Title: Feasibility and Preliminary Efficacy of a Teacher-facilitated High-Intensity Interval Training Intervention for Older Adolescents

Running head: A school-based HIIT program for older adolescents

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ABSTRACT

Purpose: This study was designed to assess the feasibility and preliminary efficacy of a teacher-facilitated high-intensity interval training (HIIT) intervention for older adolescents (i.e., 16-18 years).

Methods: Two secondary schools from New South Wales, Australia were recruited, and participants (i.e., Grade 11 students; 16.2 [0.4] years) were randomized at the school level to the Burn 2 Learn (B2L) intervention (n=38), or a wait-list control group (n=30). Teachers were trained to facilitate the delivery of the novel HIIT program, which involved 3 sessions/week (~12-20 minutes) for 14 weeks. A range of process measures were used to assess intervention feasibility (i.e., recruitment, retention, attendance, and program satisfaction). Primary (cardiorespiratory fitness [CRF], determined using the PACER shuttle run test) and secondary outcomes were assessed at baseline and posttest (14-weeks).

Results: Sixty-eight grade 11 students were recruited at baseline (85% of target sample), 61 participants completed posttest assessments (90% retention) and on average, participants performed 1.9 sessions/week. Overall, teachers (4.0 /5) and students (4.0/5) were satisfied with the B2L program. Group-by-time effects were observed for CRF (8.9 laps, 95% CI = 1.7 to 16.2) and a selection of secondary outcomes.

Conclusion: This study provides evidence for the feasibility and preliminary efficacy of a teacher-facilitated HIIT intervention for older adolescents.

INTRODUCTION

International physical activity guidelines recommend that adolescents (13-17 years) engage in a minimum of 60 minutes of moderate-to-vigorous intensity physical activity each day. Furthermore, it is recommended that adolescents engage in muscle and bone strengthening activities (e.g., resistance training) on at least three days per week (1). In spite of the well-established benefits, physical activity levels decline by approximately 7% per year during adolescence (2), and approximately 80% of adolescents worldwide are not satisfying current physical activity recommendations (3). Little is known regarding the activity patterns of older adolescents (i.e., students in the final years of secondary school) because they are underrepresented in school-based physical activity research (4). Of additional concern is the secular decline in young people's cardiorespiratory fitness (CRF) levels, which have been observed across the globe (5). CRF is a 'powerful marker of health' (6), with evidence demonstrating that lower CRF during late adolescence, is associated with an increased risk of myocardial infarction and mortality later in life (7, 8). Taken together, these findings highlight the importance of identifying strategies to engage youth in physical activity of sufficient volume and intensity to maintain/improve CRF.

High-intensity interval training (HIIT) has emerged as a relatively novel and time-efficient strategy for improving CRF in adolescents. HIIT involves short bursts of high-intensity activity (i.e., ≥85% heart rate max), interspersed with brief periods of low-intensity active recovery or rest. Despite a shorter training duration, evidence suggests that HIIT can improve adolescents' CRF to a similar extent as prolonged bouts of moderate-intensity activity (9, 10). Furthermore, participation in vigorous activity, and higher levels of CRF are important for the short- and long-term psychological health of youth (11). Although training at higher intensities may evoke feelings of displeasure, several studies have examined the perceptual responses in adolescents performing HIIT, and reported greater preference and

enjoyment of this mode of exercise, which is an important factor for maintaining exercise adherence (12). HIIT appears to be a time-efficient and effective approach to training in adolescents, however there is a need to develop and evaluate optimal and sustainable HIIT protocols for this population (13). Indeed, limited research has been conducted in older adolescents in real world settings, such as schools (9).

Schools are ideal settings for physical activity promotion because they have convenient access to young people, trained teachers, and access to the necessary facilities and equipment. A number of studies have demonstrated that HIIT programs can be successfully delivered in schools by external research teams (9). This is an important step in the research dissemination process and has helped to establish that this type of training is effective, safe and acceptable for delivery in schools. However, for HIIT to have population health benefits, a more scalable approach to delivery is required. To the authors' knowledge, no previous study has examined the feasibility of training teachers to facilitate the delivery of HIIT in secondary schools. Therefore, the objective of this study was to evaluate the impact of a teacher-facilitated HIIT program for older adolescents, embedded within the school day in regards to four domains of feasibility (i.e., recruitment, retention, adherence, and program satisfaction). Preliminary efficacy was evaluated by testing the effect of the HIIT program on CRF, muscular fitness and psychological health.

METHODS

Study design and participants

Ethics approval for the study was obtained from the University of Newcastle, Australia (H-2016-0424), and the New South Wales (NSW) Department of Education (SERAP 2017116). School principals, teachers, parents, and study participants provided informed written consent prior to enrolment. The Burn 2 Learn (B2L) trial was registered with the Australian and New

Zealand Clinical Trials Registry (ACTRN12617000544370). B2L was evaluated using a two-arm group-randomized controlled trial design in two secondary schools in NSW, Australia. Baseline data was collected the week immediately preceding commencement of the intervention (i.e., Term 2, week 2). The intervention was delivered over a 14-week period during school Terms 2 and 3 (i.e., May-July, 2017) and posttest data was collected the week immediately following the intervention period (i.e., Term 3, week 5) at the schools involved. Trained research assistants, who were blinded to group allocation, conducted assessments for the primary outcome. Assessors responsible for the collection of secondary outcomes were not blinded to group allocation.

The two schools were randomized to the B2L intervention group, or a wait-list control group using a coin flip by an independent researcher not involved in the project following baseline assessments. Participants randomized to the intervention group participated in a 14-week school-based HIIT program, whereas the wait-list control group participated in usual school activities and received the intervention following the posttest assessment period. Eligible participants (N=68) were students in Grade 11 at the study schools, who did not have an injury or illness which would preclude their participation in high-intensity activity as outlined in the participant information and consent form (e.g., existing physical injury).

Sample size calculation

A power calculation was conducted to determine the required sample size to detect a between-group difference in the primary outcome of CRF, assessed using the 20 m Progressive Aerobic Cardiovascular Endurance Run (PACER) test (outcome=laps completed). Based on previous research, an adjusted between-group difference of 5 laps was considered achievable and clinically significant in the study population (10, 14). Assuming a standard deviation of change of 7 laps, alpha levels set at .05, and an intervention: control

participant ratio of 1:1, the required sample size to achieve 80% power was 32 participants per group (64 participants in total). To account for expected dropout of 10% at the study endpoint (i.e., 14-weeks), the target sample size was inflated to 40 participants per group (i.e., 80 participants in total).

Intervention

The 14-week multi-component HIIT intervention (see Table 1) was designed to improve older adolescents' physical and mental health. A full-day professional learning workshop was provided for a school champion (i.e., teacher), and another member of staff to facilitate the B2L program. The B2L program was originally designed to be facilitated by student 'peer leaders' during recess and lunch breaks. However, after discussions with the school champions during the full-day professional learning workshop, it was decided that teachers would also facilitate the delivery of HIIT sessions during class time. Both of these delivery options were explored at the intervention school, however as the program progressed it became evident that in-class delivery was the optimal implementation model. The intervention also included an introductory seminar for students, school-based HIIT sessions, parental videos, and an equipment and resource pack (including HIIT task cards). Technique cards reinforcing correct technique were also provided to the intervention school and revised by the school champion during the early weeks of the intervention.

Participants in the intervention group were prescribed three HIIT sessions per week, for 14 weeks. School champions were asked to offer at least two opportunities during the school week for students to complete HIIT sessions during class time, with the ultimate target of students performing three sessions per week (i.e., one self-directed session outside of class). Any additional HIIT sessions performed by participants were reported individually to the school champion to monitor session adherence. HIIT sessions comprised of a brief two

minute warm-up, followed by 8-16 minutes of HIIT, followed by a two minute cool-down (12-20 minutes total), which were performed individually, in pairs, or small groups. Participants were provided with pre-designed HIIT workouts that included a combination of aerobic- (e.g., shuttle runs) and resistance- (e.g., push-ups) based exercises designed to be performed using minimal space and equipment.

Drawing upon evidence gathered from previous HIIT studies conducted with adolescents (14-16), the sessions included a variety of activities to enhance motivation and appeal to the interest of older adolescents. Participants were able to select from the following HIIT-themed workouts: Gym HIIT, Sport HIIT, Class HIIT, Dance HIIT, Combat HIIT and Brain HIIT (Table 1). Several precautions were undertaken to ensure the safety of participants, including: i) explanation of correct technique for all exercises in the introductory student seminar session, ii) inclusion of warm-ups and cool-downs, and iii) reminders for teachers to monitor and correct exercise technique. While the majority of previous HIIT interventions have studied the effects of aerobic-based exercises (e.g., running/cycling programs), the decision to include both aerobic- and resistance-based exercises was based on previous research, which established the superior efficacy of this approach (14, 17). To encourage maintenance of the appropriate exercise intensity (i.e., >85% maximum heart rate), participants were provided with heart rate monitors (Wahoo TICKR) during HIIT sessions. Participants' heart rate during sessions were viewed on smartphones utilizing a commercially available group heart rate monitoring application (OnBeat).

Theoretical basis

In line with Self-Determination Theory (SDT) (18), B2L sessions were designed to satisfy participants' basic psychological needs for autonomy, competence, and relatedness, to support autonomous motivation for physical activity. Basic psychological needs were

operationalized using the 'SAAFE' (Supportive, Active, Autonomous, Fair, and Enjoyable) teaching principles (19) that are described in greater detail in Table 2. The SAAFE teaching principles were outlined to school champions, and students, during the researcher-led seminars, and reinforced using session observational checklists, by members of the research team during weeks 4 and 7 of the intervention.

Study measures

Baseline and posttest assessments were conducted at the study schools by trained members of the research team. Health-related fitness assessments were conducted following a brief verbal demonstration of each test to familiarize participants with the assessment protocol. Baseline and posttest measures of fitness were collected at the same time of day. Measures of self-report including psychological difficulties, subjective stress, autonomous motivation for physical activity, and basic needs satisfaction questionnaires were administered on electronic tablets under exam-like conditions. Standard demographic information (e.g., age, sex) were also collected at baseline under similar conditions and took approximately 15 minutes to complete.

Process evaluation

A range of quantitative process measures were used to assess feasibility. The four domains of feasibility were (i) recruitment (achievement of target sample size), (ii) retention (retention rate at 14-week follow-up), (iii) attendance (adherence to HIIT sessions), and (iv) program satisfaction (teachers and students satisfaction with the B2L program). Session attendance was recorded by the school champion during class time HIIT sessions, with additional sessions (including school holiday weeks) reported by students to the school champion. Intervention participants completed a post-program questionnaire, regarding their experiences with various components of the B2L program, including barriers to participation, and

preferred HIIT type. Participants reported their satisfaction with the program on a 5-point scale ranging from *1 "Poor/Strongly disagree" to 5 "Excellent/Strongly agree*".

Primary outcome

Cardiorespiratory fitness (CRF). CRF was assessed via the 20 m PACER shuttle run test (20). The test is the most commonly used field-based measure of CRF worldwide, demonstrating high reliability and validity (21). A 20 m course was set up indoors on a hard surface with students instructed to run back and forth between two sets of lines in accordance with an accompanying audio file. Test administrators provided verbal encouragement to participants in order to maximize motivation. The last successful stage was recorded (e.g., 10.1), and then converted into the number of 20 m laps (e.g., 84 laps). The total number of laps was used to estimate age- and sex-specific VO_2 max values, and classify students in relation to criterion-based cardiorespiratory fitness zones (20).

Secondary outcomes

Health-related fitness. Upper-body muscular endurance was assessed via a modified push-up test (push-ups completed) and lower body muscular power was assessed via a standing long jump test (maximum distance jumped). Both tests of muscular fitness have demonstrated adequate test-retest reliability based on measures of either rank-order repeatability (ICC for push-ups = 0.90) (22), or change in mean (mean inter-trial difference for standing long jump of -0.3 to 0.3 cm) (23). Body weight was measured to the nearest 0.1 kg in light clothing without shoes using a portable digital scale. Height was measured to the nearest 0.1 cm using a portable stadiometer, and converted to meters. Body weight and height values where then used to calculate BMI using the standard equation [weight (kg)/height (m) ^{2}]. Age- and sex-specific BMI z-scores were calculated and participants were classified into weight categories according to International Obesity Task Force cut-offs (24).

Psychological health. Psychological distress was assessed using the validated 'Strengths and Difficulties Questionnaire' (SDQ) (25), which has been used extensively in adolescent populations. The SDQ consists of 25 items, covering 2 subscales (i.e., strengths and difficulties). The strength subscale consists of one domain (prosocial behavior), and the difficulties subscale consists of four domains (emotional symptoms, conduct problems, hyperactivity, and peer problems). A total difficulties score was obtained by adding the scores of all four difficulty domains. Participants were instructed to answer the questions in relation the previous 6-months. Scores are allocated based on a three-point format (i.e. *"Not true" = 0, "Somewhat true" = 1, and "Certainly true" = 2*). Lower scores indicate fewer psychological difficulties. Subjectively measured stress was assessed via the validated 'Perceived Stress Scale' which is designed to assess the degree to which situations in one's life are stressful (26). Participants were instructed to answer the 10 item questionnaire in relation to the previous month. Responses are scored on a 5-point scale ranging from *0 "Never" to 4 "Very often*" and then summing across all scale items. Higher scores indicate a greater degree of subjective stress experienced by participants.

Motivation and psychological needs. Autonomous motivation for physical activity was assessed using the 'Behavioral Regulations in Exercise Questionnaire' (27), for the following two subscales; identified (e.g., "*I value the benefits of exercise*"), and intrinsic (e.g., "*I exercise because it's fun*") regulations. Responses are scored on a 5-point scale ranging from *0 "Not true for me" to 4 "Very true for me*". Basic psychological needs satisfaction was assessed via the 'Adolescent Psychological Need Support in Exercise Questionnaire' (28). Items refer to need satisfaction regarding friends support (e.g., "*I feel they care about me*"). Responses are scored on a 7-point Likert scale ranging from *1 "Strongly disagree" to 7 "Strongly agree"*.

Statistical analysis

Analyses of the primary and secondary outcomes were conducted using linear mixed models in IBM SPSS Statistics for Windows, Version 23.0 (2010 SPSS Inc., IBM Company Armonk, NY), with alpha levels set at $p < .05$ for participants providing complete data at both time points. The models were used to assess the impact of treatment (control or B2L), time (treated as categorical with levels baseline and 14-weeks), and the group-by-time interaction. Intention-to-treat analyses were conducted as a sensitivity analysis (Supplementary Table 2). Cohen's *d* was also calculated (adjusted difference between the control and B2L group over time divided by the pooled standard deviation of change) and interpreted as follows: $d=0.2$, $d=0.5$ and $d=0.8$, considered as small, medium and large effect sizes, respectively (29).

RESULTS

Baseline characteristics of the study sample are presented in Table 3. The flow of participants throughout the study is reported in Figure 1. In total 68 participants (37 males, 31 females, mean ± SD age = 16.2 ± 0.4 years) from Grade 11 were recruited from two consenting secondary schools and performed baseline assessments, representing a recruitment rate of 85%. Immediately following baseline assessments, four participants withdrew from the study, and one participant moved schools. During the intervention period, two participants from the intervention group sustained injuries unrelated to the study and were excluded from analysis. Intervention effects for the primary and secondary outcomes were similar between completer case analysis (Table 4) and intention-to-treat analysis (Supplementary Table 2).

Process evaluation

Process evaluation data are presented in Supplementary Table 1.

Recruitment, retention and adherence. The program achieved 85% of the targeted study sample**,** with 84% of the intervention participants and 97% of the control participants retained at follow up assessments (14-weeks post-baseline). Participants averaged 1.7 (0.3)

sessions/week over the study period. Higher adherence was observed during school weeks (1.9 [0.3] sessions/week), compared to school holiday weeks (0.8 [0.9] sessions/week). Of the available heart rate data, participants reached an average of 73.4% of age-predicted max heart rate, 150 beats per minute during the B2L sessions (combination of work and rest phases). The average maximum heart rate value was 179 beats per minute, representing 87.6% of age-predicted max heart rate. Adherence to the SAAFE principles was lower than expected. The active (3.5/5), autonomous (3.0/5), and fair (3.5/5) teaching strategies were implemented most effectively by the school champions.

***Student and teacher satisfaction*.** Overall satisfaction of the program was high amongst students (4.0/5). However, students expressed their dissatisfaction with the commercially available heart rate monitoring app, which failed to work consistently (2.7/5). The practical HIIT sessions were enjoyed by students (3.9/5), with 'Sport HIIT' the most popular type. Students rated the B2L technique cards highly (4.0/5). The most common motivator for students participating in the B2L program was to improve their general health (4.4/5), while the most common barrier to participation was forgetting to perform HIIT sessions (3.3/5). Overall program satisfaction was also high amongst teachers (4.0/5). Similarly, teachers expressed their dissatisfaction with the heart rate monitoring technology and smartphone app (2.0/5). Intervention teachers also expressed high satisfaction with the professional development workshop (5.0/5), and were highly confident in their ability to facilitate the delivery of the program (5.0/5). No injuries or adverse events were recorded by the school champions.

Primary outcome

There was a group-by-time interaction in favor of the intervention group for CRF [8.9 laps (95% CI, 1.7 to 16.2), P=0.017, d=0.69], representing a moderate-to-large effect size.

Secondary outcomes

Health-related fitness. There were no group-by-time effects observed for upper-body muscular endurance (P=0.280, d=0.29). There was a group-by-time interaction for lower-body muscular power [10.1 cm (95% CI, 0.3 to 19.8), P=0.043, d=0.46], representing a moderate effect in favor of the intervention group. A group-by-time interaction was observed for BMI in favor of the control group [0.4 units (95% CI, 0.1 to 0.6), P=0.014, d=0.67].

Psychological health. There was a moderate group-by-time interaction for the total psychological difficulties score [-2.1 units (95% CI, -4.0 to -0.3), P=0.023, d=0.57]. Further analysis revealed significant reductions in two specific 'difficulties' subscales, those being 'emotional problems' [-0.9 units (95% CI, -1.6 to -0.01), P=0.022, d=0.61] and 'peer problems' [-0.7 units (95% CI, -1.3 to -0.1), P=0.017, d=0.60]. There were no group-by-time effects for perceived stress.

Motivation and psychological needs. There were no group-by-time effects for intrinsic (P=0.751, d=0.09), or identified (P=0.794, d=0.06) motivation. No group-by-time effects were observed for autonomy (P=0.764, d=0.09), relatedness (P=0.310, d=0.29), competence (P=0.447, d=0.26) or satisfaction.

DISCUSSION

The aim of this study was to assess the feasibility and preliminary efficacy of a teacher-facilitated HIIT program for senior school students. Overall, the program was well received by both students and teachers, suggesting the HIIT protocols and delivery methods were acceptable. The program resulted in relatively high recruitment and retention rates, however session adherence was lower than initially prescribed over the 14-week study period, which may be due to unavoidable interruptions to the school week (e.g., examinations, excursions, and school events). Future research should explore strategies for improving adherence, both

within and beyond the school setting. Despite achieving fewer weekly sessions than intended, there were promising findings in regards to the positive intervention effects for CRF.

A recent report compiled by the United States' physical activity guidelines review committee recommended that novel approaches to physical activity promotion such as HIIT should be explored with adolescents (30). The growing evidence base highlights the potential efficacy and acceptability of this type of training amongst adolescent populations. However, the majority of previous research has utilized running, or sprint-based training protocols evaluated in controlled laboratory conditions. Moreover, previous school-based HIIT studies have been delivered by researchers. The findings from such studies have limited generalizability to 'real world' settings (31). In the current study, four specific domains of feasibility (recruitment, retention, adherence, and satisfaction) were used to assess the suitability and acceptability of a real world HIIT program among a sample of older adolescents.

As evidenced by high levels of recruitment and retention, the B2L program appealed to participants and resulted in their on-going involvement in the program. It is important to note that retention was slightly lower in the intervention group. Reasons for withdrawal from the study were due to injuries sustained in activities unrelated to the program, change of school, and withdrawal following baseline assessments (i.e., participants recruited and assessed, however did not take part in the program). A common criticism of HIIT is that it may not be suitable for the general population due to feelings of displeasure associated with high-intensity exercise. However, this viewpoint is not supported by the available adolescent literature (12, 32). For example, Malik and colleagues (12) demonstrated that adolescents experience greater post-exercise affect following HIIT, despite higher levels of perceived exertion, compared to moderate-intensity exercise. Nevertheless, HIIT critics have argued that participating in HIIT may have a negative effect on participants' motivation to be active

(3). It is therefore promising to find that participants in the current study did not withdraw from the program due to the perceived aversive nature of HIIT. It is encouraging to find that participation in the intervention did not diminish participants' autonomous motivation for activity. Consistent with SDT, satisfying basic psychological needs (i.e., autonomy, competence, and relatedness) serves to promote participation in physical activity by enhancing autonomous motivation. Evidence from the current study suggests that school-based HIIT programs can be delivered in a way that does not thwart basic psychological needs.

Although students' completion of the exercise sessions was lower than initially planned, a number of disruptions within the school (i.e., examination periods, school excursions, and extra-curricular activities) prevented students from receiving the prescribed dose. We cannot confirm the exact number of HIIT sessions completed by the students during class time and outside of class time (i.e., recess, lunch and during school holidays) because adherence was self-reported by teachers and students, respectively. Participants completed 1.9 per week sessions during school weeks, highlighting the potential feasibility of this approach. As expected, fewer sessions were completed by students during the school holiday period (i.e., 0.8 sessions per week). Poor implementation is a common problem in school-based physical activity intervention research (33) and researchers have started to rethink the value of widely used behavior change theories. For example, Beets and colleagues recently proposed the Theory of Expanded, Extended, and Enhanced Opportunities (TEO) for physical activity promotion in youth (34). The authors suggest the extension and enhancement of existing physical activity opportunities, as well as the creation of new opportunities (i.e., expansion), such as the teacher-facilitated HIIT sessions, is needed to increase young people's physical activity levels. However, it is evident from the current study that once the provision of a physical activity opportunity (i.e., teacher facilitated HIIT

sessions) is removed, participation declines. Findings from this study highlight the need to identify innovative strategies to encourage student participation in physical activity beyond the organized sessions provided in the school setting.

Participant satisfaction can play a crucial role in the overall engagement, and effectiveness of physical activity programs. Although there is growing interest in school-based HIIT research, greater in-depth explorations of participants' experiences is needed. To the best of our knowledge, only two previous school-based HIIT studies (14, 35) have conducted extensive process evaluations. One study gathered participant feedback through post-intervention focus groups and reported that participants enjoyed the vigorous nature of the intervention, and felt more confident in performing the exercise sessions as the study progressed (35). Another study measured feedback through a post-intervention evaluation questionnaire, with participants reporting high satisfaction with the program (4.2/5) on a 5-point Likert scale (*1 "Strongly disagree to 5 "Strongly agree*) (14). In the current study, participants (both students and teachers) expressed their overall satisfaction with a teacher-facilitated HIIT program, embedded during class time, and suggests that school-based HIIT programs can be delivered in an enjoyable manner.

In the current study, students were provided with a variety of HIIT workouts (e.g., Sport HIIT, Combat HIIT), that incorporated both aerobic- and resistance-based exercises. Involving students in the design of HIIT sessions might enhance students' autonomy and motivation to participate. For example, Weston and colleagues (15), used pre-program focus groups to identify different activities to include in their HIIT intervention. In the current study, the most popular HIIT sessions (i.e., Sport HIIT) incorporated sporting equipment and movements (e.g., performing four push-ups, followed by dribbling a basketball ball 10 m, repeated for 30 seconds). In addition to the different themed HIIT workouts, students were

379 also encouraged to design their own workouts (i.e., Custom HIIT) using their acquired
380 knowledge and skills.

381 An important consideration in HIIT research is the monitoring of participants'
382 adherence to the prescribed intensity. In the current study, we used Wahoo TICKR heart rate
383 monitors and the OnBeat group heart rate monitoring app that students downloaded and used
384 on their smartphones. However, both students and teachers expressed their dissatisfaction
385 with the heart rate monitors and commercially available app, both of which failed to work
386 consistently. Evidence from the available data suggests that additional strategies and
387 technology are needed to help students achieve the prescribed heart rate targets. Providing
388 students with heart rate monitors and access to tracking software can be a time consuming
389 and costly practice. As such, group-based heart rate monitoring technology needs to be easy-
390 to-use and time-efficient. Alternatively, researchers might consider subjective measures of
391 intensity (e.g., rating of perceived exertion) in future school-based HIIT research.

392 The successful training of teachers to facilitate school-based HIIT programs is
393 essential for sustainability and scalability. While previous school-based HIIT programs have
394 been effective in improving a range of health-related outcomes, these programs were
395 delivered by, or involved extensive contact from research staff members and/or external
396 providers (9). In the current study, two school teachers attended a training workshop
397 delivered by the research team prior to implementation. Teachers reported high satisfaction
398 with the training workshop and were confident in their ability to the implement the program
399 as intended. Following the intervention, the teachers expressed their overall satisfaction with
400 program, and anecdotally were inclined to continue the program next year with a new cohort
401 of students. In addition, teachers strongly agreed that the facilitation of in-class HIIT sessions
402 led to improvements in on-task and classroom behavior of their students involved in the
403 program. Evidence suggests that classroom physical activity breaks have beneficial effects on

404 classroom behavior and concentration in children (36) but the effect on adolescents has not
405 been tested. Previous research supporting the benefits of classroom physical activity breaks,
406 identified that efforts should focus on ensuring teachers are equipped with the necessary
407 resources to perform such activity (37). In the current study, intervention materials and HIIT
408 sessions were designed to ensure teachers were well equipped with the resources in order to
409 facilitate the program.

410 A recent systematic review and meta-analysis (10) revealed that HIIT programs
411 delivered by researchers can improve adolescents' CRF [unstandardized mean difference=
412 2.6 mL/kg/min, 95% CI= 1.8 to 3.3]. More specifically, school-based HIIT studies have
413 reported improvements in CRF of approximately 5 laps on the multi-stage fitness test (14,
414 15). In the current study, we found moderate-to-large intervention effects for CRF. This
415 effect was largely driven by a decline in CRF observed in the control group. Of note, the
416 largest declines were observed among the fittest participants. A number of participants in the
417 intervention (n = 5) and control (n = 6) groups, who achieved high CRF scores at baseline
418 (i.e., ≥ 95 laps), were unable to achieve their baseline scores at posttest. Intervention group
419 participants' CRF levels were higher than expected at baseline (mean = 73 laps) and it is
420 possible that the volume and intensity of activity provided in the B2L intervention was not
421 sufficient to induce physiological adaptations among the fittest participants. In summary, the
422 CRF results should be interpreted with caution and reflect the need for a large-scale definitive
423 trial. Nevertheless, our findings indicate that a small number of HIIT sessions can have
424 positive benefits for students' CRF.

425 An important component of the B2L program was the inclusion of both aerobic-, and
426 resistance-based exercises. We have previously reported the superior effect of this approach
427 (14), however few adolescent HIIT studies have utilized resistance training (31). In the
428 current study, a moderate intervention effect was observed for lower-body muscular power

and may be due to the inclusion of exercises that required lower-body explosive power (e.g., squat jumps). Given the importance of developing muscular fitness during youth, there is a strong rationale for embedding resistance-based exercises in future physical activity interventions targeting adolescents. As a combination of aerobic and resistance exercises likely have a greater energy demand than aerobic exercises alone, this approach may also support students in achieving a heart rate at or above 85% of maximum (as required for the exercise to be considered high intensity).

Interestingly, we observed an intervention effect for BMI, in favor of the control group. This effect was largely driven by a reduction in BMI among participants in the control group, while BMI remained stable among participants in the intervention group. It is possible that this effect was independent of the research study and due to changes in behavior among participants in the control group. Of note, participants in the intervention group did not regress to an unhealthier weight range and it is therefore unlikely that participation in the study had a negative impact on their body composition. BMI calculations only take into account whole body mass and do not distinguish between muscle and fat mass. Therefore, these findings may underestimate the beneficial effects of the intervention, as performance in resistance-based exercises may have improved body composition among those in the intervention group (i.e., an increase in fat-free mass and concomitant decrease in fat mass) without a meaningful shift in total body mass.

Participants in the intervention group reported significant reductions in psychological difficulties, but not perceived stress over the study period. Further analysis of the SDQ subcomponents revealed moderate effect sizes for emotional (d = -0.61) and peer (d = -0.60) problems. Evidence from systematic reviews suggests that participation in physical activity can improve mental health and reduce symptoms of ill-being in youth (11, 38). While the mechanisms responsible for this effect are not fully understood, it is suggested that acute

454 bouts of activity may contribute to enhanced psychological health, via the release of
455 endorphins, leading to feelings of heightened euphoria (38). In previous work, we established
456 that adolescents feel better after performing HIIT (17), lending support to the neurobiological
457 hypothesis mentioned above. It is also suggested that elements of psychosocial behavior such
458 as social connectedness may contribute to positive affect by providing interaction in the
459 context of physical activity (38). Of note, the SDQ requires participants to reflect on
460 psychological difficulties they experienced in the last six months. As the current study was
461 conducted over a four-month period, participants' posttest responses included time before the
462 start of the intervention which may have some impact on our findings.

463 **Strengths and Limitations**

464 Strengths of the present study include the randomized controlled trial design, unique study
465 population and novel intervention. Although this study provided some promising results,
466 certain limitations must be acknowledged. The small and relatively homogenous sample
467 limits the generalizability of our findings. Furthermore, the study involved only two schools,
468 and we were unable to adjust for the clustering of effects at the school level. As such, the
469 findings from this study should be interpreted with caution. Despite overall satisfaction with
470 the program, some participants in the intervention group expressed difficulty with the
471 smartphone app and heart rate monitoring technology, both of which failed to work
472 consistently. As a result, we did not have objective data for the HIIT sessions that occurred
473 outside of school sessions. It is therefore unknown whether participants were working at
474 sufficient intensity during these HIIT sessions. It should also be acknowledged the present
475 study utilized teachers to facilitate the exercise sessions, which may have resulted in lower
476 than intended exercise intensity and/or fewer overall sessions delivered. Despite this
477 limitation, it is important to note that teachers are critical for the widespread implementation
478 of HIIT in schools. It is therefore promising that we observed effects for important health-

related outcomes using a more scalable intervention model than has been used in previous HIIT trials. Although we planned to include waist circumference as a measure of body composition, our research assistants were unable to achieve satisfactory intra- and inter-reliability and therefore this information cannot be presented. Finally, although the PACER test is considered the most appropriate field-based measure for evaluating CRF (39), it is difficult to determine whether maximal effort is indeed reached. Incorporating heart rate tracking technology when performing the PACER test may strengthen the validity of this measure (40), however, this strategy must be weighed against potential logistical issues such as time constraints when evaluating fitness in 'real world' settings (e.g., schools). This study provided a unique opportunity to explore different models for delivering HIIT in schools. During the early phases of the intervention period, the research team utilized a flexible delivery model, in which teachers could facilitate HIIT sessions during class or assign 'student leaders' who would facilitate HIIT sessions occurring during school breaks, or before, or after school. It quickly became evident that the most practical method of delivery to ensure greater session adherence was during class time as facilitated by teachers.

CONCLUSION

Preliminary evidence suggests that school-based HIIT can positively impact health-related fitness, as well as reduce psychological distress in older adolescents. Considering levels of physical inactivity among older adolescents, calls for novel approaches such as HIIT to increase participation in physical activity are warranted. Based on process data gathered from our trial, the B2L program was a feasible method of delivering a sufficient dose of physical activity to senior school students. It is important to note that delivering HIIT in schools is not without challenges and researchers are encouraged to utilize a range of implementation strategies, such as partnering with the appropriate educational authority, engaging school leaders, supplying schools with equipment and resources, providing professional learning and

on-going support for teachers. In summary, findings from this study provide preliminary evidence that school-based HIIT can positively impact adolescents' health-related fitness and mental health. A large-scale effectiveness evaluation of the B2L intervention in secondary schools is warranted.

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Table 1. Intervention and implementation description.

Intervention component	Dose	Description
Teachers		
1) Professional learning workshop	1 x 5 hour workshop	A professional development workshop was conducted for the intervention group teacher identified as a 'B2L school champion', as well as another member of staff. The workshop provided a rationale for the intervention, including the latest evidence regarding the benefits of vigorous physical activity, program overview, and core responsibilities.
Students		
2) Interactive seminar	1 x 2 hour seminar	A researcher-led introductory workshop was delivered to participants in the intervention school. The workshop included the following: (i) rationale for the program, (ii) introduction to the B2L program, (iii) safety considerations, and (iv) introduction to the smartphone app and explanation of the heart rate monitors.
3) School-based HIIT sessions	14-weeks 3x/week	HIIT session ranged from 12-20 minutes (including a brief warm up/cool down) and were prescribed 3 times per week. Sessions ranged from 8-16 intervals, adopting a 1:1 work to rest ratio (i.e., 30 seconds work, followed by 30 seconds rest), allowing participants to easily work together in partners or small groups. Participants were able to select from a variety of pre-designed HIIT workouts incorporating both aerobic-based and resistance-based exercises;

		Gym HIIT – combination of aerobic movements (e.g., skipping) and strength-based exercises (e.g., squat jumps). **Sport HIIT** – incorporating sporting equipment (e.g., shuttle run while dribbling a basketball). **Class HIIT** – combination of exercises that can be performed in a classroom (e.g., running on the spot, tricep dips). **Dance HIIT** – involving high-intensity dance movements designed by a professional dance instructor. **Combat HIIT** – combination of aerobic and strength-based boxing/mixed martial arts movements (e.g., front kicks). **Brain HIIT** – incorporating activities that encourage thinking while participating in high-intensity activity. **Custom HIIT** – students were encouraged to design their own workouts using their acquired knowledge and skills.
4) Smartphone application	14-weeks	OnBeat group heart rate monitoring app was used to monitor students' heart rate during HIIT sessions via a smartphone or tablet. The smartphone application paired with Wahoo TICKR heart rate monitors via Bluetooth connectivity and provided students with concurrent heart rate data. A summary email was provided to the research team, and individual participants, following the completion of a workout. Average values for percentage of age-predicted maximum heart rate, and beats per minute were, as well as the maximum value achieved during the session were provided in the email summary.
Parents		
5) Parental engagement	1 x video (prior to school holidays)	Parents of the intervention group students received an informational video prior to the school term break. The video file provided a rationale for the program, as well as identifying potential strategies to encourage their son/daughter to maintain participation in the HIIT exercise sessions during the school term break.

Schools		
6) Equipment and resource pack	14-weeks	The intervention school was provided with an equipment pack to assist in the facilitation of the intervention. The equipment pack included basic sports equipment (e.g., skipping ropes, cones, balls, sports bag), 1x Bluetooth speaker, 1x Wahoo TICKR heart rate monitor per student, B2L session cards detailing pre-designed HIIT workouts (i.e., Gym, Class, Sport, Combat, Dance, and Brain HIIT), and B2L technique cards demonstrating how to perform the exercises with correctly.

Table 2. SAAFE principles and example strategies

Principle	Definition	Example strategies
Supportive	Sessions are designed to facilitate a supportive environment	• Provide constructive feedback • Praise effort and improvement rather than performance • Demonstrate empathy towards others • Encourage supportive behavior
Active	Sessions involve a high level of movement	• Commence sessions as quickly as possible • Show an understanding of exercises and technique • Reduce instruction and talk time • Encourage students to exercise at high-intensity (e.g., heart rate monitoring)
Autonomous	Sessions involve elements of choice	• Provide students with opportunities of choice (e.g., choice of partner, music, type of HIIT session) • Encourage creation and modification of HIIT workouts • Encourage students to assess and correct their own exercise technique
Fair	Sessions provided all students with an opportunity to experience success	• Explain to students how certain exercises can be modified to make more/less difficult • Encourage self-comparison rather than peer-comparison • Treat all students equally
Enjoyable	Sessions are designed to be enjoyable and engaging for all students	• Encourage the use of motivational music • Provide a variety of HIIT workout options • Encourage students to self-select their exercise intensity

3 **Table 3**. Participant baseline demographics

Characteristics	**Control (*n*=30)**	**B2L (*n*=38)**	**Total (*N*=68)**
Age (years), mean (SD)	16.2 (0.4)	16.2 (0.4)	16.2 (0.4)
Body weight (kg), mean (SD)	65.8 (10.8)	66.1 (11.9)	66.0 (11.4)
Height (cm), mean (SD)	169.5 (8.3)	174.2 (8.4)	171.1 (8.9)
BMI (kg/m^2), mean (SD)	22.8 (2.8)	21.7 (3.1)	22.2 (3.0)
BMI z-score, mean (SD)	0.72 (0.87)	0.38 (0.87)	0.54 (0.42)
BMI classification, n (%)			
Underweight	1 (3.4)	0 (0.0)	1 (1.6)
Normal range	20 (69.0)	28 (87.5)	48 (78.7)
Overweight	8 (27.6)	3 (9.4)	11 (18)
Obese	0 (0.0)	1 (3.1)	1 (1.6)
Estimated VO_2 max (ml/kg/min), mean (SD)	45.9 (6.2)	47.6 (5.5)	46.8 (5.9)
CRF classification, n (%)			
Health risk	1 (3.3)	2 (5.3)	3 (4.4)

Needs improvement	3 (10.0)	1 (2.6)	4 (5.9)
Healthy fitness zone	25 (83.3)	27 (71.1)	52 (76.5)
Cultural background, n (%)			
Australian	20 (66.7)	28 (73.7)	48 (70.6)
European	8 (26.7)	5 (13.2)	13 (19.1)
Asian	0 (0.0)	4 (10.5)	4 (5.9)
Other	2 (6.7)	1 (0.0)	3 (4.4)
Language spoken at home, n (%)			
English	29 (96.7)	31 (97.4)	66 (96.7)
Other	1 (3.3)	1 (2.6)	2 (3.3)
ATSI descent, n (%)			
Yes	3 (10.0)	1 (2.6)	4 (5.9)
No	27 (90.0)	37 (97.4)	64 (94.1)

Abbreviations: BMI: body mass index; ATSI: Aboriginal and Torres Strait Islander.
Note: Estimated VO_2 max Value is for participants who provided a baseline value for CRF (Control=29; B2L=30; Total=59).

Table 4. Completer's analysis of the primary and secondary outcomes.

Outcome	Group (*n*)	Baseline[b]	14-weeks	Time [c] *p*	Adj. diff. in change [d]	14-week group-by-time [e] *p*	Cohen's *d*
Health-related fitness							
Cardiorespiratory fitness (laps) [a]	CON (24)	63.1 (50.8 to 75.4)	53.3 (41.7 to 65.0)	<0.001	8.9 (1.7 to 16.2)	**0.017**	0.69
	B2L (27)	72.6 (61.0 to 79.9)	71.8 (61.2 to 82.3)	0.736			
Upper-body muscular endurance (reps)	CON (28)	18.6 (15.2 to 22.0)	18.9 (15.8 to 21.9)	0.823	1.7 (-1.4 to 4.7)	0.280	0.29
	B2L (32)	19.9 (16.7 to 23.0)	21.8 (18.9 to 24.6)	0.072			
Lower-body muscular power (cm)	CON (28)	177.9 (164.9 to 190.9)	169.4 (156.6 to 182.1)	0.021	10.1 (0.3 to 19.8)	**0.043**	0.46
	B2L (29)	182.0 (170.0 to 193.9)	183.6 (171.8 to 195.2)	0.645			
BMI (kg/m^2)	CON (29)	22.8 (21.7 to 23.9)	22.6 (21.5 to 23.6)	0.016	0.4 (0.1 to 0.6)	**0.014**	0.67
	B2L (32)	21.8 (20.8 to 22.9)	21.9 (20.9 to 23.0)	0.293			
Mental health (units)							
Total difficulties	CON (29)	9.5 (7.7 to 11.3)	10.0 (7.8 to 12.2)	0.438	-2.1 (-4.0 to -0.3)	**0.023**	0.57
	B2L (32)	11.7 (10.0 to 13.4)	10.1 (8.0 to 12.2)	0.012			
Hyperactivity	CON (29)	4.2 (3.4 to 4.9)	3.8 (2.9 to 4.7)	0.341	-0.4 (-1.4 to 0.6)	0.417	0.21

	B2L (32)	5.0 (4.2 to 5.6)	4.2 (3.3 to 5.0)	0.032			
Emotional problems	CON (29)	2.8 (2.0 to 3.7)	3.3 (2.4 to 4.2)	0.056	-0.9 (-1.6 to -0.1)	**0.022**	0.61
	B2L (32)	3.0 (2.1 to 3.8)	2.6 (1.8 to 3.5)	0.179			
Conduct problems	CON (29)	0.9 (0.4 to 1.4)	1.0 (0.4 to 1.6)	0.651	-0.2 (-0.8 to 0.5)	0.599	0.16
	B2L (32)	1.8 (1.4 to 2.3)	1.8 (1.2 to 2.3)	0.774			
Peer problems	CON (29)	1.6 (1.1 to 2.1)	1.9 (1.3 to 2.4)	0.254	-0.7 (-1.3 to -0.1)	**0.017**	0.60
	B2L (32)	2.0 (1.5 to 2.4)	1.5 (1.0 to 2.0)	0.022			
Prosocial	CON (29)	8.0 (7.3 to 8.5)	8.0 (7.3 to 8.5)	0.886	0.3 (-0.3 to 1.0)	0.308	0.23
	B2L (32)	7.8 (7.2 to 8.4)	8.2 (7.6 to 8.7)	0.106			
Perceived stress	CON (29)	1.9 (1.8 to 2.1)	2.1 (1.9 to 2.2)	0.406	-0.1 (-0.3 to 0.09)	0.253	0.26
	B2L (32)	2.1 (1.9 to 2.2)	2.0 (1.9 to 2.2)	0.429			
Motivation and basic psychological needs satisfaction (units)							
Intrinsic	CON (29)	3.5 (3.3 to 3.7)	3.3 (3.1 to 3.6)	0.159	-0.05 (-0.3 to 0.3)	0.751	0.09
	B2L (32)	3.6 (3.4 to 3.8)	3.4 (3.1 to 3.6)	0.054			
Identified	CON (29)	3.3 (3.1 to 3.5)	3.3 (3.1 to 3.6)	1.0	-0.02 (-2.0 to 1.6)	0.794	0.06
	B2L (32)	3.4 (3.2 to 3.6)	3.4 (3.1 to 3.6)	0.705			

Autonomy support	CON (29)	5.7 (5.4 to 6.1)	5.8 (5.5 to 6.1)	0.773	0.08 (-0.4 to 0.5)	0.720	0.09
	B2L (32)	5.6 (5.3 to 5.9)	5.7 (5.4 to 6.0)	0.412			
Relatedness support	CON (29)	5.9 (5.6 to 6.2)	6.0 (5.7 to 6.3)	0.510	-0.2 (-0.6 to 0.2)	0.310	0.27
	B2L (32)	6.0 (5.7 to 6.3)	5.9 (5.6 to 6.2)	0.434			
Competence support	CON (29)	5.6 (5.3 to 6.0)	5.6 (5.3 to 6.0)	0.875	0.2 (-0.2 to 0.6)	0.447	0.26
	B2L (32)	5.4 (5.1 to 5.7)	5.6 (5.2 to 5.9)	0.207			

Abbreviations: CON: control; B2L: Burn 2 Learn intervention; reps: repetitions; BMI: body mass index

[a] Primary outcome.
[b] Mean (95% confidence intervals).
[c] Within group change over time.
[d] Adjusted mean difference between groups
[e] Group-by-time interaction from mixed model

FIGURE LEGEND

Figure 1. CONSORT flow diagram of participants through study.

Note: CRF: cardiorespiratory fitness.