Mental Health and Physical Activity 17 (2019) 100298

Contents lists available at ScienceDirect

Mental Health and Physical Activity

journal homepage: www.elsevier.com/locate/menpa

The effect of high-intensity interval training on inhibitory control in adolescents hospitalized for a mental illness

Jacqueline S. Lee[a,b,*], Addo Boafo[c], Stephanie Greenham[c], Patricia E. Longmuir[a,b]

[a] Children's Hospital of Eastern Ontario Research Institute, 401 Smyth Rd, Ottawa, ON, K1H 8L1, Canada
[b] University of Ottawa, Department of Health Science, 125 University, Ottawa, ON, K1N 6N5, Canada
[c] Children's Hospital of Eastern Ontario, Ottawa, 401 Smyth Rd, Ottawa, ON, K1H 8L1, Canada

ARTICLE INFO

Keywords:
Mental illness
Executive function
Inhibitory control
High-intensity interval training
Depression
Adolescents

ABSTRACT

Introduction: Inhibitory control is essential for treatment of, and recovery from mental illness. An acute bout of exercise has been shown to improve inhibitory control in healthy adolescents.
Purpose: The primary goal was to examine the effect of an acute bout of high-intensity interval training on inhibitory control both immediately and 30-min post-exercise in adolescents hospitalized for a mental illness.
Methods: Participants were recruited at the Children's Hospital of Eastern Ontario. Participants performed exercise and control conditions in a randomized, counterbalanced manner. The Colour-Word Stroop Task (CWST) assessed Interference Cost (reaction time) pre, post, and 30-min post for each condition (exercise/control). The exercise condition included a 12-min HIIT circuit consisting of body weight exercises performed in a 1:1 work to rest ratio. The control condition involved reading magazines. Repeated-measures ANOVA evaluated changes in the interference cost and accuracy measures of the CWST.
Results: There was a significant interaction between condition and time for the interference cost measure, $F(1.6,43.3) = 13.6$, $p < .0001$, $\eta^2 = .34$. Interference cost was significantly reduced immediately after exercise compared to control ($M_{diff} = 78.8 \pm 14.91$, $p < .001$) and 30-min post-exercise compared to control ($M_{diff} = 59.6 \pm 15.14$, $p = .001$). Accuracy did not differ by time, $F(2,54) = .14$, $p \leq .87$, $\eta^2 = .01$ nor condition, $F(1,27) = 2.25$, $p = .15$, $\eta^2 = .08$.
Conclusion: HIIT was able to improve inhibitory control by increasing response efficiency rather than improving the overall ability to respond correctly. The impact of pre-therapy HIIT to enhance focus and reduce impulsive thoughts and behaviours may improve adolescent patients' response to mental health treatment.

1. Introduction

It has been identified that mental illness is associated with impairments in executive function, regardless of the specific diagnosis (Goodkind et al., 2015; McTeague, Goodkind, & Etkin, 2016). Executive function deficits in patients with mental illness have been linked to increased risk of suicidality (Pu, Setoyama, & Noda, 2017) due to difficulties controlling thoughts about self-harm (Bredemeier & Miller, 2015). Furthermore, successful participation in mental health therapy is dependent on executive function being intact (Snyder, Miyake, & Hankin, 2015), since dysfunction has been shown to reduce responsiveness to pharmacological treatments (Snyder, Kaiser, et al., 2015) and Cognitive Behavioural Therapy (Julian & Mohr, 2006; Kumari et al., 2009; Mohlman & Gorman, 2005).

Adolescence is characterized by a period of robust synaptic elimination in the cortex (Selemon, 2013) which has been proposed to leave executive functions vulnerable to developmental disruption and may be a contributing factor to the development of psychopathology during this time (Blakemore & Choudhury, 2006; Crews, He, & Hodge, 2007; Keshavan, Giedd, Lau, Lewis, & Paus, 2014). This theory is supported by data indicating nearly half of mental disorders have their onset before age 14 and 75% before age 25 (Keshavan et al., 2014). Targeting executive function during this critical period of development may have important implications for improving treatment outcomes in adolescents with mental illness.

Inhibitory control (IC), one core executive function, is defined as the ability to inhibit or control one's behavior, attention, thoughts and/or emotions such that you can override a strong internal predisposition or external lure (Diamond, 2013). Impairments in IC have been shown to occur transdiagnostically across a variety of psychiatric disorders,

* Corresponding author. CHEO Research Institute, 401 Smyth Road, RI#1-214, Ottawa, Ontario, Canada, K1H 8L1.
E-mail address: jackie.lee@ubc.ca (J.S. Lee).

https://doi.org/10.1016/j.mhpa.2019.100298
Received 4 April 2019; Received in revised form 7 July 2019; Accepted 9 September 2019
Available online 12 September 2019
1755-2966/

including major depressive disorder (Snyder, 2013), post-traumatic stress disorder (Polak, Witteveen, Reitsma, & Olff, 2012), bipolar disorder (Cotrena, Damiani, Milman, & Paz, 2016), obsessive-compulsive disorder (Snyder, Kaiser, Warren, & Heller, 2015), and schizophrenia (Holmén et al., 2012). IC has also been shown to predict various components of mental illness such as disrupted emotional processing (Cohen-gilbert & Thomas, 2013; Lewis, Lamm, Segalowitz, Stieben, & Zelazo, 2007) and externalizing behaviours (Eisenberg et al., 2009). Furthermore, meta-analyses have demonstrated IC impairments to be the most pronounced executive function deficit in children, adolescents and adults with MDD (Bora, Harrison, Yücel, & Pantelis, 2013; Snyder, 2013; Wagner, Mu, Helmreich, & Huss, 2015). Due to the frequent occurrence of IC deficits in mental illness, and recent findings that suggest IC is the most dysfunctional executive function among youth with psychiatric disorders, interventions to improve IC may provide treatment benefits.

Acute bouts of aerobic exercise lead to improved executive function in healthy adolescents (Browne et al., 2016; Chang, Labban, Gapin, & Etnier, 2012; S. B.; Cooper et al., 2016; Ludyga, Gerber, Brand, & Holsboer-trachsler, 2016; Ludyga, Pühse, Lucchi, Marti, & Gerber, 2018). High-intensity interval training (HIIT) has gained recent interest as a time-efficient approach to exercise training in children and adolescents (Costigan, Eather, Plotnikoff, Taaffe, & Lubans, 2015; Winn & Mackintosh, 2017). Initial studies suggest that HIIT may be superior to moderate intensity exercise for improving and sustaining executive function (S. L. Cooper & Tomporowski, 2017; Kao, Westfall, Sobeson, Gurd, & Hillman, 2017; Tsukamoto, Suga, Takenaka, Tanaka, Takeuchi, et al., 2016). Although executive function deficits are an established comorbidity in nearly all types of mental illness (Cotrena et al., 2016; Polak et al., 2012; Snyder, 2013; Snyder, Kaiser, et al., 2015), few studies have explored the effects of exercise on executive function in this population.

The goal of this study was to determine whether an acute bout of HIIT exercise could improve IC, immediately and 30-min following exercise among adolescents hospitalized for a mental illness. We hypothesized that an acute bout of HIIT would improve IC both immediately and 30-min post-exercise in adolescents hospitalized for a mental illness. The secondary objective of this study was to assess the feasibility of the HIIT intervention based on recruitment and completion rates, as well as post-exercise enjoyment and changes in affect.

2. Methods

A total of 28 participants were recruited through the inpatient mental health unit at the Children's Hospital of Eastern Ontario (CHEO). To our knowledge, there is no previous research documenting changes in Stroop task performance in a sample of children or adolescents with mental illness. As such, the sample size was calculated from previous research among healthy adolescents that found Stroop task performance to significantly improve by 60 ± 37 ms following an acute bout of high intensity sprints (S. B. Cooper et al., 2016). Based on this finding, and using alpha level of 5% and a beta level of 20%, it was calculated that a sample of 28 participants would provide the statistical power to identify a change in reaction time of 60 ms following exercise. We hypothesized that the cognitive response to exercise in our patient population would be at least as large as that observed in healthy adolescents; an inference based on the assumption that IC is modifiable in patients with mental illness. Previous research supports this notion as adults with depression were shown to improve their IC performance after a single bout of exercise (Kubesch et al., 2003; Vasques et al., 2011).

Participants were eligible if they were male or female, between the ages of 14 and 17, and hospitalized for treatment of one or more of the following mental illnesses: major depressive disorder, anxiety disorders, obsessive compulsive disorder, bipolar disorder, or schizophrenia. Youth with all disorders were eligible to participate since there is a trans-diagnostic pattern of executive dysfunction across all mental illness (Goodkind et al., 2015; McTeague et al., 2016). Exclusion criteria included having a physical disability or neurodevelopmental disorder.

Permission to approach potential study participants was obtained from the psychiatrist responsible for their care. The study activities were clearly described to and approved by each psychiatrist before recruitment began. Participants were also screened based on their clinic nurse's perception of patient suitability. If patients were found to be suitable and willing to participate, they gave informed consent and completed the Get Active Questionnaire, a screening tool created by the Canadian Society for Exercise Physiology (CSEP) to identify underlying health conditions that may be contraindications to participating in vigorous physical activity ("Pre-Screening for Physical Activity: Get Active Questionnaire," 2017).

Study Design: All aspects of patient recruitment, consent and data collection were done at CHEO. Participants were required to do two 1-h assessment sessions over two consecutive days, 24 h apart. On one of the days, the participant performed an acute bout of circuit training (exercise condition) and on the other day the participant would read magazines (control condition). The order of the conditions was randomized and counterbalanced. For exercise and control conditions, IC was measured using a Colour-Word Stroop Task (CWST) at 3 time points: baseline (0-min), immediately after the exercise/control condition (20-min), and 30 min post-exercise/control condition (50-min after baseline). On the first day, participants performed 1 practice trial of the CWST; the next trial was recorded as the baseline measure (0-min) of IC. Between the 0- and 20-min CWST, participants in the exercise condition performed the exercise intervention and participants in the control condition read magazines. All study participants, exercise and control, read magazines between the 20- and 50 min Stroop tasks. On the second day, participants who did the exercise condition initially performed the control condition, and participants who did the control condition initially performed the exercise condition. Participants were instructed to follow standard exercise testing procedures, including no vigorous physical activity or caffeine on the day of testing (Thompson, Arena, Riebe, & Pescatello, 2013), and nothing to eat 1 h prior to testing.

Exercise Intervention: Participants performed 12-min of circuit training consisting of 4 full body exercises: jumping jacks, modified burpies, side jumps, and high knees. These exercises were repeated 3 times, using a 1:1 work to rest ratio of 30 s of work and 30 s of rest. This circuit was modified from a study by Ludyga et al. (2018) that demonstrated healthy adolescents had improved IC immediately and 60-min after exercise (Ludyga et al., 2018). In Ludyga's exercise protocol, adolescents performed 16-min of circuit training at a 1:1 work to rest ratio. However, we decided to reduce the amount of exercise to 12-min so that our sample of inpatients could feasibly complete the exercise. Participant heart rate (HR) was monitored throughout the exercise using a Polar Heart Rate Monitor (model FT4; Polar Electro, Finland) and recorded after each period of work. Participants were encouraged to keep their HR at or above 80% of their predicted maximum HR [(208 – (0.7 x Age)](Tanaka, Monahan, & Seals, 2001). After each round of exercise, participants were also asked to provide a rating of perceived exertion (RPE), using the OMNI scale for children as the reference (Utter, Robertson, Nieman, & Kang, 2002).

Colour-Word Stroop Task: The CWST is a widely used, standardized assessment of IC that directly measures an individual's ability to inhibit habitual responses during a decision-making task (Stroop, 1935). The CWST was performed manually on a laptop using PsyToolKit Software (Stoet, 2017). Each trial consisted of a fixation cross presented in the center of the screen for 500 ms, followed by a stimulus which remained on the screen until the response was given. Stimuli consisted of either a colour word (BLUE, RED, GREEN, or YELLOW) or 4X's in a row (e.g. XXXX) written in blue, red, green, or yellow ink. Participants were instructed to respond to the ink color of the word or symbols as quickly and accurately as possible. The compatibility between the identity of the word and its color is manipulated, yielding 36 congruent trials (e.g., the word red printed in red), 36 incongruent trials (e.g., the word red printed in blue) and 36 neutral trials (e.g., XXXX printed in blue). The words for each task were presented in random order. Responses for each trial were accepted between 300 ms and 2000 ms. Responses made outside of this window of time were considered as errors to minimize potential anticipatory and omission response errors respectively. Accuracy and reaction time data were recorded. Task performance was assessed by the Interference Cost, which is the reaction time cost of responding to the task when the ink color and word identity do not match.

Descriptive Variables: The Habitual Activity Estimation Scale (HAES) (Hay, 2006) was completed by participants to estimate their level of daily physical activity for a typical weekday for the two weeks prior to entering the hospital (Monday-Friday). Participants documented the amount of time spent awake in each of 4 categories: inactive (lying down), somewhat inactive (sitting down), somewhat-active (walking), and very active (breathing hard and sweating). Participants also recorded wake-up, bedtimes, and meal times. Time spent in each category per day was calculated in minutes. The inactive and somewhat inactive categories were combined to describe sedentary behaviour. The somewhat-active and very active categories were used to described light activity and moderate-to-vigorous physical activity (MVPA), respectively (Hay, 2006). Participants' affect was assessed before and after exercise using the Positive Affect Negative Affect Schedule (PANAS) (Watson, Clark, & Tellegan, 1988). The PANAS is comprised of 10 positive and 10 negative adjective words in which participants must rate their affective state from 1 (not at all) to 5 (extremely). The sums of the 10 positive and 10 negative ratings are separately calculated for the total positive and negative affect scores. Finally, we assessed participants' perception of whether they would be (a) willing to perform this type of exercise prior to therapy sessions (b) their enjoyment of the exercise session, and (c) how likely they would be physically active on most days of the week once discharged, on a scale from 1 to 10.

Statistical Testing: Data were analyzed using SPSS version 25.0 (IBM Corp, 2017). Reaction time (RT) data were expressed as a mean with standard error for incompatible and neutral trials. Interference Cost for the CWST was calculated using the following equation: Interference Cost = [(RT of incongruent task − RT of neutral task]. Preliminary analyses were conducted to ensure participant factors did not differ between groups (performed exercise first or the control first). Univariate analyses also examined whether the observed effects differed depending on participant characteristics. A Bonferroni correction was used to mitigate type 1 error due to multiple comparisons. RTs (incompatible and neutral), Interference Cost, and accuracy were analyzed using separate repeated-measures analyses of variance (ANOVA) where within subject factors were session time (0/20/50 min) and condition (exercise/control). Speed-accuracy trade-off during the CWST was assessed from pre-to post-exercise using repeated-measures ANOVAs for mean overall RT and accuracy rates. Finally, a two factor repeated measures ANOVA assessed the change in PANAS score from pre-to post-exercise. Feasibility of the HIIT intervention was quantified by recruitment/completion rates and reasons for withdrawal, as well as descriptive statistics for ratings of enjoyment and willingness to perform HIIT before therapy.

3. Results

Preliminary Results: Participant recruitment and demographics are described in Fig. 1 and Table 1. Mean improvement in Interference Cost from pre-to post-exercise was 99.9 ms ± 72.86. CWST performance for exercise and control conditions are shown in Table 2. Participants less likely to perform physical activity once discharged had significantly greater improvement in Interference Cost post-exercise. Although not significant, a lower likelihood of performing HIIT before therapy was related to greater improvement in Interference Cost post-exercise (Table 3).

Interference Cost: There was a significant interaction between condition and time for Interference Cost, $F(2, 54) = 13.6$, $p < .0001$, $\eta^2 = .34$ (Fig. 2a). The within subject effects were deconstructed by examining the effect of time at each group level. For the exercise condition, Interference Cost significantly reduced from pre to post ($M_{diff} = 85.3 \pm 12.06$, $p < .001$) and from pre to 30-min post ($M_{diff} = 84.2 \pm 11.44$, $p < .001$), with no difference from post to 30-min post ($M_{diff} = 1.1 \pm 12.06$, $p = 1.00$). For the control condition, Interference Cost did not change from pre-to post ($M_{diff} = 1.9 \pm 12.49$, $p = 1.00$), from pre to 30-min post ($M_{diff} = 12.2 \pm 9.25$, $p = .59$) or from post to 30-min post ($M_{diff} = 14.1 \pm 14.34$, $p = 1.00$). Between subject effects were deconstructed by examining the effect of condition at each time point. There was no difference in Interference Cost between exercise and control conditions at pre-test ($M_{diff} = 12.4 \pm 11.11$, $p = .28$). However, Interference Cost was significantly reduced in the exercise condition compared to the control condition at the post test ($M_{diff} = 78.8 \pm 14.91$, $p < .001$) and the 30-min post-test ($M_{diff} = 59.6 \pm 15.14$, $p = .001$).

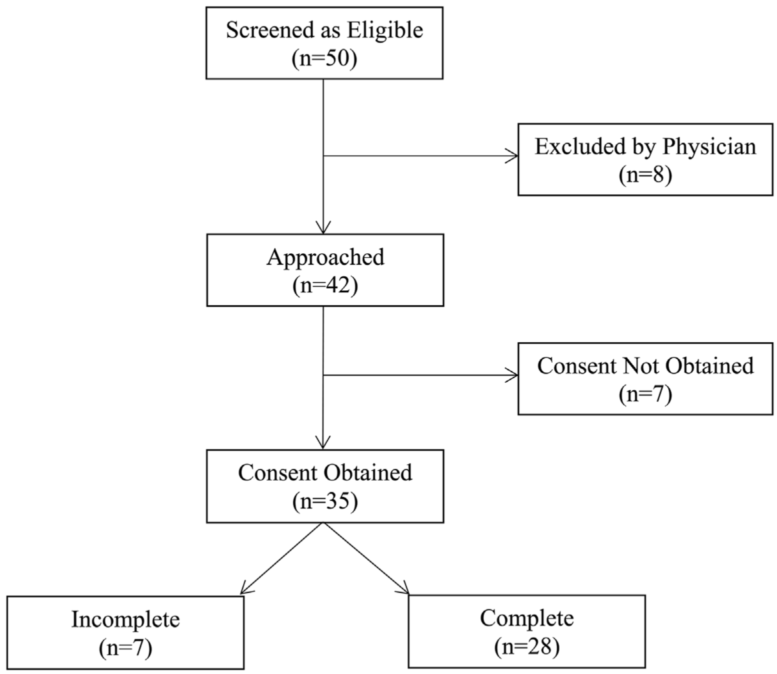
Speed-Accuracy Trade-off: In the multivariable model, participant accuracy on the CWST did not differ by condition (exercise vs control), $F(1,27) = 2.25$, $p = .15$, $\eta^2 = .08$, or time (pre, post, and 30-post), $F(2,54) = .14$, $p = .87$, $\eta^2 = .005$ (Fig. 2b). Exercise enhanced CWST performance was not explained by a speed-accuracy trade-off since RT significantly improved from pre-to post-exercise, $F(2,54) = 4.63, p = .01$, $\eta^2 = .146$, without diminishing accuracy $F(2,54) = .10, p = .91$, $\eta^2 = .003$.

Univariate Regression Analyses: Improvement in Interference Cost after exercise was not associated with participant order of trial condition, sex, baseline Interference Cost, enjoyment of HITT, or MVPA (Table 3). Lower perceived likelihood of being physically active and lower willingness to perform the exercise before therapy was associated with better IC improvement after exercise, however, trends were not significant (Table 3).

Feasibility: Participant recruitment and reasons for removal are described in Fig. 1. Of the 50 eligible patients, 42 patients (84%) were approached to participate, and of those 42, consent was obtained by 35 patients (83%), with a total of 28 patients completing the study (80%). The main reason for removal from the study was due to participants being discharged from the hospital. Only 2 participants were removed from the final analysis because they were not able to complete the total HIIT session due to fatigue. Average ratings for the questions regarding enjoyment of HIIT compared to other forms of exercise and willingness to do HIIT before therapy are described in Table 1. There was a significant interaction between time and affect scale [$F(1,27) = 13.54$, $p = .001$] for the PANAS (Fig. 3). Within subject effects were deconstructed by examining the differences between the positive and negative affect scores at each time point. At baseline, there were no differences between scores ($M_{diff} = .14 \pm 14.6$, $p = .96$). After exercise, positive affect was significantly higher than negative affect ($M_{diff} = 6.9 \pm 15.2$, $p = .02$).

4. Discussion

The main finding of this study was that in contrast to the control condition, exercise improved patients' measure of IC. Interference Cost on the CWST decreased after HIIT due to faster RT during incongruent trials. Cognitive benefits were sustained 30-min after exercise. These results suggest that HIIT can improve IC in adolescents hospitalized for a mental illness, specifically their efficiency on a task when there are conflicting stimuli presented. There were no group-specific changes in accuracy over time suggesting that improvements in CWST performance reflected greater effectiveness while inhibiting a response, rather than enhanced error detection. Since improvements in reaction time were not accompanied by reduced accuracy, we concluded that



Note. Excluded by Physician = patients had an eating disorder, too acutely ill, or getting discharged; Consent not Obtained = patients not interested in participating in the study (n=3) or getting discharged before study could be completed (n=4); Incomplete = patients did not complete the exercise session (n=2) or got discharged after first day of testing (n=5).

Fig. 1. Participant Screening and Recruitment Flow Chart
Note. Excluded by Physician = patients had an eating disorder, too acutely ill, or getting discharged; Consent not Obtained = patients not interested in participating in the study (n = 3) or getting discharged before study could be completed (n = 4); Incomplete = patients did not complete the exercise session (n = 2) or got discharged after first day of testing (n = 5).

Table 1
Participant demographics and responses to exercise.

	Female (n = 20)	Male (n = 8)	Total Sample (n = 28)
Age	15.5 ± 1.0	15.5 ± .53	15.5 ± .92
Diagnosis			
MDD/SI	15	8	23
GAD	3	0	3
PTSD	1	0	1
BD	1	0	1
HAES (min/day)			
Sedentary	451.3 ± 129.6	587.6 ± 166.5	490.2 ± 151.46
Light Activity	363.1 ± 186.5	232.5 ± 132.9	325.9 ± 180.75
MVPA	93.2 ± 72.9	153.4 ± 101.9	110.4 ± 84.89
Questionnaire			
Exercise before therapy?	6.7 ± 2.8	5.8 ± 2.7	6.4 ± 2.75
Enjoyment of exercise?	5.7 ± 2.1	5.9 ± 1.9	5.7 ± 2.02
PA once discharged?	5.9 ± 2.5	7.1 ± 3.1	6.2 ± 2.67
Heart Rate (bpm)			
Round 1	169.9 ± 10.1	171.9 ± 8.6	170.4 ± 9.56
Round 2	176.9 ± 9.5	172.5 ± 11.2	175.6 ± 10.02
Round 3	180.5 ± 8.3	176.9 ± 11.4	179.5 ± 9.24
RPE (1–10 scale)			
Round 1	5.5 ± 1.5	6.4 ± 1.3	5.7 ± 1.49
Round 2	7.5 ± 1.6	8.0 ± .9	7.6 ± 1.45
Round 3	8.8 ± 1.3	9.0 ± 1.1	8.9 ± 1.24

Note. MDD/SI = Major Depressive Disorder/Suicidal Ideation; GAD = Generalized Anxiety Disorder; PTSD = Post-Traumatic Stress Disorder: BD = Bipolar Disorder. HAES = Habitual Activity Estimation Scale (Hay, 2006). MVPA = moderate-to-vigorous physical activity. RPE = Rate of Perceived Excursion Significance from t-tests set at p ≤ .05.

Table 2
Colour-word stroop task performance.

	Pre	Post	30-Post
Exercise condition			
Congruent RT (ms)	756 ± 146	757 ± 134	736 ± 99
Incongruent RT (ms)	994 ± 146	895 ± 119	897 ± 110
Neutral RT (ms)	796 ± 139	783 ± 106	784 ± 108
Interference Cost (ms)	198 ± 60	112 ± 73	113 ± 70
Accuracy (%)	93 ± 5.4	92 ± 4.8	92 ± 10.2
Control condition			
Congruent RT (ms)	772 ± 111	762 ± 127	733 ± 131
Incongruent RT (ms)	983 ± 134	990 ± 94	972 ± 120
Neutral RT (ms)	797 ± 114	802 ± 79	799 ± 91
Interference Cost (ms)	185 ± 54	187 ± 66	173 ± 55
Accuracy (%)	93 ± 5.5	94 ± 4.0	94 ± 4.6

Note. The Colour-Word Stroop Task was performed manually on a laptop.

enhanced IC was not due to a speed-accuracy trade-off.

The feasibility of the HIIT intervention was supported by our finding that 82% of patients approached for the study consented to participate, and 80% of patients who consented were able to complete the study activities. The main reasons for consent not being obtained or participation being incomplete was discharge from the hospital, 60% and 71% respectively. Furthermore, positive affect was significantly higher than negative affect post-exercise. There was a bimodal distribution for enjoyment of HIIT compared to other forms of exercise; however, almost half of our participants (46%) rated HIIT as 8 or above. Finally, willingness to perform HIIT before therapy, if HIIT was found to be helpful, was rated a mean of 6.4 out of 10. Lower willingness to perform HIIT and lower perceived likelihood of being physically active was positively trending with improvements in IC post-exercise.

Previous research had found that an acute bout of HIIT can improve IC in healthy adolescents (Browne et al., 2016; S. B.; Cooper et al.,

Table 3
Univariate effect of participant characteristics on change in interference cost.

		Beta ± SE	F-value	P-value	Adjusted R^2
Participant Characteristics	Control first	11.7 ± 27.97	.18	.68	.03
	Female Sex	36.4 ± 30.23	1.45	.24	.02
	Higher baseline Interference	0.3 ± 0.23	1.7	.20	.06
	Less likely to do HIIT before therapy	9.1 ± 4.87	3.5	.07	.12
	Lower Enjoyment of HIIT	5.6 ± 7.00	.64	.43	.02
	Greater improvement in positive affect after HIIT	.8 ± 1.76	.19	.67	.03
	Greater improvement in negative affect after HIIT	4.3 ± 3.6	1.4	.25	.02
	Less likely to be physical active after discharge	10.1 ± 4.97	4.10	.05	.14
	Lower MVPA	0.2 ± 0.17	.94	.34	.04

Note. Higher baseline Interference = greater interference cost on baseline Stroop task; Lower MVPA = less moderate-to-vigorous physical activity per day estimated using the Habitual Activity Estimation Scale (Hay, 2006). Significance set at p ≤ .05/9 or .005.

2016; Ludyga et al., 2018). Our findings demonstrate that exercise benefits on IC can also be seen in adolescents hospitalized for mental illness, particularly those with MDD (since this comprised 82% of our sample). There is strong support for the effectiveness of exercise interventions for reducing symptoms of depression among adolescents with clinical depression (Radovic, Gordon, & Melvin, 2017). Although cognitive impairment is a major factor in relapse (Majer, Modell, Holsboer, & Zihl, 2004) and functional outcomes (Woo, Rosenblat, Kakar, Bahk, & McIntyre, 2016) in MDD, comparatively less research has examined the cognitive benefits of exercise. We chose to examine the IC benefits of exercise since impairments are not only present in the acute phases of depression (Snyder, 2013), they have also been shown to persist in remission (Hasselbalch, Knorr, & Kessing, 2011). Furthermore, IC impairments are recognized as common symptoms of depression, including the inability to focus, concentrate or make decisions (Davidson, Pizzagalli, Nitschke, & Putnam, 2002). However, research examining the immediate effect of exercise on IC in MDD is limited, with only few studies in adults examining changes in IC following acute moderate-aerobic exercise (Kubesch et al., 2003; Vasques et al., 2011). This study adds to the growing literature on the cognitive benefits of exercise in patients with depression.

Improvements in RT have been most commonly used to describe changes in IC during Stroop Tasks (S. B. Cooper et al., 2016; Ludyga et al., 2018), however, the current study also sought to examine changes in accuracy. Our findings revealed that exercise enhanced IC through improvements in efficiency (i.e. reaction time) rather than accuracy. In healthy adolescents, the effects of HIIT on IC has also been characterized by enhanced reaction time, rather than accuracy for Stroop (S. B. Cooper et al., 2016) and Flanker tasks (Ludyga et al., 2018). In contrast, healthy adolescents were shown to improve accuracy on a Flanker task that had a response window of only 1000 ms, following a 5-min bout of exercise (either at 50, 65, and 80% of maximal intensity)(Gejl et al., 2018). In the current study, we speculate that insufficient task difficulty may have contributed to participants experiencing ceiling effects since baseline accuracy was high (92.5% ± 5.38). It could be that post-exercise accuracy improvements would have been observed if participants were given a smaller response window, such as 300–1200 ms, instead of 300-2000 ms. While our findings support HIIT improved our patients' response efficiency, improving accuracy may also be clinically relevant for individuals with depression who are impaired at decision making (Davidson et al., 2002). Future research should continue to examine IC performance as it relates to changes in accuracy as a primary outcome.

To our knowledge, there has been no previous research documenting the acute benefits of exercise on IC in adolescents with depression. Several studies do however support these benefits in adults with depression. Performing 30-min of continuous moderate-aerobic exercise improved mean RTs on Stroop tasks in adult outpatients with MDD (n = 24, 42.2 ± 12.2 years) (Kubesch et al., 2003) and elderly patients with MDD (n = 10, age = 71.5 ± 6.0 years) (Vasques et al., 2011). Interestingly, findings for the IC benefits of exercise in healthy populations are not as consistent (Ludyga et al., 2016). Studies in healthy children and adolescents found that an acute bout of continuous moderate-aerobic exercise was not able to improve IC on a Flanker task (Stroth et al., 2009; Themanson & Hillman, 2006). One explanation is that research suggests acute exercise facilitates IC in those who need it the most, i.e. low-performers improve more than high-performers (Drollette et al., 2014). One of the major limitations in studies examining the benefits of exercise on global cognition in depression is that cognitive impairment is not a prerequisite for study participation (Sun, Lanctot, Herrmann, & Gallagher, 2018). This has been proposed to lead to an underestimation of the impact of long-term exercise interventions on cognition. While MDD is characterized by difficulty inhibiting negative thoughts and emotions (Peckham, McHugh, & Otto, 2010), however, the disorder affects each individual differently and thus severity of cognitive impairments vary. For example, it has been estimated that approximately 28–37% of depressed individuals score between 1 and 2 SD below healthy controls, and 16–39% score 2 SD or greater below healthy controls (Gualtieri, C. T. and Morgan, 2008). Since more severe depressive symptoms are related to a higher degree of dysfunctional cognitions (Köhler et al., 2015), we suspect our patients had low levels of IC at baseline and thus responded positively to treatment. However, future research should pre-screen for cognitive impairment as samples could notably vary in their degree of cognitive dysfunction which may affect the impact of exercise on IC.

There is debate on whether HIIT is an appropriate type of exercise for patients with depression. Some researchers argue that HIIT may be too arduous and could evoke feelings of incompetence, failure, and lower self-esteem, thus reducing participants' motivation to engage PA (Hardcastle, Ray, And, & Hagger, 2017). However, studies in adult populations with mental illness have shown HIIT to be just as feasible as continuous aerobic exercise, in terms of drop-out rates, self-determined exercise motivation, and affective responses post-exercise (Bartlett et al., 2011; Gerber, Minghetti, Beck, Zahner, & Donath, 2018). Furthermore, studies examining healthy adults have suggested that HIIT may be superior to continuous aerobic exercise for improving IC task performance as a result of longer sustained benefits and increased neural efficiency (Kao et al., 2017; Tsukamoto, Suga, Takenaka, Tanaka, & Takeuchi, 2016). Since the current study did not compare HIIT with continuous aerobic exercise, we cannot comment on whether these trends hold true for adolescent inpatients with mental illness. What was demonstrated was the importance of patient discharge as a major barrier to study participation. Since recruitment was dependent on obtaining physician and nurse approval, we would not expect discharges to decrease participation if pre-therapy HIIT was implemented as a regular part of treatment. We speculate that the bimodal distribution for HIIT enjoyment could have been due to previous engagement in sports or physical activity, data which were not collected in the current study. From our perspective, an average rating of 6.4/10 on willingness to perform HIIT before therapy is promising given the

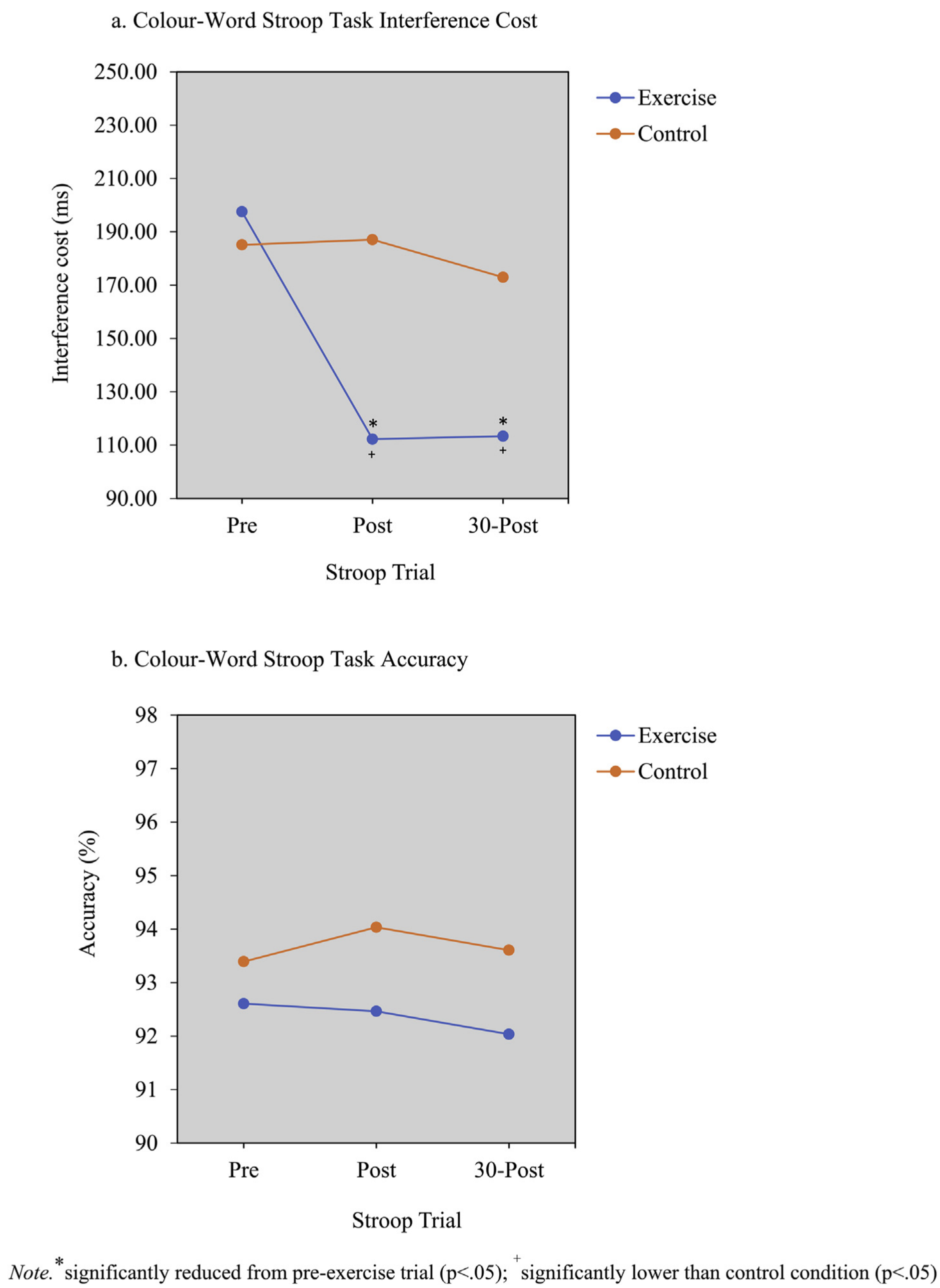


Fig. 2. aColour-word stroop task interference cost. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)
bColour-Word Stroop Task Accuracy.
*Note.**significantly reduced from pre-exercise trial ($p < .05$); $^{+}$significantly lower than control condition ($p < .05$). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

population of interest. Finally, the most important consideration in support of using HIIT as an intervention is that performing the exercise did not contribute towards participants' negative feelings and emotions.

Neuroimaging techniques have allowed researchers to infer neural substrates in the brain by which an acute bout of exercise improves IC. Studies using functional near-infrared spectroscopy (fNIRS) in healthy individuals have revealed that an acute bout of low (Byun et al., 2014), moderate (Yanagisawa et al., 2010), or high-intensity exercise (Kujach et al., 2018) increased activation of the left-dorsolateral prefrontal cortex (DLPFC) in conjunction with improved Stroop performance. As such, exercise is hypothesized to facilitate IC by enhancing cortical activations in the DLPFC(Krompinger & Simons, 2011)(Dietrich & Audiffren, 2011). The means by which exercise improves IC is thought to be a common underlying process among the overarching construct of executive function. However, sensitivity to aerobic exercise has been shown to vary between the core components of executive function which include inhibitory control, working memory, and cognitive flexibility (Etnier & Chang, 2009). Although these constituents are distinguishable, executive function is recognized as a unitary construct since proper functioning relies on the interdependence between the core components (Miyake et al., 2000). For instance, the use of cognitive flexibility to change perspectives first requires deactivating the previous perspective using IC, followed by forming a new perspective using working memory. Therefore, our findings may be more generalizable to the literature on IC, while still contribute to the broader knowledge on the acute effects of exercise on executive function.

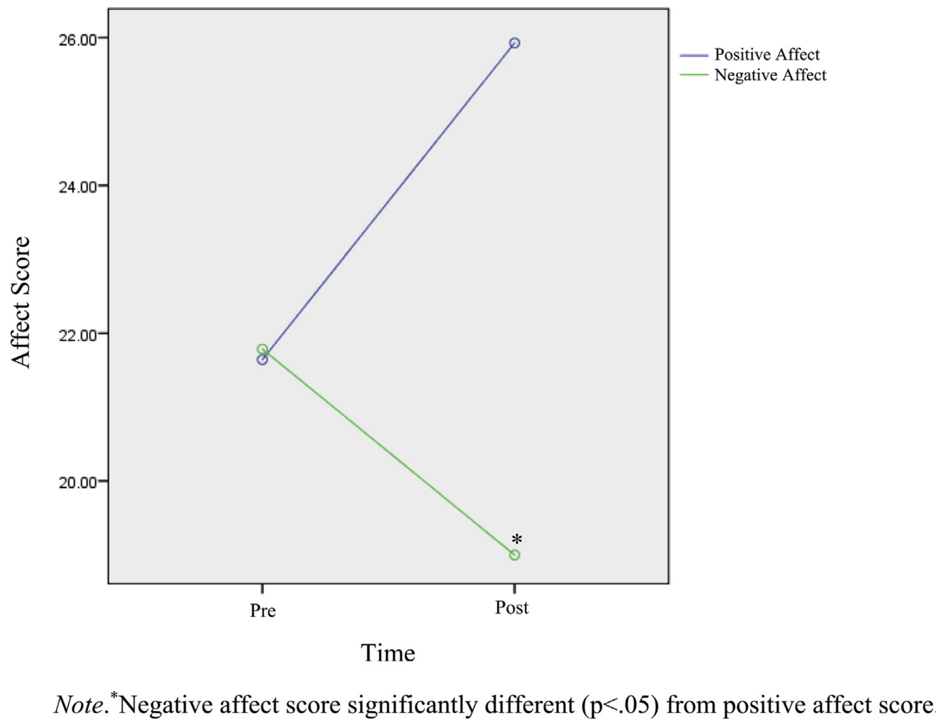


Fig. 3. Change in Positive and Negative Affect after Exercise.
*Note.**Negative affect score significantly different ($p < .05$) from positive affect score.

Assumptions, *Strengths and Limitations:* It is important to note that these findings are based on the assumption that CWST performance represents a persons' level of IC. This task assumes that reading the word is an overlearned cognitive process and will be the automatic response when participants are instructed to name the ink colour. During the incongruent trials, participants must resolve this cognitive interference when the word and the colour do not match. Since it is assumed that there is no response competition for neutral trials (XXXX written in blue, red, or green), incongruent trials are compared to neutral trials to determine interference (Schroeter, Zysset, Kupka, Kruggel, & Von Cramon, 2002). Congruent trials are important to include in the task to decrease the likelihood that subjects use the suppression strategy, i.e. avoid reading the word by not focusing their gaze (MacLeod, 1991).

This study provides preliminary evidence that HIIT can improve IC in adolescents hospitalized for a mental illness. A major strength of this study was the use of a randomized crossover design. Since each participant acted as his/her own control, the study design minimized the extent to which individual factors may have influenced the results. In addition, our assessment of feasibility provided practical knowledge on whether an intervention such as this one could be used in the future. Interestingly, our results suggest there may be greater support for the use of this intervention among individuals who perceive themselves less likely to perform exercise before therapy and after discharge.

The main limitation of this study was that the power analysis used to determine our sample size was derived from healthy adolescents. This could have influenced our type 1 error since adolescents with mental illness may have more variability in their cognitive response to exercise compared to healthy adolescents. To our knowledge, this is the first study to asses changes in CWST performance from an acute bout of HIIT in adolescents with hospitalized for a mental illness. As such, future studies will be able to use our results to conduct a priori sample size calculations. Of note, our sample was not adequately powered to perform meaningful subgroup analyses which would have allowed us to assess moderators of IC improvement after exercise. For instance, 24/28 of our participants had a diagnosis of MDD; as such we could not assess the impact of diagnosis on the results. Furthermore, we did not measure differences in patients' medication, length of hospitalization stay, age of illness onset, history of relapse, or past treatments. Finally, participants' ability to recall a 'typical week' for the HAES may have been influenced by the length of their hospital stay prior to the study. We expect that this limitation may have contributed to participants' overall high level of estimated MVPA.

5. Conclusion

This study provides preliminary evidence that HIIT can improve inhibitory control, with the greatest benefit potentially accruing to those who perceived themselves to be less physically active. Further research appears warranted to investigate whether HIIT prior to therapy could improve the efficacy of mental health treatment for adolescents with mental illness though enhanced cognitive pathways. It may also be beneficial to investigate whether exercise enhanced performance on cognitive tasks are reflected in real word cognitive outcomes, such as improvements in focus or reduction of impulsive behaviours. Additional research is required to determine the optimal exercise type and intensity for enhanced IC and participant enjoyment and whether enjoyment and cognition are independent effects. Finally, it will be important to examine whether individual factors (e.g., diagnosis, medication, age of illness onset, length of hospitalization, and treatment history) impact the extent to which exercise improves IC.

Funding & conflicts

The time of the graduate student was supported by the Queen Elizabeth II Graduate Scholarship in Science and Technology. There are no conflicts of interest to report.

References

Bartlett, J. D., Close, G. L., Maclaren, D. O. N. P. M., Gregson, W., Drust, B., & Morton, J. P. (2011). *High-intensity interval running is perceived to be more enjoyable than moderate-intensity continuous exercise : Implications for exercise adherence, 29*, 547–553. 6

https://doi.org/10.1080/02640414.2010.545427.
Blakemore, S., & Choudhury, S. (2006). Development of the adolescent brain : Implications for executive function and social cognition. *Journal of Child Psychology and Psychiatry, 47*, 296–312. https://doi.org/10.1111/j.1469-7610.2006.01611.x.
Bora, E., Harrison, B. J., Yücel, M., & Pantelis, C. (2013). Cognitive impairment in euthymic major depressive disorder: A meta-analysis. *Psychological Medicine, 43*(10), 2017–2026. https://doi.org/10.1017/S0033291712002085.
Bredemeier, K., & Miller, I. W. (2015). Clinical psychology review executive function and suicidality : A systematic qualitative review. *Clinical Psychology Review, 40*, 170–183. https://doi.org/10.1016/j.cpr.2015.06.005.
Browne, R. A. V., Costa, E. C., Sales, M. M., Fonteles, A. I., Nova de Moraes, J. F. V., & Barros, J. de G. (2016). Acute effect of vigorous aerobic exercise on the inhibitory control in adolescents. *Revista Paulista de Pediatria, 34*(2), 154–161. https://doi.org/10.1016/j.rppede.2016.01.005.
Byun, K., Hyodo, K., Suwabe, K., Ochi, G., Sakairi, Y., Kato, M., et al. (2014). Positive effect of acute mild exercise on executive function via arousal-related prefrontal activations: An fNIRS study. *NeuroImage, 98*, 336–345. https://doi.org/10.1016/j.neuroimage.2014.04.067.
Chang, Y. K., Labban, J. D., Gapin, J. I., & Etnier, J. L. (2012). The effects of acute exercise on cognitive performance : A meta-analysis. *Brain Research, 1453*(250), 87–101. https://doi.org/10.1016/j.brainres.2012.02.068.
Cohen-gilbert, J. E., & Thomas, K. M. (2013). Inhibitory Control during emotional distraction across adolescence and early adulthood. *Child Development, 84*(6), 1954–1966. https://doi.org/10.1111/cdev.12085.
Cooper, S. B., Bandelow, S., Nute, M. L., Dring, K. J., Stannard, R. L., Morris, J. G., et al. (2016). Sprint-based exercise and cognitive function in adolescents. *Preventive Medicine Reports, 4*, 155–161. https://doi.org/10.1016/j.pmedr.2016.06.004.
Cooper, S. L., & Tomporowski, P. D. (2017). Acute effects of exercise on attentional bias in low and high anxious young adults. *Mental Health and Physical Activity, 12*, 62–72. https://doi.org/10.1016/j.mhpa.2017.02.002.
Costigan, S. A., Eather, N., Plotnikoff, R. C., Taaffe, D. R., & Lubans, D. R. (2015). High-intensity interval training for improving health-related fitness in adolescents : A systematic review and meta-analysis. *British Journal of Sports Medicine, 49*, 1253–1261. https://doi.org/10.1136/bjsports-2014-094490.
Cotrena, C., Damiani, L., Milman, F., & Paz, R. (2016). Executive function impairments in depression and bipolar disorder : Association with functional impairment and quality of life. *Journal of Affective Disorders, 190*, 744–753. https://doi.org/10.1016/j.jad.2015.11.007.
Crews, F., He, J., & Hodge, C. (2007). *Adolescent cortical development : A critical period of vulnerability for addiction, 86*, 189–199. https://doi.org/10.1016/j.pbb.2006.12.001.
Davidson, R. J., Pizzagalli, D., Nitschke, J. B., & Putnam, K. (2002). Depression: Perspectives from affective neuroscience. *Annual Review of Psychology, 53*(1), 545–574. https://doi.org/10.1146/annurev.psych.53.100901.135148.
Diamond, A. (2013). Executive functions. *Annual Review of Psychology, 64*, 135–168. https://doi.org/10.1146/annurev-psych-113011-143750.
Dietrich, A., & Audiffren, M. (2011). The reticular-activating hypofrontality (RAH) model of acute exercise. *Neuroscience & Biobehavioral Reviews, 35*(6), 1305–1325. https://doi.org/10.1016/j.neubiorev.2011.02.001.
Drollette, E. S., Scudder, M. R., Raine, L. B., Moore, R. D., Saliba, B. J., Pontifex, M. B., et al. (2014). Developmental Cognitive Neuroscience Acute exercise facilitates brain function and cognition in children who need it most : An ERP study of individual differences in inhibitory control capacity. *Accident Analysis & Prevention, 7*, 53–64. https://doi.org/10.1016/j.dcn.2013.11.001.
Eisenberg, N., Valiente, C., Spinrad, T. L., Cumberland, A., Reiser, M., Zhou, Q., et al. (2009). Longitudinal relations of Children's effortful control. *Developmental Psychology, 45*(4), 988–1008. https://doi.org/10.1037/a0016213.Longitudinal.
Etnier, J. L., & Chang, Y.-K. (2009). The effect of physical activity on executive function: A brief commentary on definitions, measurement issues, and the current state of the literature. *Journal of Sport & Exercise Psychology, 31*(4), 469–483. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/19842543.
Gejl, A. K., Bugge, A., Ernst, M. T., Tarp, J., Hillman, C. H., Have, M., et al. (2018). The acute effects of short bouts of exercise on inhibitory control in adolescents. *Mental Health and Physical Activity, 15*, 34–39. https://doi.org/10.1016/j.mhpa.2018.06.003.
Gerber, M., Minghetti, A., Beck, J., Zahner, L., & Donath, L. (2018). Sprint interval training and continuous aerobic exercise training have similar effects on exercise motivation and affective responses to exercise in patients with major depressive disorders: A randomized controlled trial. *Frontiers in Psychiatry, 9*(December), 1–11. https://doi.org/10.3389/fpsyt.2018.00694.
Goodkind, M., Eickhoff, S. B., Oathes, D. J., Jiang, Y., Chang, A., Jones-hagata, L. B., et al. (2015). Identification of a common neurobiological substrate for mental illness. *JAMA Psychiatry, 5797*(4), 305–315. https://doi.org/10.1001/jamapsychiatry.2014.2206.
Gualtieri, C. T., & Morgan, D. W. (2008). Frequency of cognitive impairment in patients with anxiety, depression, and bipolar disorder: An unaccounted source of variance in clinical trials. *Journal of Clinical Psychiatry, 69*(7), 1123–1131.
Hardcastle, S. J., Ray, H., B, L., & Hagger, M. S. (2017). Commentary: Why sprint interval training is inappropriate for a largely sedentary population. *Frontiers in Psychology, 8*. (December), 2013–2015 https://doi.org/10.3389/fpsyg.2017.01603.
Hasselbalch, B. J., Knorr, U., & Kessing, L. V. (2011). Cognitive impairment in the remitted state of unipolar depressive disorder: A systematic review. *Journal of Affective Disorders, 134*(1–3), 20–31. https://doi.org/10.1016/j.jad.2010.11.011.
Hay, J. A. (2006). Development of the habitual activity estimation scale for clinical Research : A systematic approach development of the HAES. *Pediatric Exercise Science, 18*, 193–202.
Holmén, A., Juuhl-langseth, M., Thormodsen, R., Ueland, T., Agartz, I., Sundet, K., et al. (2012). Executive function in early- and adult onset schizophrenia. *Schizophrenia Research, 142*(1–3), 177–182. https://doi.org/10.1016/j.schres.2012.10.006.
Julian, L. J., & Mohr, D. C. (2006). Cognitive predictors of response to treatment for depression in multiple sclerosis. *Journal of Neuropsychiatry and Clinical Neurosciences, 18*(3), 356–363. https://doi.org/10.1176/jnp.2006.18.3.356.
Kao, S., Westfall, D. R., Sobeson, J., Gurd, B., & Hillman, C. H. (2017). Comparison of the acute effects of high-intensity interval training and continuous aerobic walking on inhibitory control. *Psychophysiology,* (54), 1335–1345. https://doi.org/10.1111/psyp.12889.
Keshavan, M. S., Giedd, J., Lau, J. Y. F., Lewis, D. A., & Paus, T. (2014). Changes in the adolescent brain and the pathophysiology of psychotic disorders. *Lancet Psychiatry, 1*, 549–558. https://doi.org/10.1016/S2215-0366(14)00081-9.
Köhler, S., Unger, T., Hoffmann, S., Mackert, A., Ross, B., & Fydrich Kliniken im Theodor-Wenzel-Werk, T. (2015). Dysfunctional cognitions of depressive inpatients and their relationship with treatment outcome. *Comprehensive Psychiatry, 58*, 50–56. https://doi.org/10.1016/j.comppsych.2014.12.020.
Krompinger, J. W., & Simons, R. F. (2011). Cognitive inefficiency in depressive undergraduates: Stroop processing and ERPs. *Biological Psychology, 86*(3), 239–246. https://doi.org/10.1016/j.biopsycho.2010.12.004.
Kubesch, S., Bretschneider, V., Freudenmann, R., Weidenhammer, N., Lehmann, M., Spitzer, M., et al. (2003). Aerobic endurance exercise improves executive functions in depressed patients. Background *Journal of Clinical Psychiatry, 64*(9), 1005–1012.
Kujach, S., Byun, K., Hyodo, K., Suwabe, K., Fukuie, T., Laskowski, R., et al. (2018). A transferable high-intensity intermittent exercise improves executive performance in association with dorsolateral prefrontal activation in young adults. *NeuroImage, 169*, 117–125. https://doi.org/10.1016/j.neuroimage.2017.12.003.
Kumari, V., Peters, E. R., Fannon, D., Antonova, E., Premkumar, P., Anilkumar, A. P., et al. (2009). Responsiveness to cognitive – behavioral therapy in schizophrenia. *Biological Psychiatry, 66*, 594–602. https://doi.org/10.1016/j.biopsych.2009.04.036.
Lewis, M. D., Lamm, C., Segalowitz, S. J., Stieben, J., & Zelazo, P. D. (2007). Neurophysiological correlates of emotion regulation in adults and children. *Psychophysiology, 44*(s1), S10–S11. https://doi.org/10.1111/j.1469-8986.2007.00578.x.
Ludyga, S., Gerber, M., Brand, S., & Holsboer-trachsler, E. (2016). Acute effects of moderate aerobic exercise on specific aspects of executive function in different age and fitness groups : A meta-analysis. *Psychophysiology, 53*, 1611–1626. https://doi.org/10.1111/psyp.12736.
Ludyga, S., Pühse, U., Lucchi, S., Marti, J., & Gerber, M. (2018). Immediate and sustained effects of intermittent exercise on inhibitory control and task-related heart rate variability in adolescents. *Journal of Science and Medicine in Sport, 22*(1), 96–100. https://doi.org/10.1016/j.jsams.2018.05.027.
MacLeod, C. M. (1991). Half a century of research on the Stroop effect: An integrative review. *Psychological Bulletin, 109*(2), 163–203. https://doi.org/10.1037/0033-2909.109.2.163.
Majer, M., Modell, S., Holsboer, F., & Zihl, J. (2004). Neuropsychological deficits and long-term outcomes in patients with affective disorders. *Pharmacopsychiatry, 36*(05) https://doi.org/10.1055/s-2003-825433.
McTeague, L. M., Goodkind, M. S., & Etkin, A. (2016). Transdiagnostic impairment of cognitive control in mental illness. *Journal of Psychiatric Research, 83*, 37–46. https://doi.org/10.1016/j.jpsychires.2016.08.001.
Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). *The unity and diversity of executive functions and their contributions to complex "" frontal lobe "' Tasks : A latent variable analysis, 100*, 49–100. https://doi.org/10.1006/cogp.1999.0734.
Mohlman, J., & Gorman, J. M. (2005). The role of executive functioning in CBT: A pilot study with anxious older adults. *Behaviour Research and Therapy, 43*(4), 447–465. https://doi.org/10.1016/j.brat.2004.03.007.
Peckham, A. D., McHugh, R. K., & Otto, M. W. (2010). A meta-analysis of the magnitude of biased attention in depression. *Depression and Anxiety, 27*(12), 1135–1142. https://doi.org/10.1002/da.20755.
Polak, A. R., Witteveen, A. B., Reitsma, J. B., & Olff, M. (2012). The role of executive function in posttraumatic stress disorder : A systematic review. *Journal of Affective Disorders, 141*(1), 11–21. https://doi.org/10.1016/j.jad.2012.01.001.
Pre-Screening for Physical Activity: Get Active Questionnaire (2017). Retrieved January 21, 2019, from http://www.csep.ca/en/publications/get-active-questionnaire.
Pu, S., Setoyama, S., & Noda, T. (2017). Association between cognitive deficits and suicidal ideation in patients with major depressive disorder. *Scientific Reports, 7*, 8–13. https://doi.org/10.1038/s41598-017-12142-8.
Radovic, S., Gordon, M. S., & Melvin, G. A. (2017). Should we recommend exercise to adolescents with depressive symptoms? A meta-analysis. *Journal of Paediatrics and Child Health, 53*(3), 214–220. https://doi.org/10.1111/jpc.13426.
Schroeter, M. L., Zysset, S., Kupka, T., Kruggel, F., & Von Cramon, D. Y. (2002). Near-infrared spectroscopy can detect brain activity during a color-word matching stroop task in an event-related design. *Human Brain Mapping, 17*(1), 61–71. https://doi.org/10.1002/hbm.10052.
Selemon, L. D. (2013). A role for synaptic plasticity in the adolescent development of executive function. *Translational Psychiatry, 3*, 238–239. https://doi.org/10.1038/tp.2013.7.
Snyder, H. R. (2013). Major depressive disorder is associated with broad impairments on neuropsychological measures of executive Function : A meta-analysis and review. *Psychological Bulletin, 139*(1), 81–132. https://doi.org/10.1037/a0028727.
Snyder, H. R., Kaiser, R. H., Warren, S. L., & Heller, W. (2015a). Obsessive-compulsive disorder is associated with broad impairments in executive Function : A meta-analysis. *Cinical Psychology Science, 3*(2), 301–330. https://doi.org/10.1177/2167702614534210.
Snyder, H. R., Miyake, A., & Hankin, B. L. (2015b). Advancing understanding of executive

function impairments and psychopathology : Bridging the gap between clinical and cognitive approaches. *Frontiers in Psychology, 6*, 328. https://doi.org/10.3389/fpsyg.2015.00328.

Stoet, G. (2017). PsyToolkit: A novel web-based method for running online questionnaires and reaction-time experiments. *Teaching of Psychology, 41*(1), 24–31.

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology, 18*(6), 643–662. https://doi.org/10.1037/h0054651.

Stroth, S., Kubesch, S., Dieterle, K., Ruchsow, M., Heim, R., & Kiefer, M. (2009). Physical fitness , but not acute exercise modulates event-related potential indices for executive control in healthy adolescents. *Brain Research, 1269*, 114–124. https://doi.org/10.1016/j.brainres.2009.02.073.

Sun, M., Lanctot, K., Herrmann, N., & Gallagher, D. (2018). Exercise for cognitive symptoms in depression: A systematic review of interventional studies. *Canadian Journal of Psychiatry*. https://doi.org/10.1177/0706743717738493.

Tanaka, H., Monahan, K. D., & Seals, D. R. (2001). Age-predicted maximal heart rate revisited. *Journal of the American College of Cardiology, 37*(1), 153–156. https://doi.org/10.1016/S0735-1097(00)01054-8.

Themanson, J. R., & Hillman, C. H. (2006). Cardiorespiratory fitness and acute aerobic exercise effects on neuroelectric and behavioral measures of action monitoring. *Neuroscience, 141*(2), 757–767. https://doi.org/10.1016/j.neuroscience.2006.04.004.

Thompson, P. D., Arena, R., Riebe, D., & Pescatello, L. S. (2013). ACSM's new pre-participation health screening recommendations from ACSM's guidelines for exercise testing and prescription. (Ninth Edition). *Current Sports Medicine Reports: 12*, (pp. 215–217). . 4 https://doi.org/10.1249/jsr.0b013e31829a68cf.

Tsukamoto, H., Suga, T., Takenaka, S., Tanaka, D., & Takeuchi, T. (2016a). Greater impact of acute high-intensity interval exercise on post-exercise executive function compared to moderate-intensity continuous exercise. *Physiology & Behavior, 155*, 224–230. https://doi.org/10.1016/j.physbeh.2015.12.021.

Tsukamoto, H., Suga, T., Takenaka, S., Tanaka, D., Takeuchi, T., Hamaoka, T., et al. (2016b). Greater impact of acute high-intensity interval exercise on post-exercise executive function compared to moderate-intensity continuous exercise. *Physiology & Behavior, 155*, 224–230. https://doi.org/10.1016/j.physbeh.2015.12.021.

Utter, A. C., Robertson, R. J., Nieman, D. C., & Kang, J. I. E. (2002). Children' s OMNI scale of perceived Exertion : Walking/running evaluation. *Medicine & Science in Sports & Exercise, 34*(1), 139–144.

Vasques, P. E., Moraes, I. I. H., Silveira, I. I. H., Andrea, I. I., Deslandes, C., & Jerson, I. V. (2011). Acute exercise improves cognition in the depressed elderly : The effect of dual-tasks. *Clinical Science, 66*(9), 1553–1557. https://doi.org/10.1590/S1807-59322011000900008.

Wagner, S., Mu, C., Helmreich, I., & Huss, M. (2015). A meta-analysis of cognitive functions in children and adolescents with major depressive disorder. *European Child & Adolescent Psychiatry,* 5–19. https://doi.org/10.1007/s00787-014-0559-2.

Watson, D., Clark, L.a., & Tellegan, A. (1988). Development and validation of brief measures of positive and negative affect: The PANAS scales. *Journal of Personality and Social Psychology, 54*(6), 1063–1070.

Winn, C. O. N., & Mackintosh, K. A. (2017). High-intensity interval training interventions in children and Adolescents : A systematic review. *Sports Medicine, 47*(11), 2363–2374. https://doi.org/10.1007/s40279-017-0753-8.

Woo, Y. S., Rosenblat, J. D., Kakar, R., Bahk, W. M., & McIntyre, R. S. (2016). Cognitive deficits as a mediator of poor occupational function in remitted major depressive disorder patients. *Clinical Psychopharmacology and Neuroscience, 14*(1), 1–16. https://doi.org/10.9758/cpn.2016.14.1.1.

Yanagisawa, H., Dan, I., Tsuzuki, D., Kato, M., Okamoto, M., Kyutoku, Y., et al. (2010). Acute moderate exercise elicits increased dorsolateral prefrontal activation and improves cognitive performance with Stroop test. *NeuroImage, 50*(4), 1702–1710. https://doi.org/10.1016/j.neuroimage.2009.12.023.