those not "at risk" indicating that endurance running may drive these differences more than exercise addiction level.

The neuroimaging results suggested that endurance runners showed altered recruitment of cognitive control regions including the ACC and dmPFC when making monetary decisions involving forgoing exercise compared to exercising as usual. Neuroimaging studies of delay discounting in addictive populations have demonstrated increased activation compared to control participants in cognitive control regions (2, 15, 30) when making monetary decisions. Unlike these previous studies in addictive populations the current study specifically examined brain activation when choices were linked to the addictive behavior (i.e. exercise) and suggested decreased activation in the cognitive control regions when choices are associated with not exercising during the delay period. This is consistent with theoretical models of addiction in which the cognitive control regions are considered underactive compared to reward-related regions which are considered overactive and lead to choices to use and/or continuing using a drug despite an individual's long-term goals (3, 4, 9, 26). Consistent with this model of addiction, the current results suggest that altered cognitive control is present when endurance athletes must weigh decisions for immediately available compared to delayed rewards in the context of exercise availability during the delay period. Brain activation did not significantly differ between those "at risk" for exercise addiction and those not "at risk", indicating that endurance running may drive these differences more than exercise addiction level.

Based on the current data we cannot separate whether this preference for immediate rewards in the presence of not being able to exercising for the positive reward of exercise (running "high") or the avoidance of negative affect related to withdrawal like sypmtoms from not running. Furthermore, we are unable to separate whether the preference for the immediate reward when is related to placing a greater value on the long-term health benefits of exercise; thus not exercising is less rewarding in the long-term. Future research is needed to

systematically address these questions and identify when choosing an immediate reward may actually be more beneficial for long-term health outcomes.

Limitations of the current study include the small sample size, lack of control group of non-endurance runners, and lack of measures of socioeconomic status. Furthermore, no significant behavioral or brain differences were found between participants considered "at risk" for exercise addiction and those not "at risk". However, scores on the Exercise Addiction Scale ranged from 11 to 28 with a mean of 22.33 demonstrating that all participants showed some exercise addiction symptoms. Without a control group of non-endurance runners or individuals who do not demonstrate symptoms of exercise addiction, we cannot separate whether or not the differences observed in the current study are due to endurance running or exercise addiction symptoms. In addition, due to the small sample size, gender differences in exercise addiction and delay discounting could not be examined in the current study. Finally, socioeconomic status was not measured in the current study therefore we do not know the impact this may have had on participants' behavioral decisions. Despite these limitations, the current results add to the literature on behavioral and neural differences in measures of impulsivity and exercise addiction symptoms. Specifically, our data suggest that endurance running relates to moderate to high levels of exercise addiction symptoms and differences in impulsive behavior and brain activation when presented with monetary decisions during which exercise was sometimes prohibited.

Overall, high levels of self-reported addiction symptoms, greater levels of behavioral impulsivity, and altered recruitment of cognitive control regions when decisions involved not exercising during the delay were observed in a sample of endurance runners. This pilot study tested responses to a behavioral task that has been used in other addictive populations. Future research will build on this study to tease apart what aspects of exercise addiction contribute to negative health and psychosocial outcomes and what aspects may actually be beneficial for long-term health outcomes. Thus better understanding the distinction between "positive" addictions vs. "negative" addictions.

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