High-Intensity Interval Training for Cognitive and Mental Health in Adolescents

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ABSTRACT

COSTIGAN, S. A., N. EATHER, R. C. PLOTNIKOFF, C. H. HILLMAN, and D. R. LUBANS. High-Intensity Interval Training for Cognitive and Mental Health in Adolescents. *Med. Sci. Sports Exerc.*, Vol. 48, No. 10, pp. 1985–1993, 2016. **Purpose**: Emerging literature suggests that physical activity and fitness may have a positive effect on cognitive and mental health in adolescents. The purpose of the current study was to evaluate the efficacy of two high-intensity interval training (HIIT) protocols for improving cognitive and mental health outcomes (executive function, psychological well-being, psychological distress, and physical self-concept) in adolescents. **Methods**: Participants (n = 65; mean age = 15.8 ± 0.6 yr) were randomized to three conditions: aerobic exercise program (AEP; n = 21), resistance and aerobic program (RAP; n = 22), and control (n = 22). HIIT sessions (8–10 min per session) were delivered during physical education lessons or at lunchtime three times per week for 8 wk. Assessments were conducted at baseline and immediately postintervention to detect changes in executive function (trail making test), psychological well-being, psychological distress, and physical self-description by researchers blinded to treatment allocation. Intervention effects were examined using linear mixed models. Cohen's d effect sizes and clinical inference were also calculated. **Results**: While results were not significant, small improvements in executive function (mean change (95% CI) −6.69 (−22.03, 8.64), d = −0.32) and psychological well-being (mean change (95% CI) 2.81 (−2.06, 7.68), d = 0.34) were evident in the AEP group; and moderate improvements in executive function (mean change (95% CI) −10.73 (−26.22, 4.76), d = −0.51), and small improvements in well-being (mean change (95% CI) 2.96 (−1.82, 7.75), d = 0.36) and perceived appearance (mean change (95% CI) 0.32 (−0.25, 0.86), d = 0.35), were observed for the RAP group. Mean feeling state scores improved from preworkout to postworkout in both HIIT conditions, with significant results for the AEP (P = 0.001). **Conclusions**: This study highlights the potential of embedding HIIT within the school day for improving cognitive and mental health among adolescents.
Key Words: HIGH-INTENSITY INTERVAL TRAINING, COGNITIVE HEALTH, MENTAL HEALTH, ADOLESCENTS

Regular participation in physical activity is associated with a wide range of physical health benefits for young people, including improvements in body composition, physical capacity, and overall health-related indicators (e.g., blood pressure, insulin resistance, lipid profile) (20). Emerging literature also suggests that physical activity and fitness may have a positive effect on mental health outcomes for youth (e.g., depression and anxiety) (34). Furthermore, it has been suggested that participation in physical activity and the attainment of high levels of physical fitness are linked to enhanced brain structure and function, cognition, and academic performance, via direct and indirect physiological, cognitive, emotional, and learning mechanisms (17).

Despite the extensive benefits of an active lifestyle, approximately 80% of young people across the globe do not achieve the international physical activity recommendations of 60 min·d^{-1} (16), and trends in this generation show a secular decline in health-related physical fitness (especially cardiorespiratory fitness) (5). These findings, combined with the dramatic decline in physical activity (33) typically observed during adolescence (7% per year from age 12 to 19) (14), highlight the need for effective solutions to the inactivity pandemic. However, physical activity and fitness interventions targeting adolescents have been largely unsuccessful (13), and developing innovative and time efficient strategies that provide potent health benefits for young people are urgently needed.

High-intensity interval training (HIIT) has emerged as a feasible and efficacious strategy for increasing physical health outcomes in young people (9,25). HIIT involves either a) short or long intervals (from ≤45 s to 2–4 min) of high-intensity exercise (e.g., >85% max heart rate) interspersed by short rest periods or b) reoccurring short or long (<10 s to 20–30 s) bouts of maximal sprints interspersed by a prolonged rest period between exercises (8). The main appeal of HIIT is that it can be completed in a short period while resulting in equivalent physiological adaptations to longer sessions of traditional aerobic training (8). There is strong evidence indicating that HIIT can improve physical health (9,22), with additional evidence demonstrating a positive effect on depression (41), sleep quality (41), and emotional

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well-being (1) in a range of adult population groups (e.g., older adults, cancer patients, and cancer survivors). However, little is known regarding the effect of HIIT on cognitive and mental health outcomes in adolescent populations.

Mental health is not merely the absence of a mental illness but a state of positive well-being and effective functioning in which an individual realizes his or her potential and is able to make a positive contribution to his or her community (44). Therefore, indicators of mental health can be classified into three broad categories: cognitive function (e.g., attention, perception, and memory), well-being (e.g., self-concept and eudemonic well-being), and ill-being (e.g., depression and anxiety). Relative to cognition, the strongest relationship for physical activity appears for tasks or task components that require extensive amounts of executive function (i.e., the intentional component of environmental interaction entailing processes such as inhibition, working memory, and cognitive flexibility) (18). Considering the global inactivity pandemic and the large numbers of adolescents who have been diagnosed as having a mental illness (35), the current study was designed to evaluate the efficacy of two HIIT protocols (aerobic exercise program [AEP] and resistance and aerobic program [RAP]) for improving cognitive and mental health outcomes (executive function, psychological well-being, psychological distress, and physical self-concept) in a sample of adolescents from one secondary school in New South Wales, Australia.

METHODS

Study Design and Participants

The study methods have been described in detail previously (10). Briefly, ethical approval to conduct the study was gained from the University of Newcastle Human Research Ethics Committee (H-2014-0083). The study protocol was registered with the Australian and New Zealand Clinical Trials Registry (ACTRN12614000729628). The school principal, parents, and study participants provided written informed consent to participate in the study. Study participants (n = 65) were students in grades 9 and 10 (ages 14–16 yr) attending the study school. The design, conduct, and reporting for this randomized controlled trial (RCT) adhered to the guidelines of the Consolidated Standards of Reporting Trials (32).

A three-arm school-based RCT was conducted with adolescents from one secondary school. The HIIT sessions ranged from 8 to 10 min in duration (weeks 1–3: 8 min; weeks 4–6: 9 min; weeks 7–8: 10 min), with a work to rest ratio of 30:30 s. The AEP and the RAP sessions were delivered by the research team at the study school.

Our first study examined changes in health-related fitness outcomes associated with the two HIIT protocols (10). Briefly, a small intervention effect was evident for cardiorespiratory fitness in the RAP group; participants in the AEP and RAP groups had moderate intervention effects for waist circumference (AEP: mean change = −1.5, 95% confidence interval [CI] = −3.4 to 0.4, d = −0.5; RAP: mean change = −2.1, 95% CI = −4.0 to −0.3, d = −0.7), body mass index (AEP: mean change = −0.27, 95% CI = −0.57 to 0.04, d = −0.5; RAP: mean change −0.28, 95% CI = −0.57 to 0.02, d = −0.5), and body mass index z (AEP: mean change = −0.10, 95% CI = −0.20 to −0.01, d = −0.6; RAP: mean change = −0.08, 95% CI = −0.17 to 0.01, d = −0.5) in comparison with the control group. Heart rate targets were met, with a higher average heart rate evident for the RAP (AEP: 74.04% of max, 148.09 bpm; RAP: 77.58% of max, 155.15 bpm).

Power calculations were based on change in the primary outcome (cardiorespiratory fitness, assessed using the multistage shuttle test [24]). A between-group difference of 10 laps was considered achievable, assuming an SD of nine laps, 80% power with alpha levels set at 0.05. It was determined that 20 participants per group would provide adequate power to detect statistically significant effects.

After baseline measures had been assessed by research assistants blinded to treatment allocation, participants were randomized using a random number-producing algorithm. A stratified random sampling procedure was conducted to ensure that equal numbers of boys and girls were allocated between the three groups.

Participants randomized to the intervention conditions (AEP and RAP groups) participated in three HIIT sessions per week for 8 wk (24 sessions in total). Two HIIT sessions per week were delivered in scheduled PE lessons, and a third session was delivered at lunch time. The focus of each of the three programs included the following:

i. AEP: Participants completed HIIT sessions primarily involving gross motor cardiorespiratory exercises (e.g., shuttle runs, jumping jacks, and skipping).
ii. RAP: Participants completed HIIT sessions that included a combination of cardiorespiratory and body weight resistance training exercises (e.g., shuttle runs, jumping jacks, skipping, combined with body weight squats, and push-ups). For example, one RAP work phase included the following sequence of cardiorespiratory and resistance exercises (four walking lunges, 10-m sprint, and three push-ups) repeated as many times as possible in a 30-s period. The RAP treatment did not include a separate resistance training component with a prespecified number of sets and repetitions.
iii. Control: Participants continued with their programmed PE and usual lunchtime activities for the 8-wk intervention period (Fig. 1).

The AEP and the RAP groups engaged in their HIIT sessions (inclusive of a short warm-up activity including dynamic stretching, 8–10 min of HIIT and cooldown), whereas the control group did their typical warm-up and stretching and completed one activity with their PE teacher. Following the HIIT session, the groups were combined to complete the

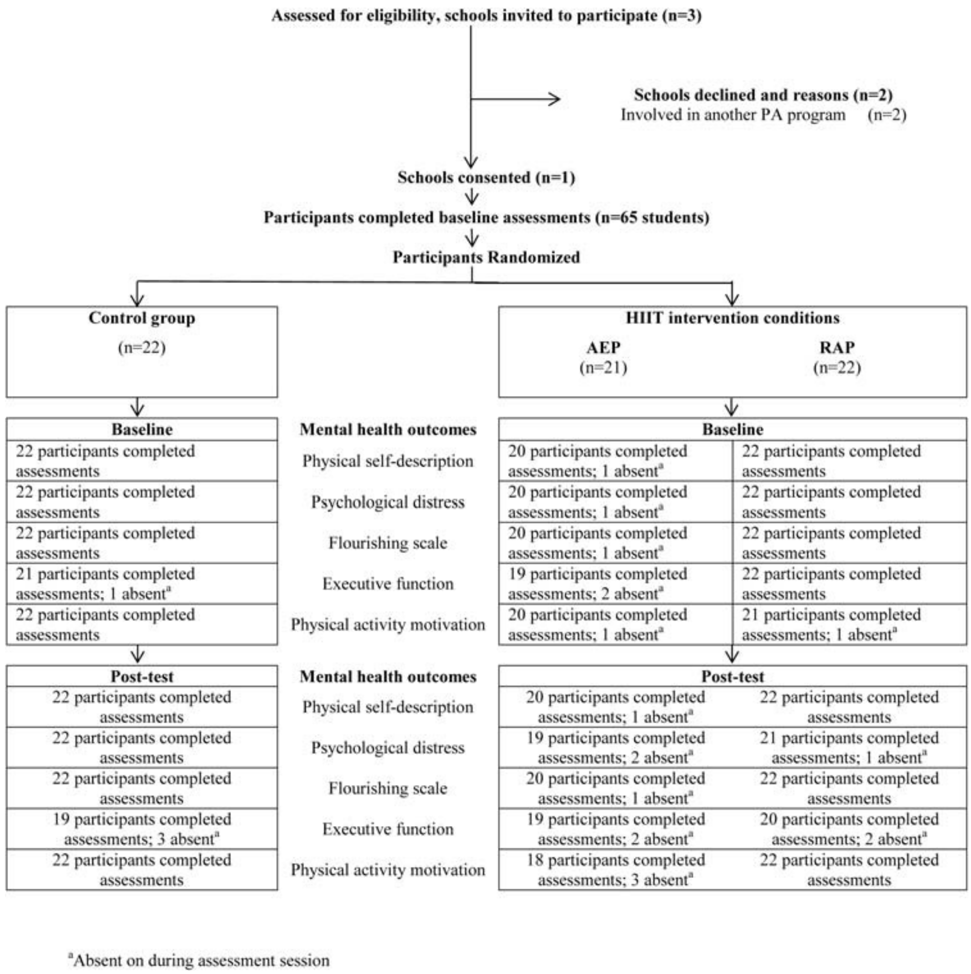

FIGURE 1—Flow of participants through the study. K10, Kessler Psychological Distress Scale; FL SCALE, Flourishing Scale; MOT, physical activity motivation; PSC, physical self-concept.

remainder of the scheduled PE lesson. Session duration and intensity were the same for both intervention groups. Participants wore heart rate monitors (Polar H7) to encourage maintenance of the appropriate exercise intensity, which were connected to a central iPad application (Polar Team). Heart rates were displayed on a projector screen during sessions.

Given that both adolescent girls and boys have reported difficulty starting and adhering to regular exercise, several approaches (based on self-determination theory [39]) were undertaken to promote adherence to the program. First, sessions were designed to be enjoyable by including a fun warm-up and cooldown activity or game, and participants worked with a partner of their choice (one participant undertook the "work" phase of the sessions, while their partner completed the "rest" phase). To create a supportive environment, a focus of all sessions was to promote and reward students for providing verbal encouragement and support to peers and for working hard during the HIIT sessions. A "Trainer of the Day" certificate was presented to one pair per session for providing positive feedback and motivation for their partner and for demonstrating outstanding effort and dedication during the workout. Prizes (e.g., a gift voucher) were also awarded to the pairs in each study arm receiving the most certificates at the end of the program. To promote autonomy, participants were also given the opportunity a) to choose music (student playlists used weeks 2–8), b) to select specific exercises to be completed during a workout (weeks 4–6), and c) to choose a workout (between two workouts previously completed; weeks 7 and 8) once exercises were mastered.

Outcomes

All assessments were conducted by trained researchers blinded to group allocation. A measurement training session and protocol manual, including specific instructions for conducting all assessments, was provided for all research staff to ensure accuracy and consistency. All physical assessments were conducted discretely, and questionnaires were completed under exam-like conditions.

Mental Health Outcomes

Executive function. The trail making test (TMT) is a measure of visual attention, speed, scanning, speed of

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processing, and mental flexibility and has been validated in youth (43). The TMT involves a two-part visual task in which participants are required to, first (trail a), draw a line from one point to the next as quickly as possible to connect numbers in ascending order (e.g., 1-2-3-4, etc.) and, second (trail b), draw a line from one point to the next as quickly as possible to connect both numbers and letters in an ascending and alternating order (e.g., 1-a-2-b-3-c-4-d, etc.) (37). Lower scores indicate greater cognitive performance, and in the literature, various methods have been used to obtain an overall measure of cognitive flexibility. For instance, in one method, the time to complete trail A is subtracted from the time to complete trail b (B-A) (40), whereas another method includes time to complete trail b divided by the time to complete trail A (B/A) (40). As TMT B is a more complex test compared with TMT A, some studies have only considered the time taken to complete trail b (30). Therefore, each of these methods are calculated and reported.

Psychological well-being. The Flourishing Scale is a brief eight-item summary measure of the respondent's self-perceived success in areas such as relationships, self-esteem, purpose, and optimism. Students responded on a seven-point scale (1 = *strongly disagree* to 7 = *strongly agree*) to how much they agreed with each statement relating to indicators of social well-being (e.g., *I lead a purposeful and meaningful life*). The scale provides a single psychological well-being score. A composite score was created by summing the scores for each item (possible range, 8–56). Higher scores indicate greater well-being. Cronbach's α was used as a measure of scale reliability for psychological well-being (baseline: $\alpha = 0.77$; posttest: $\alpha = 0.92$).

Psychological distress. The Kessler Psychological Distress Scale (K10) involves 10 questions about a person's emotional state (2). The K10 questionnaire is intended to measure distress based on questions about anxiety and depressive symptoms that a person has experienced in the last 4 wk. Each question is scored from 0 (*none of the time*) to 5 (*all of the time*). Scores for the 10 questions are then summed, producing a minimum score between 0 and 50. Low scores indicate low levels of psychological distress, and high scores indicate high levels of psychological distress (2). Cronbach's α was used as a measure of scale reliability for the K10 (baseline: $\alpha = 0.93$; posttest: $\alpha = 0.91$).

Physical self-concept. The global physical self-concept and perceived appearance subscales from the Physical Self-Description Questionnaire (validated in adolescence [28]) were used. Participants were asked to respond on a six-point scale (1 = "false," to 6 = "true") how true each statement was for them (e.g., "I am attractive for my age" and "I feel good about who I am and what I can do physically"). Total scores were divided by number of items to provide a mean value for the subscales of global physical self-concept and perceived appearance. Cronbach's α was used as a measure of scale reliability for perceived appearance (baseline: $\alpha = 0.94$; posttest: $\alpha = 0.94$) and global physical self-concept (baseline: $\alpha = 0.88$; posttest: $\alpha = 0.95$).

Process Evaluation

Feelings state. A one-item Feelings State questionnaire was administered before and after each HIIT session for the duration of the intervention (total 24 sessions) (38). Participants were asked to respond on an 11-point scale (−5 = very bad to +5 = very good) to the question *How are you feeling right now?* Mean pre- and postworkout scores were calculated for each session according to intervention condition.

Heart rate data. To monitor exercise intensity (target: efforts ≥85% of heart rate maximum), participants were fitted with Polar H7 heart rate monitors, which were connected to a central iPad application (Polar Team). The mean heart rate for the entire session and the mean maximum heart rate were tracked over the study period.

Statistical Analyses

Statistical analyses of the primary and secondary outcomes were conducted with linear mixed models using IBM SPSS Statistics for Windows, Version 20.0 (2010 SPSS Inc., IBM Company Armonk, NY). Intervention effects for the primary and secondary outcomes were examined by using linear mixed models. Because of the small sample size and the potential issues associated with interpreting *P* values (15), Cohen's *d* was included to provide a measure of effect size (adjusted difference between HIIT and control groups over time divided by the pooled SD of change), and 95% CI values were also determined. Moderators of HIIT effects were explored using linear mixed models with interaction terms for the following: i) sex (boys vs girls), ii) weight status (healthy weight vs overweight/obese), and iii) baseline fitness level (i.e., healthy fitness zone vs needs improvement). Subgroup analyses were only conducted if significant interaction effects were observed ($P = 0.10$).

In addition to Cohen's *d* effect sizes (mean difference [posttest – baseline] between groups divided by the pooled SD of change for the whole group), and based on a previous literature, the clinical inference of the true value of change scores was derived using a custom made spreadsheet developed by Hopkins (19). A clinical inference was based on the probabilities of harm and benefit for each outcome and is presented as the chance that the true value of the change scores was beneficial, trivial, or harmful (19). Our study used the default probabilities (%) and associated descriptors of 0 "most unlikely," 0.5 "very unlikely," 5 "unlikely," 25 "possibly" 75 "likely," 95 "very likely," and 99.5 "most likely" (19).

RESULTS

The number of participants involved at each phase of the study is reported in Figure 1. One secondary school was successfully recruited, and 65 adolescents from three classes (45 males, 20 females, mean ± SD age = 15.8 ± 0.6 yr) from grades 9 and 10 completed baseline testing (see Table 1). The intervention groups were similar for baseline characteristics.

TABLE 1. Participant baseline demographics *(Australia, July 2014)*.

	Control	AEP	RAP
	Total (n = 22)	Total (n = 21)	Total (n = 22)
	Mean ± SD	Mean ± SD	Mean ± SD
Age (yr)	15.6 ± 0.6	15.7 ± 0.7	15.5 ± 0.6
Weight (kg)	66.0 ± 15.8	64.7 ± 9.8	67.0 ± 12.9
Height (cm)	171.3 ± 10.6	172.3 ± 8.6	173.8 ± 7.1
BMI (kg·m^{-2})	22.29 ± 3.53	21.72 ± 2.10	22.08 ± 3.56
BMI-z	0.51 ± 0.94	0.43 ± 0.60	0.45 ± 1.05

BMI = body mass index.

Changes in Executive Function (TMT)

Small-to-moderate intervention effects for executive function were found for the RAP condition for all methods of calculation used (B/A: −0.56, 95% CI = −1.47 to 0.35; d = −0.37, 95% CI = −0.29 to 1.04; B-A: −7.76, 95% CI = −21.79 to 6.27; d = −0.40, 95% CI = −8.24 to 8.85; TMT B: −10.73, 95% CI = −26.22 to 4.76; d = −0.51, 95% CI = −8.92 to 9.73), which were all classified as "possibly beneficial." For the AEP condition, however, a small intervention effect for executive function was only evident when considering TMT B scores (−6.69, 95% CI = −22.03 to 8.64; d = −0.32, 95% CI = −9.12 to 9.77), which was also classified as "possibly beneficial."

Changes in Psychological Well-being (Flourishing Scale)

Small intervention effects for well-being were found for both HIIT conditions (AEP: 2.81, 95% CI = −2.06 to 7.68; d = 0.34, 95% CI = −3.84 to 3.32; RAP: 2.96, 95% CI = −1.82 to 7.75; d = 0.36, 95% CI = −3.86 to 3.13), which was "possibly beneficial."

Changes in Psychological Distress (K10)

There were no intervention effects for psychological distress for either HIIT groups, in comparison with the control condition. A clinical inference of "very unlikely harmful" was apparent for both conditions.

Changes in Physical Self-Concept

Changes for all outcomes are reported in Table 2. Analyses of efficacy (adjusted difference between groups and Cohen's d effect sizes reported) identified a small intervention effect for the RAP condition for perceived appearance (0.32, 95% CI = −0.25 to 0.86; d = 0.35, 95% CI = −0.74 to 0.01; clinical inference: "unclear"). However, no intervention effects were apparent for global physical self-concept in either HIIT group (clinical inference: AEP "most unlikely harmful"; RAP "unlikely harmful").

Process Outcomes

Changes in feelings state. Mean pre- and postworkout scores were calculated for each session according to intervention condition (see Figs. 2 and 3). For the AEP group, mean feeling state scores increased from pre = 1.57 ± 1.13 to post = 2.54 ± 1.00, which was statistically significant (P = 0.001), representing an average improvement of 0.97 ±

TABLE 2. Changes in cognitive and mental health outcomes postintervention.

	Control Group		AEP Group		RAP Group		Adjusted Difference between Groups[a]							
							AEP − Control				RAP − Control			
Variable	Baseline Mean (95% CI)	Postintervention Mean (95% CI)	Baseline Mean (95% CI)	Postintervention Mean (95% CI)	Baseline Mean (95% CI)	Postintervention Mean (95% CI)	Mean Change (95% CI)	P	Cohen's d (95% CI)	Clinical Inference[b]	Mean Change (95% CI)	P	Cohen's d (95% CI)	Clinical Inference[b]
Executive function (trails B − trail A)	34.25 (25.07 to 43.45)	34.95 (26.41 to 43.49)	36.05 (28.28 to 43.83)	32.80 (24.69 to 40.91)	39.88 (32.33 to 47.43)	32.81 (24.55 to 41.07)	−3.95 (−17.85 to 9.95)	0.571	−0.21 (−8.44 to 8.87)	Very unlikely harmful	−7.76 (−21.79 to 6.27)	0.273	−0.40 (−8.24 to 8.85)	Possibly beneficial
Executive function (trail B / trail A)	1.46 (0.98 to 1.94)	1.63 (1.09 to 2.17)	1.99 (1.49 to 2.48)	2.18 (1.62 to 2.73)	2.40 (1.92 to 2.88)	2.01 (1.47 to 2.55)	0.02 (−0.90 to 0.94)	0.968	0.01 (−0.69 to 0.66)	Very unlikely harmful	−0.56 (−1.47 to 0.35)	0.222	−0.37 (−0.29 to 1.04)	Possibly beneficial
Executive function (TMT B)	57.87 (47.2 to 68.54)	57.32 (47.43 to 67.21)	63.21 (54.10 to 72.33)	55.97 (46.80 to 65.14)	65.07 (56.24 to 73.91)	53.79 (44.50 to 63.08)	−6.69 (−22.03 to 8.64)	0.386	−0.32 (−9.12 to 9.77)	Unclear	−10.73 (−26.22 to 4.76)	0.171	−0.51 (−8.92 to 9.73)	Possibly beneficial
Flourishing Scale (psychological well-being)	48.27 (46.16 to 50.38)	47.00 (44.22 to 49.78)	46.38 (44.17 to 48.59)	47.92 (44.92 to 50.91)	46.59 (44.48 to 48.70)	48.28 (45.36 to 51.20)	2.81 (−2.06 to 7.68)	0.252	0.34 (−3.84 to 3.32)	Possibly beneficial	2.96 (−1.82 to 7.75)	0.219	0.36 (−3.86 to 3.13)	Possibly beneficial
Psychological distress	22.05 (18.87 to 25.23)	22.10 (18.83 to 25.36)	18.60 (15.27 to 21.94)	18.17 (14.74 to 21.59)	17.68 (14.50 to 20.86)	17.55 (14.31 to 20.78)	−0.49 (−3.37 to 2.40)	0.737	−0.11 (−1.76 to 2.13)	Very unlikely harmful	−0.19 (−2.97 to 2.59)	0.891	−0.04 (−1.83 to 1.96)	Very unlikely harmful
Mean physical self-description score (appearance)	4.49 (3.92 to 5.06)	5.00 (4.52 to 5.48)	4.09 (3.49 to 4.68)	4.69 (4.19 to 5.19)	3.52 (2.95 to 4.09)	4.35 (3.88 to 4.83)	0.89 (−0.47 to 0.65)	0.753	0.10 (−0.48 to 0.29)	Very unlikely harmful	0.32 (−0.25 to 0.86)	0.249	0.35 (−0.74 to 0.01)	Unclear
Mean physical self-description score (global physical)	5.00 (4.52 to 5.48)	5.04 (4.54 to 5.54)	4.69 (4.19 to 5.19)	4.71 (4.19 to 5.24)	4.35 (3.88 to 4.83)	4.41 (3.91 to 4.91)	−0.01 (−0.49 to 0.46)	0.957	0.00 (−0.32 to 0.33)	Most unlikely harmful	0.02 (−0.45 to 0.48)	0.935	−0.03 (−0.28 to 0.35)	Unlikely harmful

[a]Adjusted difference between groups and 95% CI between intervention and control groups after the 8-wk intervention (AEP minus control; RAP minus control).
[b]Likelihood of intervention being beneficial/trivial/harmful.
*P < 0.05.

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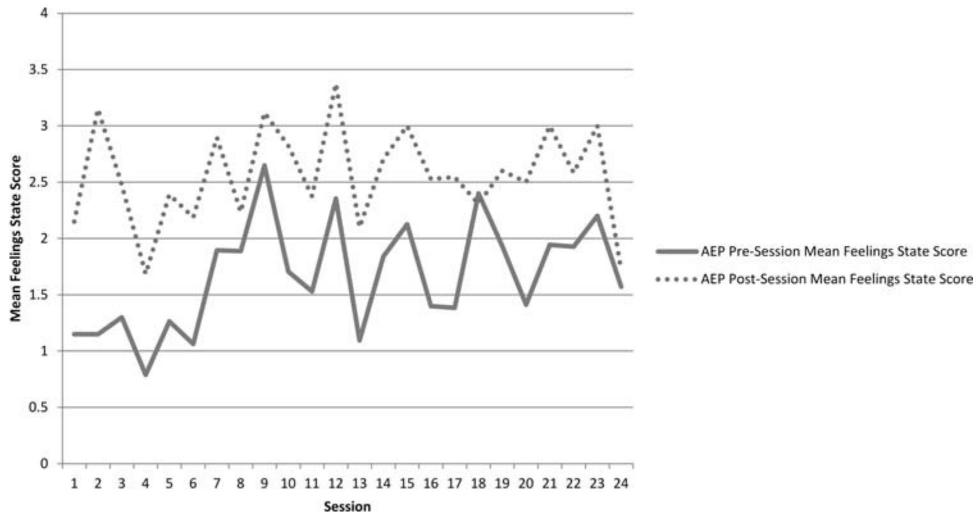

FIGURE 2—Mean feeling state scores recorded pre- and postsessions for the AEP condition.

1.08. The improvement in mean feeling state scores among participants in RAP approached statistical significance (pre = 1.85 ± 1.54 to post = 2.19 ± 1.54; $P = 0.06$), an improvement of 0.34 ± 0.80.

Heart rate data. Mean heart rate scores were calculated for each session according to intervention conditions. Higher average heart rates (AEP: 74.0%, 148.1 bpm; RAP: 77.6%, 155.2 bpm) were evident in the RAP group, in comparison with the AEP (note: session average heart rate included the warm-up, work periods, rest periods, and cooldown). By contrast, mean maximum heart rate was higher for the AEP group (AEP: 92.4%, 184.8 bpm; RAP: 91.8%, 182.2 bpm) in comparison with the RAP group.

Moderators. As there were no significant ($P < 0.10$) interaction effects for any of the potential moderators, subgroup analyses were not conducted.

DISCUSSION

The aim of the current study was to evaluate the effect of two HIIT protocols (AEP and RAP) on a range of cognitive and mental health outcomes in a sample of adolescents. Overall, small improvements in executive function (TMT B) and psychological well-being were evident in the AEP group, and small improvements in executive function (B-A; B/A), well-being, and perceived appearance were observed for the RAP group. However, when considering TMT B only, a moderate effect was apparent for the RAP condition. Mean feeling state scores improved from preworkout to postworkout in both HIIT groups; however, significant results were observed only among participants in the AEP group.

Executive function comprises several cognitive processes, which contribute to organizing and controlling goal-directed behavior, and includes inhibition, working memory, and cognitive flexibility (31). Although the evidence is still emerging, regular participation in physical activity has been linked to enhanced brain function and cognition and improved academic performance in adolescents (17). Evidence also suggests that incorporating physical activity into the school day is associated with improvements in attention, concentration, and time on task in the classroom (36). In our study, small and moderate improvements in executive

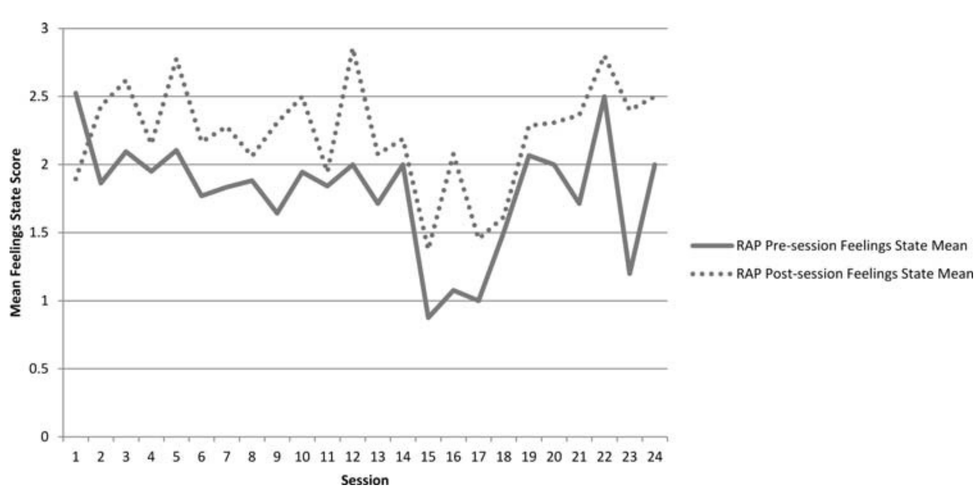

FIGURE 3—Mean feeling state scores recorded pre- and postsessions for the RAP condition.

function (TMT B) were evident in the AEP and RAP groups, respectively. Similarly, a 4-month cluster RCT of Spanish adolescents (n = 67) examined the effect of four PE lessons (embedded with high-intensity activities) per week versus four regular lessons per week versus two regular lessons per week (control; regular lesson duration = 55 min) on cognitive performance and academic achievement (3). Overall, no differences in cognitive performance or academic achievement were evident between having two or four regular PE lessons per week; however, students randomized to four sessions per week embedded with high-intensity activities achieved improvements in all cognitive performance variables (excluding verbal reasoning) and for average school grades. Our study builds on these findings by using very short duration HIIT to improve cognitive function in adolescents. Further research involving larger sample sizes and long-term follow-up is needed to investigate the effect that the intensity of PE lessons can have on cognition and academics for adolescents. Although session attendance plays a role for adolescent cognition and academics (18), the effect of intensity does not appear to have been examined.

Psychological well-being refers to an individual's perception of their success in relationships, self-esteem, purpose, and optimism (12). In our study, there was a small intervention effect for psychological well-being suggestive of a "possibly beneficial" effect for both HIIT intervention protocols. Each HIIT session was designed to meet participants' basic psychological needs for autonomy (e.g., choice of music, exercise choices during a workout, and choice of workout), competence (e.g., provision of challenging yet achievable workouts and sense of accomplishment), and relatedness (e.g., working in pairs, sessions focused on promoting encouragement, and support to peers), which may have also affected well-being. Similarly, in a recent 8-month RCT examining psychological well-being in adolescent boys (mean ± SD age = 12.7 ± 0.5) participating in the Active Teen Leaders Avoiding Screen time study (27), the intervention resulted in a small yet statistically significant effect on well-being. Interestingly, the intervention effect on well-being was mediated by improvements in muscular fitness and the provision of autonomy within lessons, indicating that the inclusion of resistance training within the intervention facilitated improvements in well-being. Although resistance training was included in the sessions programmed for the RAP group, there do not appear to be any substantial differences in well-being effects between groups in the current study. As the effect of HIIT on well-being appears promising, further research spanning beyond one school term with a focus on resistance training is needed to investigate the ongoing effect of this approach to exercise.

The HIIT intervention effect on psychological distress was marginal in the current study. Similarly, a meta-analysis of nine studies (1982–2010) examining the effect of physical activity on depression in youth (7) reported a small yet significant treatment effect. Of note, the greatest effects on depression were evident in RCT of <3 months, which used an educational component in addition to physical activity (7). Conversely, a review of five studies investigating the effect of exercise for the prevention and treatment of anxiety and depression in youth (1983–2005) reported that physical activity interventions had a statistically significant effect on reducing depression (standard mean difference effect size = −0.66, 95% CI = −1.25 to −0.08) (23). Given the inconsistent findings and limited number of current studies available, future research is needed to clarify the relationship between physical activity and psychological distress among adolescents and to determine the optimal intensity and duration of physical activity intervention to achieve the greatest improvements in psychological distress. Moreover, subgroup analyses are required to determine whether the effects of physical activity on depressive symptoms are stronger among individuals who are "at risk" or have depression. Because of the small sample size, this was not possible for the current study.

Physical self-concept refers to an individual's beliefs about their physical characteristics, and adolescence represents a significant period for the development of physical self-concept (29). Evidence suggests that in comparison with adolescents who engage in low levels or no physical activity, adolescents participating in higher levels of physical activity have greater self-concept (4). Adolescents' perceptions of physical appearance are typically formed by comparing themselves with peers (29). In our study, the RAP condition achieved a small positive intervention effect for the perceived appearance subscale. Similarly in a previous 8-wk study examining the effects of resistance training on physical self-perception in a sample of adolescents (n = 108) (26), significant changes in perceived body attractiveness were evident among girls randomized to the free weights resistance training condition (P < 0.01, d = 0.76); however, no significant changes were found for boys. A recent meta-analysis examining physical activity and domains of physical self-concept in youth reported a weak association between perceived appearance and physical activity (r = 0.14, 95% CI = 0.09–0.18, P > 0.001) (4). Given that physical self-concept (including perceived competence and appearance) is an important component of global self-esteem, the small improvements in perceived appearance demonstrated in our study (RAP condition) may have important implications for improving mental health outcomes. However, longer-term studies may be necessary (i.e., >8 wk) to improve perceived appearance, particularly among boys, and further investigations are needed to determine whether improvements in perceived appearance contribute to improvements in global self-esteem and serve as a protective factor against mental illness during adolescence.

Process outcomes. The high retention rate suggests that intervention strategies used in this program appealed to participants and resulted in their continued involvement in the program. Although the maximum heart rate data suggest that our target heart rates were achieved (i.e., ≥85% maximum heart rate), this cannot be confirmed with the available data. It should be noted that heart rate monitors were worn for the entire HIIT session, which included a warm-up, rest periods, and cooldown. Therefore, it is not surprising that participants' mean heart rates were less than 85% maximum heart rate. Unfortunately, we did not specifically ask participants to reflect on the potential benefits of incorporating resistance exercise into the HIIT protocols. However, considering the benefits of muscular fitness for health among adolescents (42), there is clear advantage to including resistance exercise in future interventions targeting adolescents. Encouragingly, mean feeling state scores improved from pre- to postworkout, suggesting that high-intensity exercise is likely to result in improved affective responses for this population group (38). However, results were only statistically significant for the AEP group, which could be explained by the slightly lower average heart rate reached across AEP sessions in comparison with the RAP sessions. It may be that AEP sessions were somewhat less strenuous than the RAP sessions and perceived as more achievable and enjoyable for participants. Although a recent commentary (6) has proposed that prescribing intense exercise to the general/sedentary population may lead to feelings of incompetence and failure resulting in reduced physical activity motivation and participation, this was not the case in our study. Interestingly, in a study conducted by Crisp et al. (11), the male participants did not consider sprint interval cycling to be more strenuous than moderate-intensity continuous cycling, and in a study conducted by Jung et al. (21), examining the affective response to high-intensity exercise compared with continuous moderate- or vigorous-intensity exercise conducted on cycle ergometers, participants reported greater enjoyment and a preference to participate in high-intensity intervals in comparison with continuous moderate-intensity exercise and continuous vigorous-intensity exercise. This highlights the importance of the type of exercises included in HIIT sessions being appealing for participants to maintain/improve enjoyment and motivation for physical activity.

Strengths and limitations. This novel study has several strengths, including the randomized design, assessor blinding, and high retention rates. However, some limitations should also be acknowledged. The small sample from one school and the uneven distribution of girls and boys participating in the study may limit the generalizability of our findings. In addition, the intervention period was relatively short, with no long-term follow-up conducted. Finally, the heart rate monitoring application did not allow for heart rate to be recorded during the work interval only (i.e., maximum heart rate and mean heart rate for the entire session were recorded). Our heart rate monitoring protocol provided a summary of the entire session and did not isolate participants' heart rates during the work interval only (i.e., maximum heart rate and mean heart rate for the entire session were recorded). In future studies, researchers are encouraged to use the lap function on the heart rate monitors to isolate HIIT work periods from rest periods and if possible record the length of time (number of minutes and percentage of session) that each participant met heart rate targets. This protocol will provide a better indication of HIIT session intensity.

CONCLUSION

The outcomes of this research contribute to understanding how short bouts of intense exercise influence cognitive and mental health outcomes in adolescent populations. Although evidence from this study highlights the potential of embedding HIIT within the school day for improving executive function, physical self-concept (especially appearance), and well-being among adolescents, no significant ($P < 0.05$) findings emerged. Therefore, further longitudinal research with longer follow-up periods, investigating a larger sample of adolescents from a range of year levels and schools, should be conducted.

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