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Time-efficient intervention to improve older adolescents' cardiorespiratory fitness: findings from the 'Burn 2 Learn' cluster randomised controlled trial

David R Lubans ,[1] Jordan J Smith,[1] Narelle Eather,[1] Angus A Leahy,[1] Philip J Morgan,[1] Chris Lonsdale ,[2] Ronald C Plotnikoff,[1] Michael Nilsson,[3] Sarah G Kennedy,[1] Elizabeth G Holliday,[4] Natasha Weaver,[4] Michael Noetel,[2,5] Tatsuya T Shigeta,[6] Myrto F Mavilidi,[1,7] Sarah R Valkenborghs,[1,8] Prajwal Gyawali,[9] Frederick R Walker,[3,8] Sarah A Costigan,[1,10] Charles H Hillman[6,11]

For numbered affiliations see end of article.

Correspondence to
Dr David R Lubans, Priority Research Centre for Physical Activity and Nutrition, Faculty of Education and Arts, The University of Newcastle, Callaghan, New South Wales, Australia;
david.lubans@newcastle.edu.au

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ABSTRACT

Background Cardiorespiratory fitness (CRF) is an important marker of current and future health status. The primary aim of our study was to evaluate the impact of a time-efficient school-based intervention on older adolescents' CRF.

Methods Two-arm cluster randomised controlled trial conducted in two cohorts (February 2018 to February 2019 and February 2019 to February 2020) in New South Wales, Australia. Participants (N=670, 44.6% women, 16.0±0.43 years) from 20 secondary schools: 10 schools (337 participants) were randomised to the Burn 2 Learn (B2L) intervention and 10 schools (333 participants) to the control. Teachers in schools allocated to the B2L intervention were provided with training, resources, and support to facilitate the delivery of high-intensity interval training (HIIT) activity breaks during curriculum time. Teachers and students in the control group continued their usual practice. The primary outcome was CRF (20 m multi-stage fitness test). Secondary outcomes were muscular fitness, physical activity, hair cortisol concentrations, mental health and cognitive function. Outcomes were assessed at baseline, 6 months (primary end-point) and 12 months. Effects were estimated using mixed models accounting for clustering.

Results We observed a group-by-time effect for CRF (difference=4.1 laps, 95% CI 1.8 to 6.4) at the primary end-point (6 months), but not at 12 months. At 6 months, group-by-time effects were found for muscular fitness, steps during school hours and cortisol.

Conclusions Implementing HIIT during curricular time improved adolescents' CRF and several secondary outcomes. Our findings suggest B2L is unlikely to be an effective approach unless teachers embed sessions within the school day.

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INTRODUCTION

Cardiorespiratory fitness (CRF) is an important marker of current and future health status.[1] CRF during adolescence is inversely associated with the clustering of cardiometabolic risk factors[2 3] and lower burden of future disability.[4] Adolescents with high levels of CRF have better mental health,[5] while lower CRF during adolescence is associated with increased risk of depression in adulthood.[6] Of concern, there has been a secular decline in young people's CRF.[7] Participation in physical activity, particularly of vigorous-intensity, is the primary means of improving CRF.[8]

High-intensity interval training (HIIT) is a time-efficient form of physical activity that typically consists of short, yet intense bouts of vigorous activity interspersed with brief periods of rest or light activity. Recent systematic reviews have shown that HIIT can improve adults and adolescents' CRF and metabolic health.[9 10] HIIT has been criticised as a public health strategy and some researchers have expressed concern about the feasibility, motivation of individuals and potential injury risk of the 'all out' maximal effort required.[11] Importantly, there is emerging evidence for the efficacy of less demanding HIIT protocols (ie, ~85% age-predicted maximal heart rate (HR_{max})) that retain their potency and are well received by adolescents.[9] To date, the majority of these HIIT interventions have been conducted on a small-scale, delivered by researchers, evaluated over relatively short periods of time (~8 weeks) and not designed to be scalable.

We recently conducted a pilot study to evaluate the first 'teacher-facilitated' HIIT intervention for senior school students (ie, those in the final 2 years of secondary school), known as Burn 2 Learn (B2L).[12] Physical activity levels decline dramatically during adolescence[13] and in many countries, including Australia, there is no compulsory physical education in the senior school years.[14] Moreover, high stakes standardised testing at the end of secondary school places considerable pressure on schools, teachers and students to concentrate on academic outcomes. For these reasons, B2L was promoted to schools as a time-efficient intervention to improve students' cognitive and mental health during a challenging life stage. In our pilot study, we observed favourable intervention effects for CRF, muscular fitness, and internalising problems.[12]

The primary aim of our current study was to assess the impact of the B2L intervention on CRF in a sample of senior school students using a cluster randomised controlled trial (RCT). Secondary aims included assessing the impact of B2L on muscular fitness, objectively measured physical activity, body

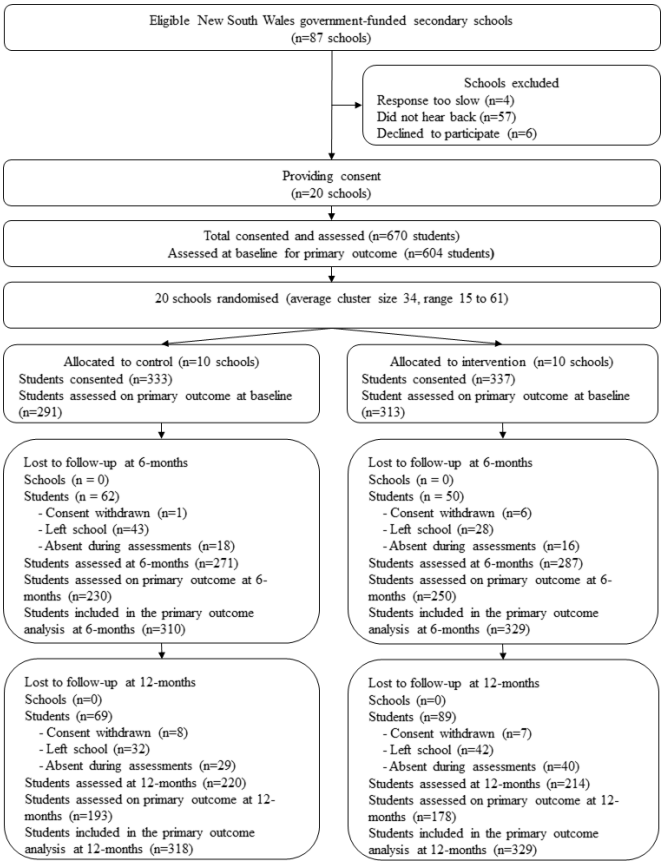

Figure 1 Consolidated Standards of Reporting Trials flow diagram.

composition, hair cortisol concentrations, mental health and cognitive function.

METHODS

Study design

Our rationale and study methods have been described in detail previously.[15] Our reporting adheres to the Consolidated Standards of Reporting Trials[16] and Template for Intervention Description and Replication (TIDier)[17] checklists. The intervention was evaluated using a two-arm parallel group cluster RCT with an intervention group and wait-list control group (figure 1). Assessments were conducted at baseline, 6 months (primary endpoint) and 12 months from baseline (secondary endpoint). The RCT was conducted in two cohorts: the first started in 2018 and finished in 2019 (10 schools); the second started in 2019 and finished in 2020 (10 schools) (online supplemental figure 1). Baseline data collection and teacher training occurred in the school term preceding the intervention delivery (ie, term 1 (February to April, 2018 and 2019)). Post-test data collection (ie, 6-month follow-up) commenced midway through term 3 and continued until the end of term 3 (August to September, 2018 and 2019). Final follow-up assessments (ie, 12-month follow-up) were completed in term 1 of the following year (February to April, 2019 and 2020).

School recruitment and participants

New South Wales (NSW) government secondary schools with senior school students (ie, grades 11 and 12, students aged 16–18) were eligible to participate in the study. We recruited two grade 11 teachers from each school and eligible participants were grade 11 students taught by one of the participating teachers. School principals, teachers, parents and students all provided informed written consent prior to enrolment.

Sample size calculation

Power calculations were based on the primary outcome of CRF, assessed using the 20 m multistage fitness test.[18] Baseline post-test correlation (r=0.90) and SD (29 laps) values were obtained from our pilot trial, and intraclass correlation coefficient (ICC) values of 0.20 and 0.03 were used to account for clustering at the class-levels and school-levels, respectively.[19] To detect a clinically meaningful between-group difference of 6 laps[20 21] with 80% power at a 5% significance level it was necessary to recruit 280 students per group (ie, 2 classes of 14 students from each of 10 schools).

Randomisation

Randomisation at the school level occurred after baseline data collection. To ensure balance within cohorts, pairs of schools were matched based on the following characteristics: geographic location, school area-level socioeconomic status, and where possible, the teaching discipline of the participating class (eg, Mathematics). Paired schools (within cohorts) were randomised by an independent researcher using a computer-based random number generator.

Intervention delivery, components and implementation strategies

A detailed description of the intervention is provided in our published protocol. In summary, teachers from the intervention schools were provided with training, resources and support to facilitate the delivery of high-intensity activity breaks. In addition to the HIIT activity breaks (hereafter, referred to as B2L sessions), the B2L intervention also included: (i) information seminar for students delivered by teachers, (ii) purpose-built smartphone application and HR monitors to support B2L session delivery and (iii) newsletters for parents. We used a range of implementation strategies to support the delivery of the B2L programme in schools.[22]

Teachers were trained to facilitate HIIT activity breaks during academic lesson time. The intervention was delivered in three phases: in Phases I and II (term 2–term 3; May–September 2018 and 2019), teachers were asked to facilitate at least two B2L sessions per week during academic lessons. In Phase III (term 4/term 1; October–April 2018/2019 and 2019/2020), students were encouraged to complete B2L sessions outside of lesson time. The duration of B2L sessions ranged from 8 to 20 min (including warm-up and cool down), and involved a combination of aerobic (eg, shuttle runs, jumping jacks, dance sequences) and body weight resistance exercises (eg, push-ups, squat jumps). Students were encouraged to reach 85% of their age-predicted HR_{max} using the B2L smartphone app (figure 2) and HR monitors. Teachers were provided with 11 different styles of HIIT, designed to appeal to the interest of students.[15]

Measures and data collection

Assessments were conducted at the study schools by trained research assistants. Our intention was to blind all assessors to group allocation for the primary outcome at all time-points. However, our checks revealed that assessors were aware of allocation in four schools at follow-up. Demographic information and self-report measures were collected using electronic tablets under examination-like conditions.

Figure 2 Snapshot of Burn 2 Learn (B2L) smartphone application dashboard and group session.

Primary outcome

Cardiorespiratory fitness

CRF was assessed using the 20 m multistage fitness test, which has good validity in adolescents[23] and is the most widely accepted field-based measure of CRF.[8] Verbal encouragement was provided by test administrators and the last successful stage was recorded and converted to the number of laps completed.

Secondary outcomes

Physical activity

Participants wore ActiGraph GT9X Link accelerometer on their non-dominant wrist for seven consecutive days. School hour, weekday and weekend day physical activity were calculated separately. Existing thresholds were used to categorise intensity.[24]

Hair cortisol

All participants in cohort 1 (298/378, 75% consented) were invited to provide hair samples to examine the accumulation of cortisol and provide a retrospective index of stress exposure.[25] The inter-assay coefficient of variation in the study sample was 8.42%.

Muscular fitness

The 90° push-up and standing long jump tests were used to assess upper body muscular endurance[26] and lower body muscular power,[27] respectively.

Body composition

Body weight and height were measured using a portable digital scale10 (A&D Medical UC-352-BLE Digital Scales) and a portable stadiometer (Seca 213 Portable11 Height Measuring Rod Stadiometer), respectively. Body mass index was calculated (weight (kg)/height (m)^2) and the International Obesity Task Force cut-offs[28] were used to classify participants into weight categories.

Cognitive control

Participants completed tests of cognitive control using laptops installed with specialised software (PsychoPy).[29] A modified version of the Eriksen flanker task was used to modulate inhibitory control demands using congruent and incongruent trials. Response time and response accuracy were recorded. An interference score was calculated for both accuracy and response time. Working memory was assessed using a serial *n*-back task.[30]

Perceived stress

Participants completed the 10-item Perceived Stress Scale.[31] Responses were scored on a 5-point scale ranging from 0 'Never' to 4 'Very often' and then summed across all scale items.

Psychological difficulties

Participants completed the Strengths and Difficulties Questionnaire which consists of five 5-item subscales.[32] The emotional symptoms and peer problems subscales were combined to create an internalising problems composite. The conduct and hyperactivity problems subscales were combined to create an externalising problems composite.

Well-being

Well-being was assessed using the 7-item Warwick-Edinburgh Mental Well-being Scale.[33]

Self-efficacy for HIIT

Participants completed the validated 6-item High-Intensity Interval Training Self-efficacy Questionnaire.[34]

Motivation for exercise

Autonomous motivation for exercise was assessed using the intrinsic and identified subscales from the Behavioral Regulations in Exercise Questionnaire.[35]

Process evaluation

We conducted an extensive process evaluation to determine dose delivered, fidelity, satisfaction and sustainability using teacher logbooks, app usage data, teacher and student surveys and B2L session observations (online supplemental table 1).

Statistical analyses

Data were analysed by statisticians blinded to group allocation using linear mixed models in SAS (V.9.4). Alpha levels were set at $p<0.05$ for the single primary outcome and all secondary outcomes. The models included fixed effects for treatment (B2L or control), time (treated as categorical with levels baseline, 6 months and 12 months), the group-by-time interaction (ie, intervention post-test mean−intervention baseline mean)−(control post-test mean−control baseline mean)) and randomisation pair, using random intercepts to account for the clustered nature of the data (ie, clustering within school, and class, and repeated measures on individuals). Two sensitivity analyses were conducted for the primary outcome to assess the impact of different missing data mechanisms. The primary analysis used a linear mixed model, which uses all available data assuming a missing at random (MAR) mechanism. Sensitivity analyses comprised multiple imputation (assuming MAR) and complete-case analysis (assuming data are missing completely at random: MCAR). Multiple imputed datasets (n=20 replicates) were generated using linear models including auxiliary variables associated with the outcome variable and/or missingness of this variable. Intervention effects and their variances were estimated separately for each imputed dataset and pooled using Rubin's rules. Complete case analyses were performed using listwise deletion of observations with any missing values of model variables. In addition, we conducted two per-protocol analyses that were determined a priori (ie, at the class and student levels, respectively—table 1)—see online supplemental tables 13 and 14 for ICC values. Five potential moderators of intervention effects were identified a priori and assessed by estimating interaction terms between group, time and each individual moderator: (i) socioeconomic status (low/medium or high based on household postcode), (ii) sex (men or women), (iii) weight status (healthy weight/underweight or overweight/obese,[28] (iv) mental health status (close to average and slightly raised or high to very high levels of internalising problems[36] and (v) CRF status (health risk and needs improvement or healthy fitness zone).[37] Moderators were considered significant at $p<0.10$, based on a type III significance test.

RESULTS

The flow of participants through the study is displayed in figure 1. A total of 670 participants were recruited from 20 schools in term 1 (February–March) of 2018 (cohort 1) and 2019 (cohort 2). Of these, 558 (83.2%) and 434 (64.7%) of participants were assessed at 6 months (primary endpoint) and 12 months, respectively. Of the participants who were not followed-up, 71 (10.6%) and 74 (11.0%) permanently left their school at 6 months and 12 months, respectively. None of the clusters (ie, schools or classes) withdrew from the study.

Baseline characteristics

Participants' characteristics are reported in table 2. School clusters ranged in size from 15 to 61, with a mean of 34 participants from each school. The recruitment rate of 79% was calculated as the percentage of participants from the classes in each school consenting to participate in the study. A total of 45 classes were included in the study: Biology=3, Community and Family Studies=2, English=1, Mathematics=2, Modern History=1, Health and Physical Education=20, Sports Coaching=1, Sport Leisure and Recreation=12 and registration classes=3. Baseline, 6-month and 12-month values are reported in online supplemental tables 2-4.

Change in CRF at 6 months (primary outcome)

The mean change difference in CRF between groups at 6 months is reported in table 1. In the intention-to-treat analysis, a difference between groups was found for CRF (4.1 laps, 95% CI 1.8 to 6.4) in favour of the intervention group. Intervention effects did not differ by baseline socio-economic status (SES), sex, weight status, mental health or CRF (online supplemental table 5).

Secondary outcomes

Fitness and physical activity outcomes

Fitness and physical activity secondary outcomes are presented in table 3. Improvements in CRF were not sustained at 12 months (1.4 laps, 95% CI −1.4 to 4.3). Differences in upper body muscular endurance were significant at 6 months and 12 months, in favour of the intervention group. Differences were found between groups for steps and light physical activity during school hours at 6 months, in favour of the intervention group.

Cortisol and mental health outcomes

Changes in cortisol and mental health outcomes are reported in table 4. A difference between groups (in favour of the

Table 1 Changes in cardiorespiratory fitness at 6-month follow-up between participants randomised to usual practice (control) or the Burn 2 Learn intervention

	No of clusters (participants)		Mean change from baseline (95% CI)		Adjusted difference at follow-up*	
Primary outcome (6 months)	Control	Intervention	Control	Intervention	Coefficient (95% CI)	P value
Cardiorespiratory fitness: intention-to-treat†	10 (310)	10 (329)	−3.52 (−5.50 to −1.54)	0.91 (−0.46 to 2.28)	4.10 (1.78 to 6.42)	<0.001
Cardiorespiratory fitness: complete case‡	10 (211)	10 (234)	−3.52 (−5.50 to −1.54)	0.91 (−0.46 to 2.28)	4.43 (2.08 to 6.78)	<0.001
Cardiorespiratory fitness: multiple imputation§	10 (310)	10 (329)	−3.01 (−4.47 to −1.56)	0.97 (−0.22 to 2.16)	3.98 (1.61 to 6.36)	<0.001
Cardiorespiratory fitness: per protocol (group)¶	10 (310)	7 (226)	−3.52 (−5.50 to −1.54)	1.55 (−0.13 to 3.23)	4.61 (1.98 to 7.24)	<0.001
Cardiorespiratory fitness: per protocol (individual)**	10 (310)	10 (133)	−3.52 (−5.50 to −1.54)	1.20 (−0.69 to 3.09)	4.23 (1.19 to 7.26)	0.007

*Adjusted difference ((intervention post-test mean−intervention baseline mean)−(control post-test mean−control baseline mean)) in multi-stage fitness test laps. P value adjusted for clustering and randomisation pair.
†Intention-to-treat analysis included all participants who completed the multi-stage fitness test at baseline or follow-up.
‡Complete case analysis included participants who completed the multi-stage fitness test at baseline and follow-up.
§Multiple imputation analysis included all participants who completed the multi-stage fitness test at baseline or follow-up.
¶Class-level per-protocol analysis included students from classes in which at least 28 school-based sessions were delivered.
**Student-level per-protocol analysis included students who achieved an average peak heart rate (HR) of ≥80% HR_{max} during sessions.

Table 2 Baseline characteristics of the study sample

Characteristics	Control	Intervention	Total
Cluster level	(n=10)	(n=10)	(n=20)
Mean number of participants (range)	33 (15–47)	34 (15–61)	34 (15–61)
Mean (range) of students in cluster taking part (%)	80 (69–100)	79 (48–100)	79 (48–100)
Individual level	(n=333)	(n=337)	(n=670)
Age, mean (SD), years	16.0 (0.5)	16.0 (0.4)	16.0 (0.4)
Female participants, n (%)	130 (39.0)	169 (50.1)	299 (44.6)
Born in Australia, n (%)*	291 (87.9)	296 (88.4)	587 (88.1)
English spoken at home, n (%)*	308 (93.1)	310 (92.5)	618 (92.8)
Cultural background, n (%)* Australian European African Asian Middle Eastern Other	230 (69.5) 28 (8.5 3 (0.9) 18 (5.4) 3 (0.9) 49 (14.8)	239 (71.3) 39 (11.6) 3 (0.9) 21 (6.3) 4 (1.2) 29 (8.7)	469 (70.4) 67 (10.1) 6 (0.9) 39 (5.9) 7 (1.1) 78 (11.6)
Indigenous decent, n (%)* Yes No	37 (11.2) 294 (88.8)	24 (7.2) 311 (92.8)	61 (9.2) 605 (90.8)
Socioeconomic status, n (%)† Low Medium High	48 (14.5) 170 (51.4) 113 (34.1)	81 (24.3) 169 (50.8) 83 (24.9)	129 (19.4) 339 (51.1) 196 (29.5)
Weight status, n (%)‡ Underweight Healthy weight Overweight Obese	16 (4.9) 207 (63.1) 72 (22.0) 33 (10.1)	10 (3.0) 238 (71.5) 62 (18.6) 23 (6.9)	26 (3.9) 445 (67.3) 134 (20.3) 56 (8.5)

*Four participants did not answer the background demographic questions.
†Socioeconomic status determined by population tertile using socioeconomic indexes for areas of relative socioeconomic disadvantage based on residential postcode; six participants did not provide their residential postcode.
‡Nine participants were not measured for height and/or weight.

intervention group) was found for hair cortisol concentrations at 6 months. Moderation effects were found for weight status and mental health status, with stronger intervention effects on hair cortisol concentrations observed among youth with overweight and obesity, and among those with poor mental health at baseline (online supplemental table 6). No differences were found between groups for any of the mental health outcomes at 6 months or 12 months in the full study sample. Weight status moderated the effect of the intervention on internalising problems (online supplemental table 7). Both weight status and mental health status moderated the effect of the intervention on perceived stress (online supplemental table 8).

Cognitive function outcomes

Cognitive function improved over time, with no differences between groups in the full sample (online supplemental table 9). No moderation effects were found for flanker interference accuracy (online supplemental table 10) or reaction time (online supplemental table 11). Analyses of the *d*-prime data (online supplemental table 12) revealed moderation effects for SES and weight status.

Process evaluation

The process evaluation results are displayed in online supplemental table 1. Teachers delivered 2.0±0.8, 1.7±0.6 and 0.6±0.7 sessions/week in phases I, II and III, respectively. Researcher observations showed the B2L sessions were delivered as intended (16.4/20±2.5 units). Overall satisfaction was high for teachers (3.3/4±0.5 units) and moderate-to-high for students (3.8/5±0.9 units). No injuries or adverse events were recorded by the school champions.

DISCUSSION

This cluster RCT evaluated the effectiveness of a time-efficient intervention, involving teacher facilitated high-intensity activity breaks for improving CRF in a sample of older adolescents from secondary schools. We observed a group-by-time effect for CRF at the primary endpoint of our study. Positive intervention effects were also observed for a range of secondary outcomes, including hair cortisol concentrations, upper body muscular endurance, steps per day and light physical activity during school hours and HIIT self-efficacy. No notable between group differences were found in mental health and cognitive function outcomes at 6 months or 12 months in the full study sample. However, reductions in perceived stress and internalising problems were observed among students who were classified as overweight or obese at baseline.

Comparison with other studies

Older adolescents have been largely neglected in school-based physical activity intervention research. A small number of studies have demonstrated improvements in older adolescents' CRF, but these studies were delivered by researchers[38] and involved quasi-experimental designs,[38 39] thus limiting their comparability to the current study. One notable exception was the Physical Activity and Teenage Health study, which was a school-based intervention evaluated in three New York high schools.[40] The exercise component of the intervention involved 20–25 min of vigorous physical activity five times a week for 12 weeks. Despite this higher volume of exercise, the intervention did not improve students' CRF. The use of the Queen's College step test may explain the null finding, as submaximal measures lack sensitivity to detect small improvements in CRF.[41]

A range of strategies have been utilised in school-based interventions to increase younger adolescents' CRF, such as increasing the quantity and intensity of physical education, changing the school's physical environment, offering additional opportunities for physical activity during break times and in the afterschool period, and targeting parents as agents of change.[42] While interventions delivered in the school environment can improve younger adolescents' CRF, effect sizes in small-scale RCTs are considerably larger than those observed in cluster RCTs.[42] The largest intervention conducted with adolescents was the diabetes risk reduction trial known as HEALTHY.[43] Despite extensive support and funding, the intervention did not improve adolescents' CRF in comparison to those in the control group over the 3-year study period. The study did not provide a process evaluation or assess change in CRF within the school year. Therefore, it is not clear if the null findings were due to poor implementation or the timing of assessments.

The structured environment of school days may help protect children (but not senior school students) from poor fitness through compulsory opportunities for physical activity (ie, physical education and school sport).[44] Consistent with the 'Structured Days Hypothesis',[44] participants in the B2L intervention improved their CRF at 6 months while the intervention was being delivered, but lost their gains in CRF the following year (assessments were conducted at the start of the school year

Table 3 Changes in fitness and physical activity outcomes at 6-month and 12-month follow-up between participants randomised to control or the Burn 2 Learn intervention

	No of clusters (participants)		Mean change from baseline (95% CI)		Adjusted difference at follow-up*	
Secondary outcomes	Control	Intervention	Control	Intervention	Coefficient (95% CI)	P value
Cardiorespiratory fitness (laps): 12 months	10 (318)	10 (329)	−6.79 (−8.96 to −4.63)	−5.18 (−7.77 to −2.59)	1.43 (−1.42 to 4.29)	0.326
Upper body muscular endurance (reps): 6 months	10 (312)	10 (333)	−0.42 (−1.15 to 0.31)	0.95 (0.35 to 1.55)	1.23 (0.31 to 2.14)	0.009
Upper body muscular endurance (reps): 12 months	10 (320)	10 (333)	−0.34 (−1.05 to 0.38)	1.53 (0.71 to 2.35)	1.76 (0.77 to 2.76)	<0.001
Lower body muscular power (cm): 6 months	10 (329)	10 (332)	0.41 (−1.72 to 2.54)	−0.30 (−2.04 to 1.44)	−0.87 (−3.56 to 1.82)	0.526
Lower body muscular power (cm): 12 months	10 (331)	10 (332)	4.62 (1.73 to 7.51)	0.40 (−2.11 to 2.90)	−5.27 (−8.45 to −2.10)	<0.001
BMI z-scores: 6 months	10 (328)	10 (335)	0.07 (0.01 to 0.14)	0.09 (0.04 to 0.13)	0.02 (−0.06 to 0.09)	0.604
BMI z-scores: 12 months	10 (328)	10 (335)	0.04 (−0.03 to 0.11)	0.06 (−0.00 to 0.13)	0.03 (−0.05 to 0.11)	0.412
MPA min/school hours: 6 months	10 (229)	10 (206)	−2.22 (−3.36 to −1.09)	−1.77 (−3.06 to −0.48)	1.03 (−0.60 to 2.65)	0.217
MPA min/school hours: 12 months	10 (229)	10 (206)	−1.48 (−2.84 to −0.13)	−4.70 (−6.43 to −2.98)	−0.88 (−2.74 to 0.98)	0.355
VPA min/school hours: 6 months	10 (229)	10 (206)	0.00 (−0.16 to 0.17)	0.10 (−0.09 to 0.30)	0.04 (−0.20 to 0.29)	0.729
VPA min/school hours: 12 months	10 (229)	10 (206)	−0.11 (−0.33 to 0.12)	−0.09 (−0.31 to 0.13)	0.00 (−0.29 to 0.30)	0.973
MVPA min/school hours: 6 months	10 (333)	10 (337)	−2.22 (−3.46 to −0.98)	−1.59 (−2.95 to −0.24)	1.12 (−0.63 to 2.86)	0.212
MVPA min/school hours: 12 months	10 (333)	10 (337)	−2.74 (−5.16 to −0.32)	−4.35 (−7.34 to −1.35)	−1.44 (−4.70 to 1.82)	0.387
Steps/school hours: 6 months	10 (229)	10 (206)	−981 (−1314 to −648)	−300 (−504 to −97)	904 (535 to 1273)	<0.001
Steps/school hours: 12 months	10 (229)	10 (206)	−969 (−1412 to −525)	−1014 (−1331 to −696)	462 (45 to 879)	0.030
MPA min/weekday: 6 months	10 (229)	10 (206)	−3.85 (−5.84 to −1.85)	−4.03 (−5.95 to −2.11)	−0.05 (−2.55 to 2.44)	0.966
MPA min/weekday: 12 months	10 (229)	10 (206)	−2.32 (−4.55 to −0.09)	−4.15 (−7.01 to −1.29)	−1.49 (−4.49 to 1.52)	0.333
VPA min/weekday: 6 months	10 (229)	10 (206)	−0.08 (−0.42 to 0.26)	−0.02 (−0.32 to 0.27)	−0.08 (−0.51 to 0.35)	0.715
VPA min/weekday: 12 months	10 (229)	10 (206)	−0.42 (−0.87 to 0.02)	−0.19 (−0.51 to 0.12)	−0.02 (−0.52 to 0.48)	0.929
MVPA min/weekday: 6 months	10 (333)	10 (337)	−1.59 (−3.05 to −0.13)	−4.13 (−5.93 to −2.33)	−0.44 (−2.45 to 1.58)	0.670
MVPA min/weekday: 12 months	10 (333)	10 (337)	−5.03 (−11.59 to 1.52)	1.13 (−4.30 to 6.56)	3.32 (−3.42 to 10.05)	0.337
Steps/weekday: 6 months	10 (229)	10 (206)	−661 (−1002 to −320)	−461 (−813 to −110)	171 (-224 to 566)	0.398
Steps/weekday: 12 months	10 (229)	10 (206)	−862 (−1274 to −451)	−826 (−1359 to −293)	−249 (−735 to 236)	0.314
MPA min/weekend day: 6 months	10 (164)	10 (139)	−5.05 (−11.41 to 1.31)	1.18 (−4.13 to 6.49)	3.55 (−2.97 to 10.08)	0.288
MPA min/weekend day: 12 months	10 (182)	10 (153)	−8.47 (−16.65 to −0.28)	2.75 (−6.90 to 12.39)	6.64 (−0.50 to 13.78)	0.070
VPA min/weekend day: 6 months	10 (164)	10 (139)	0.02 (−0.43 to 0.46)	−0.05 (−0.38 to 0.27)	−0.22 (−0.67 to 0.22)	0.331
VPA min/weekend day: 12 months	10 (182)	10 (153)	0.18 (−0.51 to 0.88)	−0.25 (−0.69 to 0.20)	−0.59 (−1.14 to −0.04)	0.035
MVPA min/weekend day: 6 months	10 (333)	10 (337)	−3.93 (−6.11 to −1.75)	−4.05 (−6.13 to −1.98)	−0.09 (−2.83 to 2.64)	0.946
MVPA min/weekend day: 12 months	10 (333)	10 (337)	−8.28 (−16.58 to 0.01)	2.50 (−7.28 to 12.28)	6.08 (−1.25 to 13.41)	0.106
Steps/weekend day: 6 months	10 (164)	10 (139)	−107 (−1208 to 995)	438 (−584 to 1459)	230 (−871 to 1331)	0.683
Steps/weekend day: 12 months	10 (182)	10 (153)	−912 (−2218 to 395)	815 (−736 to 2366)	1215 (−8 to 2438)	0.053

*Adjusted difference ((intervention post-test mean−intervention baseline mean)−(control post-test mean−control baseline mean)) in secondary outcomes at 6 months and 12 months between treatment groups. P value adjusted for cluster effect, randomisation pair and accelerometer wear-time for physical activity outcomes.
BMI z-scores, Body mass index scores standardised to age and sex; MPA, moderate physical activity; MVPA, moderate-to-vigorous physical activity; VPA, vigorous physical activity.

after the summer holiday period). In the final phase of the B2L intervention, participants were encouraged to complete sessions outside of lesson-time, with no expectation on teachers to facilitate B2L session delivery. As such, the lack of difference between groups at 12 months may be explained by discontinuation of compulsory sessions during curriculum time.

School-based HIIT programs are usually delivered by researchers over short periods of time.[9] While these studies lack generalisability, they typically have high levels of internal validity and provide evidence for the clinical significance of improvements in CRF. For example, Weston and colleagues[20] evaluated the impact of a novel school-based HIIT intervention for adolescents. Similar to our study, the authors reported a group-by-time effect of five laps and improvements in triglycerides and waist circumference. Similarly, Delgado-Floody *et al*[45] found that HIIT delivered twice per week during physical education resulted in small improvements in CRF and reductions in cardiometabolic risk factors in overweight and obese children. Of note, there are no established criteria for determining a clinically meaningful change in adolescents' CRF and the clinical significance of effects are likely to be determined by an individual's baseline fitness and/or health status. For these reasons, we are unable to conclude that our intervention effect on CRF was clinically significant.

The B2L intervention was designed to provide older adolescents with a 'new opportunity' to be physically active during the school day. While the intervention effect on steps/day during school hours were notable, the effects did not extend to activity of any intensity accumulated across the full weekday or on weekends. Our null findings for physical activity may be due to activity compensation. It is possible that students in the intervention group were less active for the rest of the day after participating in a B2L session. Alternatively, our failure to detect an increase in moderate-to-vigorous physical activity (MVPA) may be a result of type of activity (eg, body weight resistance exercise) and the use of wrist-worn devices to measure physical activity. Although accelerometers are considered the gold standard for assessing physical activity behaviour change in interventions, there is a

Table 4 Changes in mental health outcomes at 6-month and 12-month follow-up between participants randomised to control or the Burn 2 Learn intervention

	No of clusters (participants)		Mean change from baseline (95% CI)		Adjusted difference at follow-up*	
Secondary outcomes	Control	Intervention	Control	Intervention	Coefficient (95% CI)	P value
Cortisol (pg/mg): 6 months	5 (141)	5 (157)	2.00 (0.48 to 3.53)	−2.08 (−4.86 to 0.69)	−3.80 (−6.67 to −0.93)	0.010
Perceived stress: 6 months	10 (331)	10 (337)	−0.37 (−1.04 to 0.30)	−0.43 (−1.03 to 0.18)	−0.02 (−0.89 to 0.86)	0.972
Perceived stress: 12 months	10 (333)	10 (337)	0.90 (0.11 to 1.69)	0.83 (−0.09 to 1.75)	−0.16 (−1.22 to 0.90)	0.771
Internalising problems: 6 months	10 (331)	10 (337)	0.17 (−0.13 to 0.47)	0.06 (−0.23 to 0.34)	−0.13 (−0.53 to 0.28)	0.535
Internalising problems: 12 months	10 (333)	10 (337)	0.18 (−0.12 to 0.47)	0.19 (−0.15 to 0.53)	−0.10 (−0.54 to 0.33)	0.637
Externalising problems: 6 months	10 (331)	10 (337)	0.15 (−0.16 to 0.45)	0.25 (−0.04 to 0.54)	0.09 (−0.32 to 0.51)	0.665
Externalising problems: 12 months	10 (333)	10 (337)	0.16 (−0.18 to 0.49)	−0.15 (−0.46 to 0.16)	−0.19 (−0.62 to 0.24)	0.386
Well-being: 6 months	10 (332)	10 (337)	0.45 (−0.15 to 1.05)	−0.31 (−0.85 to 0.23)	−0.69 (−1.47 to 0.09)	0.084
Well-being: 12 months	10 (333)	10 (337)	0.42 (−0.26 to 1.10)	−0.13 (−0.73 to 0.48)	−0.46 (−1.28 to 0.36)	0.273
HIIT self-efficacy: 6 months	10 (332)	10 (337)	−0.05 (−0.25 to 0.16)	0.78 (0.56 to 1.00)	0.80 (0.50 to 1.10)	<0.001
HIIT self-efficacy: 12 months	10 (333)	10 (337)	−0.05 (−0.27 to 0.17)	0.80 (0.54 to 1.06)	0.80 (0.49 to 1.11)	<0.001
Intrinsic motivation for exercise: 6 months	10 (331)	10 (337)	−0.08 (−0.16 to 0.01)	0.00 (−0.09 to 0.09)	0.07 (−0.05 to 0.19)	0.240
Intrinsic motivation for exercise: 12 months	10 (333)	10 (337)	−0.05 (−0.16 to 0.05)	0.01 (−0.09 to 0.11)	0.07 (−0.06 to 0.20)	0.290
Identified motivation for exercise: 6 months	10 (331)	10 (337)	−0.02 (−0.10 to 0.05)	0.01 (−0.06 to 0.09)	0.03 (−0.07 to 0.14)	0.548
Identified motivation for exercise: 12 months	10 (333)	10 (337)	0.03 (−0.06 to 0.13)	0.08 (−0.02 to 0.17)	0.04 (−0.08 to 0.15)	0.504

*Adjusted difference ((intervention post-test mean−intervention baseline mean)−(control post-test mean−control baseline mean)). P value adjusted for cluster effect and randomisation pair.
HIIT, high-intensity interval training; pg/mg, pictogram of cortisol per microgram of hair.

lack of consensus regarding the application of cut-points for classifying physical activity intensity.[46] Novel approaches for analysing accelerometer data are emerging in the literature,[47] however, their application is not yet commonplace. Our findings are broadly consistent with meta-analyses showing significant changes in CRF in school-based interventions,[42] but not in accelerometer measured MVPA.[48]

Complex interventions require considerable support and poor implementation may explain the 'voltage drop' that occurs as school-based interventions progress from efficacy to effectiveness to implementation at-scale. Of note, the effects of scaled-up behavioural interventions are typically 25% smaller than those reported in pre-scale-up efficacy trials.[49] Implementation support was a key feature of the B2L intervention. In addition to the provision of professional learning, teachers were provided with on-going support from the research team in the first two phases of the intervention. Support included two school visits per teacher to observe sessions, provide feedback and address implementation challenges. This level of support is consistent with what is provided by NSW Health Project Officers in primary school-based health promotion dissemination trials. We consider this level of support to be both necessary for intervention success and scalable in NSW government schools. However, we do not know if the cost and logistical support needed to deliver the B2L intervention is translatable to educational settings in other countries.

Global secular trends suggest levels of stress, anxiety and depression (ie, internalising problems) among adolescents have increased in recent decades,[50 51] and school-related stress is a major contributor.[52] In our study, we examined hair cortisol concentrations as a biomarker of chronic exposure to stress. Guided by the cross-stressor adaptation theory,[53] we hypothesised that participation in the B2L sessions would stimulate beneficial adaptation of the hypothalamic-pituitary-adrenocortical axis and the sympathoadrenal medullary system, leading to greater resilience to psychosocial stress.[54] At the 6-month assessments, we observed a significant group-by-time effect for hair cortisol concentrations in favour of the B2L intervention. Of note, this intervention effect was strongest among adolescents with moderate-to-high levels of internalising problems at baseline and those who were overweight or obese.

The B2L intervention did not reduce perceived stress or internalising problems in the full study sample. This is somewhat consistent with reviews focused on the effects of exercise on internalising disorders in non-clinical populations, which have found small-to-moderate effects.[55 56] Alternatively, exercise appears to be a promising and acceptable intervention for adolescents experiencing depression.[57] For this reason, we conducted prespecified moderator analyses to determine if the B2L intervention effect was stronger among adolescents considered at-risk of poor mental health at baseline. Partially consistent with our hypotheses, baseline weight status and mental health status were moderators of intervention effects. More specifically, adolescents in the B2L intervention group, with overweight or obesity (this group also reported reductions in perceived stress), and poor mental health at baseline, reported reductions in internalising problems at 6 months, compared with those in the control group.

Study limitations

There are some limitations that should be noted. First, our study had 35.3% loss to follow-up at 12 months. It is important to note that our study focused on an understudied population of students (ie, senior school students) and 22% (145 students) of those assessed at baseline left school during the study period to commence paid employment or vocational education. We targeted this population because they experience high levels of school-related stress and very few are sufficiently active. Second, we used a field-based measure of CRF performance, rather than the gold standard measure of peak oxygen consumption. Third, the majority of classes that agreed to participate in the study were Health and Physical Education classes, thus limiting the generalisability of our findings, as this subject is not mandatory in year 11 in New South Wales. It is important to note that in Australia, this subject does not involve any compulsory practical activity in grade 11.

CONCLUSIONS

Our 6-month findings highlight the health benefits of re-allocating curriculum time to physical activity during the senior school years. The B2L intervention improved CRF and muscular fitness in a sample of older adolescents in NSW government secondary schools. In addition, the intervention had a positive effect on hair cortisol concentrations, stress, internalising problems and working memory in a prespecified subsample of students. Participants who were overweight or obese at baseline had the largest improvements in a range of secondary outcomes. Our 12-month findings suggest that the majority of benefits are not sustained once the intervention was no longer delivered by teachers. Additional strategies are required to ensure that effects are sustained over time. It is important to note that the B2L programme was not designed to promote long-term behaviour change. Instead, it was designed to provide older adolescents with a health enhancing dose of physical activity during a challenging life stage.

What are the findings?

- Participation in teacher facilitated high-intensity interval training (HIIT) breaks improved older adolescents' cardiorespiratory fitness (CRF) at the primary end-point of 6 months.
- Improvements in CRF were not sustained once teachers ceased the delivery of HIIT breaks during curriculum time.
- Improvements were found in a range of secondary outcomes including muscular fitness, hair cortisol concentrations, steps/day during school hours and HIIT self-efficacy.
- Participants who were overweight or obese at baseline had the largest improvements in cortisol, mental health and cognitive function.

How might it impact on clinical practice in the future?

- This study provides support for the importance of mandatory physical activity during the senior school years.
- Further evidence for the mental health benefits of HIIT for adolescents with overweight or obesity.
- A larger dose of HIIT is needed to improve body composition in adolescents.

Author affiliations
[1]Priority Research Centre for Physical Activity and Nutrition, Faculty of Education and Arts, University of Newcastle, Callaghan, New South Wales, Australia
[2]Institute for Positive Psychology and Education, Faculty of Health Sciences, Australian Catholic University, North Sydney, New South Wales, Australia
[3]Centre for Rehab Innovations and Priority Research Centre for Stroke and Brain Injury, University of Newcastle, Callaghan, New South Wales, Australia
[4]School of Medicine and Public Health, University of Newcastle, Callaghan, New South Wales, Australia
[5]School of Behavioural and Health Sciences, Australian Catholic University, Banyo, Queensland, Australia
[6]Department of Psychology, Northeastern University, Boston, Massachusetts, USA
[7]Early Start, School of Education, University of Wollongong, Wollongong, New South Wales, Australia
[8]School of Biomedical Sciences and Pharmacy, University of Newcastle, Callaghan, New South Wales, Australia
[9]School of Health and Wellbeing, Faculty of Health, Engineering and Sciences, University of Southern Queensland, Toowoomba, Queensland, Australia
[10]School of Exercise and Nutrition Sciences, Deakin University, Geelong, Victoria, Australia
[11]Department of Physical Therapy, Movement and Rehabilitation Sciences, Northeastern University, Boston, Massachusetts, USA

Twitter Michael Noetel @mnoetel and Sarah R Valkenborghs @SarahValko

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Contributors DRL: conceptualisation, methodology, investigation, resources, writing-original draft, supervision, funding acquisition. JJS: methodology, investigation, resources, writing-review and editing, funding acquisition. NE: methodology, investigation, resources, writing-review and editing, funding acquisition. AAL: investigation, resources, data curation, writing-review and editing. PM: methodology, resources, writing-review and editing, funding acquisition. CL: methodology, resources, writing-review and editing, funding acquisition. RP: methodology, writing-review and editing, funding acquisition. MN: methodology, writing-review and editing, funding acquisition. SK: investigation, data curation, writing-review and editing, project administration. EGH: formal analysis, writing-review and editing, funding acquisition. NW: writing- review and editing, formal analysis. MN: resources, writing- review and editing. TTS: software, writing-review and editing. MM: investigation, data curation, software, writing-review and editing. SRV: investigation, data curation, writing-review and editing. PG: investigation, data curation, writing-review and editing. FRW: investigation, data curation, writing-review and editing. SAC: resources, writing-review and editing. CHH: methodology, software, resources, writing-review and editing, funding acquisition.

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Competing interests None declared.

Patient and public involvement statement The need for a time-efficient physical activity intervention for older adolescents was identified through consultation with the New South Wales Department of Education School Sport Unit, who provided initial funding to evaluate feasibility of the B2L intervention. We conducted a pilot study in two secondary schools, and participants (ie, students and teachers) were invited to provide feedback on the intervention. This feedback was then used to refine the B2L intervention components and implementation strategies. Study findings will be disseminated through institutional websites, press releases, and tailored messages to schools, educational organisations, and governing bodies.

Patient consent for publication Not required.

Ethics approval This study received approval from the University of Newcastle (H-2016-0424) and the NSW Department of Education (SERAP: 2017116) human research ethics committees.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data are available upon reasonable request. Requests for access to data from the study should be addressed to the corresponding author at david.lubans@newcastle.edu.au. The study protocol has been published. All proposals requesting data access will need to specify how it is planned to use the data, and all proposals will need approval of the trial co-investigator team before data release.

ORCID iDs
David R Lubans http://orcid.org/0000-0003-2147-9420
Chris Lonsdale http://orcid.org/0000-0002-2523-5565

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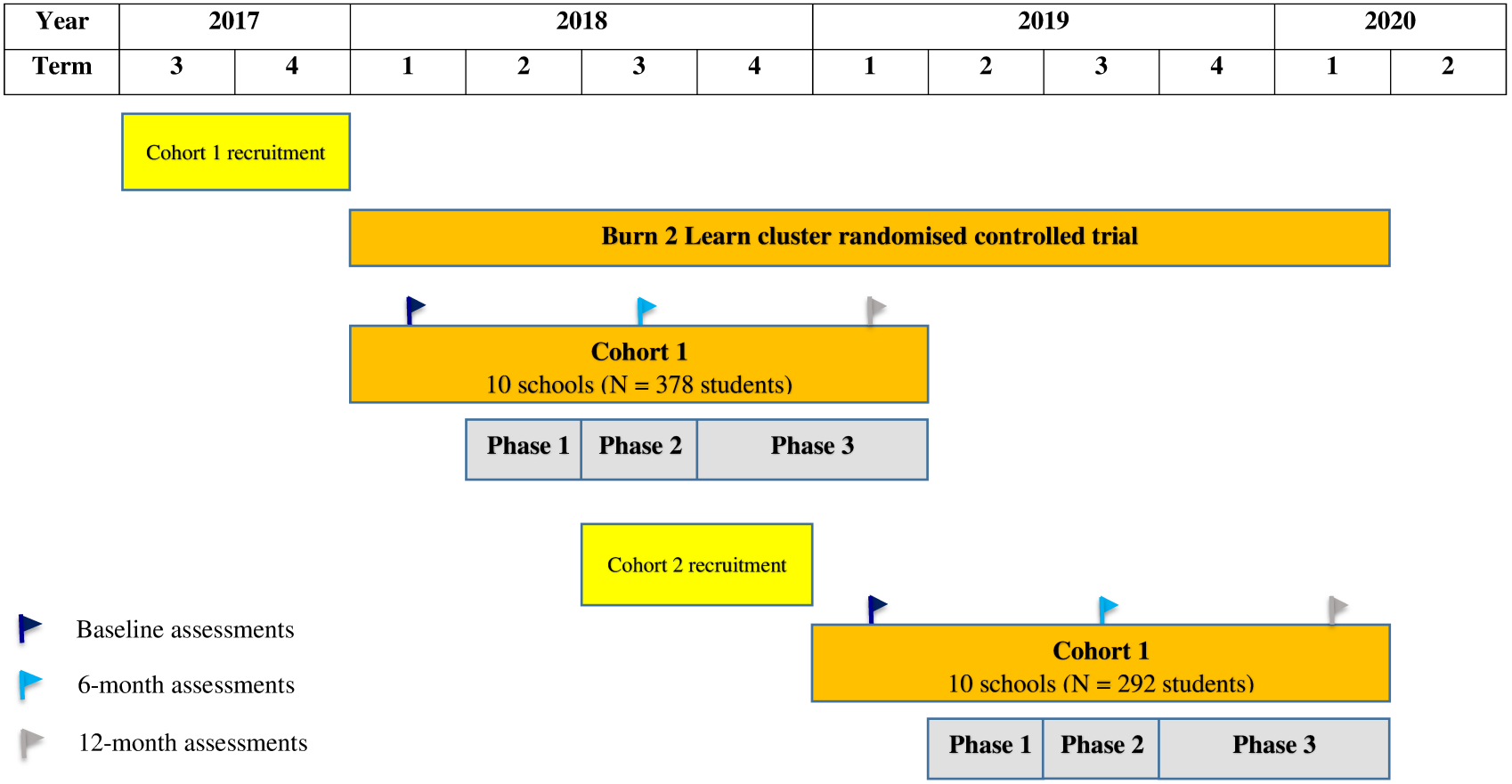
SUPPLEMENTARY MATERIAL

Supplementary Figure 1: Study timeline and assessment points



Supplementary Table 1. Process evaluation

1. Intervention dose	
B2L sessions/week in Phase 1, mean (SD)[a]	2.0 (0.8)
B2L sessions/week in Phase 2, mean (SD)[a]	1.7 (0.6)
B2L sessions/week in Phase 3, mean (SD)[a]	0.6 (0.7)
Total number of teacher reported B2L sessions delivered, mean (SD)[b]	25.9 (5.2)
Typical length of B2L sessions, n (%)	
4 minutes	4 (19.0)
8 minutes	12 (57.1)
12 minutes	4 (19.0)
16 minutes	1 (4.8)
2. Intervention fidelity (session quality)[c]	
Adherence to SAAFE delivery principles, mean (SD)	16.4 (2.5)
3. Intervention fidelity (session intensity)[d]	
Average HR during sessions, mean beats per minute (SD)	143.1 (21.8)
Average HR during sessions, mean % of HR_{max} (SD)	70 (11)
Peak HR during sessions, mean beats per minute (SD)	167.6 (20.4)
Peak HR during sessions, mean % of HR_{max} (SD)	82 (10)
Perceived level of exertion during B2L sessions, mean (SD)[e]	6.3 (2.0)
4. Satisfaction with the program	
Teacher satisfaction, mean (SD)[f]	3.3 (0.5)
Student satisfaction, mean (SD)[g]	3.8 (0.9)
Popularity of different B2L sessions (most to least popular)	Ranking (1-5)
Class HIIT	1
Quick HIIT	2
Gym HIIT	3
Sport HIIT	4
Custom HIIT	5
5. Sustainability	
Participation in future HIIT (student), Yes, %	69.6
Delivery of B2L program to future student cohorts (teacher), Yes, %	81.8

Note. B2L = Burn 2 Learn; SAAFE = Supportive, Active, Autonomous, Fair and Enjoyable; HR = heart rate; SD = standard deviation; HIIT = high-intensity interval training

[a] Teachers asked to retrospectively report number of sessions they delivered in Phases 1-3.

[b] Number of sessions delivered in Phases 1-2, logged by teachers in B2L handbook.

[c] Observations of session quality of scored on a 4-point Likert scale- Strongly disagree (1) to Strongly agree (4), total /20.

[d] Mean peak heart rate (% HRmax) and mean heart rate for the entire session (% HRmax) extracted from the B2L app.

[e] Scored on an 11-point Likert scale ranging from Extremely easy (0) to Extremely hard (10)

[f] Scored on a 4-point Likert scale ranging from Strongly disagree (1) to Strongly agree (4)

[g] Scored on a 5-point Likert scale ranging from Poor (1) to Excellent (5)

Supplementary Table 2. Baseline, 6- and 12-month statistics for fitness and physical activity outcomes

		Baseline		6-months		12-months	
Variable	**Statistic**	**CON**	**INT**	**CON**	**INT**	**CON**	**INT**
Cardiorespiratory fitness (laps)	mean (SD)	49.9 (27.3)	47.8 (24.5)	50.3 (29.1)	51.0 (24.0)	46.5 (27.5)	45.5 (21.2)
	median (min, max)	49.0 (8.0, 123.0)	43.0 (6.0, 109.0)	46.0 (6.0, 138.0)	49.0 (7.0, 116.0)	42.0 (5.0, 145.0)	42.0 (8.0, 98.0)
Upper body endurance (reps)	mean (SD)	11.7 (9.6)	11.1 (8.4)	12.2 (9.9)	12.2 (8.8)	12.7 (10.2)	12.9 (8.8)
	median (min, max)	10.0 (0.0, 41.0)	10.0 (0.0, 36.0)	10.0 (0.0, 40.0)	11.0 (0.0, 37.0)	10.0 (0.0, 41.0)	13.0 (1.0, 35.0)
Lower body power (cm)	mean (SD)	172.3 (39.5)	174.1 (36.8)	174.3 (39.0)	174.9 (36.8)	180.1 (43.0)	170.8 (39.1)
	median (min, max)	168.5 (84.0, 281.0)	174.0 (90.0, 260.0)	176.0 (95.0, 274.0)	170.5 (99.0, 260.0)	179.0 (73.0, 293.0)	167.0 (66.0, 260.0)
BMI z-score	mean (SD)	0.78 (1.11)	0.75 (0.98)	0.76 (1.08)	0.82 (0.92)	0.72 (1.13)	0.76 (0.96)
	median (min, max)	0.68 (-2.05, 3.74)	0.74 (-1.32, 3.22)	0.77 (-2.65, 3.70)	0.80 (-1.28, 3.23)	0.66 (-2.50, 3.65)	0.78 (-1.13, 3.14)
MPA mins/school hours	mean (SD)	17.6 (7.2)	19.0 (8.6)	15.6 (8.6)	17.7 (9.3)	15.3 (7.8)	14.5 (9.6)
	median (min, max)	16.7 (3.6, 42.2)	17.6 (2.2, 54.2)	13.9 (0.3, 48.6)	16.4 (0.3, 61.6)	13.2 (0.2, 45.5)	13.1 (0.0, 40.6)
VPA mins/school hours	mean (SD)	0.7 (0.8)	0.8 (1.2)	0.8 (1.1)	0.9 (1.3)	0.6 (1.1)	0.7 (1.2)
	median (min, max)	0.5 (0.0, 5.9)	0.4 (0.0, 9.1)	0.3 (0.0, 6.6)	0.5 (0.0, 9.3)	0.3 (0.0, 8.5)	0.2 (0.0, 6.6)
MVPA mins/school hours	mean (SD)	18.4 (7.6)	19.9 (9.3)	16.3 (9.4)	18.6 (10.1)	15.9 (8.3)	15.9 (9.7)
	median (min, max)	17.1 (3.6, 42.7)	18.3 (2.6, 60.2)	14.3 (0.3, 54.4)	17.0 (0.3, 69.1)	13.6 (0.2, 47.8)	13.7 (0.0, 44.5)
Steps/school hours	mean (SD)	6,560 (2,219)	6,157 (1,506)	5,562 (1,388)	5,923 (1,903)	5,611 (1,381)	5,222 (1,802)
	median (min, max)	6,108 (3,573, 17,810)	5,911 (1,668, 11,507)	5,575 (1,513, 9,113)	5,489 (1,692, 12,482)	5,609 (1,042, 9,417)	5,311 (1,354, 10,092)
MPA mins/weekday	mean (SD)	36.1 (13.6)	36.9 (13.7)	32.7 (13.4)	33.2 (12.7)	31.6 (11.1)	32.8 (15.3)
	median (min, max)	34.5 (5.4, 81.8)	35.0 (3.5, 83.2)	32.1 (0.3, 84.0)	32.5 (2.3, 76.4)	29.0 (3.6, 61.1)	31.2 (0.2, 88.5)

		Baseline		6-months		12-months	
Variable	**Statistic**	**CON**	**INT**	**CON**	**INT**	**CON**	**INT**
VPA mins/weekday	mean (SD)	1.6 (1.7)	1.7 (2.1)	1.6 (1.8)	1.5 (1.9)	1.4 (1.5)	1.2 (1.7)
	median (min, max)	1.1 (0.0, 12.4)	1.0 (0.0, 14.7)	0.9 (0.0, 8.0)	1.0 (0.0, 12.9)	0.8 (0.0, 7.9)	0.6 (0.0, 7.6)
MVPA mins/weekday	mean (SD)	37.7 (14.2)	38.6 (14.8)	34.4 (14.4)	34.8 (13.8)	33.0 (11.3)	34.1 (16.2)
	median (min, max)	35.8 (5.4, 82.8)	36.5 (4.3, 97.9)	32.8 (0.3, 91.1)	34.0 (2.3, 84.4)	31.2 (3.9, 61.3)	32.1 (0.2, 94.5)
Steps/weekday	mean (SD)	11,392 (2,050)	10,858 (2,107)	10,919 (2,171)	10,479 (2,229)	10,620 (1,972)	10,016 (2,572)
	median (min, max)	11,240 (6,502, 18,085)	10,672 (2,385, 17,263)	10,775 (4,959, 16,658)	10,398 (3,928, 16,859)	10,192 (5,598, 16,951)	10,067 (2,091, 14,640)
MPA mins/weekend day	mean (SD)	33.5 (19.8)	33.9 (17.0)	29.6 (18.5)	33.0 (18.7)	27.9 (17.0)	34.6 (17.9)
	median (min, max)	29.6 (5.9, 135.1)	31.5 (7.0, 118.8)	25.7 (5.1, 105.4)	29.1 (4.0, 102.6)	22.1 (0.7, 89.6)	30.4 (6.7, 101.0)
VPA mins/weekend day	mean (SD)	0.6 (1.0)	0.8 (1.3)	0.7 (1.3)	0.7 (1.5)	0.8 (1.8)	0.4 (0.6)
	median (min, max)	0.2 (0.0, 6.1)	0.3 (0.0, 6.5)	0.2 (0.0, 7.7)	0.2 (0.0, 10.4)	0.2 (0.0, 12.2)	0.2 (0.0, 2.8)
MVPA mins/weekend day	mean (SD)	34.1 (20.2)	34.7 (17.7)	30.4 (18.9)	33.7 (19.5)	28.7 (17.3)	35.0 (17.9)
	median (min, max)	30.5 (5.9, 138.8)	31.9 (7.0, 123.2)	25.8 (5.1, 105.9)	29.5 (4.0, 113.0)	23.0 (0.7. 89.8)	30.5 (6.8, 101.0)
Steps/weekend day	mean (SD)	9,403 (2,999)	9,623 (3,021)	9,418 (3,577)	9,857 (3,723)	8,505 (3,311)	9,925 (3,186)
	median (min, max)	9,331 (4,206, 19,673)	9,629 (3,212, 17,519)	9,173 (2,139, 20,427)	9,000 (3,913, 25,292)	8,555 (2,533, 19,085)	9,474 (4,388, 16,661)

Note. CON = control; INT = intervention; BMI z-score = body mass index z-score; MPA = moderate physical activity; VPA = vigorous physical activity; MVPA = moderate-to-vigorous physical activity.

Supplementary Table 3. Baseline, 6- and 12-month statistics for mental health outcomes

		Baseline		6-months		12-months	
Variable	**Statistic**	**CON**	**INT**	**CON**	**INT**	**CON**	**INT**
Hair cortisol concentration (pg/mg)	mean (SD)	10.6 (6.2)	14.6 (12.0)	13.0 (5.6)	13.3 (5.3)	-	-
	median (min, max)	8.9 (2.5, 37.4)	10.8 (1.7, 68.5)	11.6 (4.6, 33.0)	12.4 (0.0, 35.4)		
Perceived stress	mean (SD)	18.8 (6.2)	19.1 (6.1)	18.1 (6.5)	18.4 (5.8)	19.6 (6.2)	19.5 (6.4)
	median (min, max)	19.0 (1.0, 40.0)	19.0 (2.0, 37.0)	18.0 (1.0, 34.0)	19.0 (1.0, 40.0)	20.0 (0.0, 38.0)	19.0 (2.0, 40.0)
Internalising problems	mean (SD)	5.5 (3.2)	5.4 (3.2)	5.6 (3.4)	5.3 (3.1)	5.6 (3.3)	5.3 (3.1)
	median (min, max)	5.0 (0.0, 18.0)	5.0 (0.0, 17.0)	5.0 (0.0, 18.0)	5.0 (0.0, 14.0)	5.0 (0.0, 15.0)	5.0 (0.0, 16.0)
Externalising problems	mean (SD)	6.1 (3.3)	6.1 (3.4)	6.1 (3.4)	6.1 (3.2)	6.0 (3.2)	5.8 (3.2)
	median (min, max)	6.0 (0.0, 16.0)	6.0 (0.0, 17.0)	6.0 (0.0, 18.0)	6.0 (0.0, 16.0)	6.0 (0.0, 16.0)	6.0 (0.0, 15.0)
Well-being	mean (SD)	23.9 (5.0)	24.9 (4.8)	24.5 (5.0)	24.8 (4.5)	24.6 (4.9)	25.0 (4.5)
	median (min, max)	25.0 (7.0, 35.0)	25.0 (9.0, 35.0)	25.0 (8.0, 35.0)	24.0 (14.0, 35.0)	24.0 (7.0, 35.0)	25.0 (9.0, 35.0)
HIIT self-efficacy	mean (SD)	6.2 (2.1)	6.3 (2.2)	6.3 (2.2)	7.2 (2.2)	6.3 (2.2)	7.2 (2.3)
	median (min, max)	6.4 (1.0, 10.0)	6.4 (1.0, 10.0)	6.5 (1.0, 10.0)	7.5 (1.0, 10.0)	6.5 (1.0, 10.0)	7.3 (1.0, 10.0)
Intrinsic motivation for exercise	mean (SD)	2.9 (1.0)	2.9 (1.0)	2.9 (1.1)	2.9 (0.9)	2.9 (1.0)	2.9 (1.0)
	median (min, max)	3.0 (0.0, 4.0)	3.0 (0.0, 4.0)	3.0 (0.0, 4.0)	3.0 (0.0, 4.0)	3.0 (0.0, 4.0)	3.0 (0.0, 4.0)
Identified motivation for exercise	mean (SD)	2.9 (0.9)	2.9 (0.9)	2.9 (0.9)	2.9 (0.9)	3.0 (0.9)	3.0 (0.9)
	median (min, max)	3.0 (0.0, 4.0)	3.0 (0.0, 4.0)	3.0 (0.0, 4.0)	3.0 (0.0, 4.0)	3.3 (0.0, 4.0)	3.3 (0.0, 4.0)

Note. CON = control; INT = intervention; pg/mg = picograms of cortisol per milligram of hair; HIIT = high-intensity interval training.

Supplementary Table 4. Baseline, 6- and 12-month means and standard deviation for cognitive outcomes

		Baseline		6-months		12-months	
Variable	**Statistic**	**CON**	**INT**	**CON**	**INT**	**CON**	**INT**
Congruent, accuracy (%)	mean (SD)	92.7 (7.8)	93.1 (7.7)	96.5 (5.6)	97.6 (3.2)	97.1 (5.3)	98.0 (3.1)
	median (min, max)	96.0 (56.0, 100.0)	96.0 (52.0, 100.0)	98.7 (66.7, 100.0)	98.7 (82.7, 100.0)	98.7 (61.3, 100.0)	98.7 (72.0, 100.0)
Incongruent, accuracy (%)	mean (SD)	76.9 (14.4)	79.0 (12.7)	85.7 (12.0)	87.9 (10.2)	88.4 (11.4)	90.3 (8.8)
	median (min, max)	80.0 (10.7, 98.7)	81.3 (26.7, 98.7)	89.3 (25.3, 100.0)	90.7 (37.3, 100.0)	92.0 (42.7, 100.0)	92.0 (40.0, 100.0)
Interference, accuracy (%)	mean (SD)	15.8 (11.3)	14.1 (9.1)	10.8 (9.1)	9.7 (8.7)	8.7 (8.6)	7.7 (7.5)
	median (min, max)	13.3 (-6.7, 82.7)	12.0 (-2.7, 57.3)	8.0 (-4.0, 54.7)	6.7 (-8.0, 48.0)	6.7 (-6.7, 50.7)	6.0 (-2.7, 45.3)
Congruent, RT (ms)	mean (SD)	419.5 (53.4)	415.9 (50.9)	420.0 (48.4)	421.7 (46.5)	419.8 (47.1)	418.2 (41.1)
	median (min, max)	409.2 (298.4, 637.7)	407.9 (316.3, 605.6)	413.5 (312.8, 602.8)	416.3 (333.7, 611.8)	416.7 (303.0, 609.1)	414.0 (332.6, 555.3)
Incongruent, RT (ms)	mean (SD)	481.4 (57.8)	477.3 (56.7)	480.2 (55.0)	479.9 (48.4)	474.5 (47.5)	470.6 (41.2)
	median (min, max)	477.5 (315.7, 680.7)	476.0 (329.5, 720.6)	473.2 (350.9, 757.1)	475.3 (372.0, 737.7)	468.3 (343.9, 638.4)	466.3 (373.3, 584.6)
Interference, RT (ms)	mean (SD)	61.9 (25.9)	61.4 (27.9)	60.2 (27.2)	58.2 (22.9)	54.7 (23.3)	52.4 (20.0)
	median (min, max)	60.4 (-35.5, 141.1)	60.2 (-19.3, 147.9)	58.7 (-9.2, 259.9)	56.9 (-7.3, 193.4)	53.8 (-17.8, 168.5)	50.4 (-5.4, 108.3)
Non-target, accuracy (%)	mean (SD)	84.3 (14.4)	85.0 (12.7)	89.9 (10.3)	89.3 (12.1)	90.0 (12.3)	90.5 (10.8)
	median (min, max)	89.1 (18.5, 100.0)	89.1 (25.0, 100.0)	93.5 (31.5, 100.0)	92.4 (0.0, 100.0)	94.6 (28.3, 100.0)	94.6 (37.0, 100.0)
Target, accuracy (%)	mean (SD)	74.8 (16.7)	75.4 (14.5)	81.2 (13.8)	82.6 (14.9)	83.3 (15.6)	84.3 (13.3)
	median (min, max)	79.2 (14.6, 100.0)	79.2 (12.5, 100.0)	85.4 (35.4, 100.0)	87.5 (0.0, 100.0)	87.5 (27.1, 100.0)	87.5 (33.3, 100.0)
d-prime	mean (SD)	2.0 (1.0)	2.0 (0.8)	1.8 (1.0)	1.9 (1.0)	2.7 (1.1)	2.7 (1.0)
	median (min, max)	2.1 (-0.8, 4.5)	2.0 (-0.2, 4.2)	1.9 (-1.3, 3.9)	2.0 (-1.1, 3.9)	2.8 (-1.1, 4.6)	2.8 (0.0, 4.5)

Variable	Statistic	Baseline		6-months		12-months	
		CON	INT	CON	INT	CON	INT
Non-target, RT (ms)	mean (SD)	830.5 (209.1)	828.2 (201.0)	772.5 (183.3)	767.4 (178.8)	759.3 (191.2)	735.4 (172.7)
	median (min, max)	831.8 (288.5, 1416.2)	825.2 (292.5, 1521.8)	764.3 (337.5, 1376.4)	773.6 (0.0, 1208.1)	738.8 (334.9, 1359.1)	727.5 (331.8, 1532.3)
Target, RT (ms)	mean (SD)	723.6 (204.1)	707.2 (179.8)	673.4 (164.8)	665.4 (156.1)	673.8 (178.0)	646.3 (164.7)
	median (min, max)	719.3 (263.5, 1372.9)	706.2 (264.8, 1248.5)	657.9 (304.4, 1132.9)	658.7 (0.0, 1143.0)	658.7 (282.8, 1596.8)	617.9 (295.5, 1379.3)

Note. RT = reaction time; ms = milliseconds. Consistent with previous research, participants were included in the analysis if their overall mean flanker accuracy (i.e., congruent and incongruent) was higher than 50% and if their mean d-prime score was greater than 0 for the 1- and 2-back conditions. At baseline (37 cases), 6-month (13 cases) and 12-months (11 cases) flanker accuracy and reaction values were removed. At baseline (8 cases), 6-month (3 cases) and 12-months (2 cases) n-back accuracy and reaction values were removed.

Supplementary Table 5. Effect modification of CRF at 6-months

			Within group mean change (95% CI) (6-month minus baseline)		Adjusted difference[1] (INT v. CON)
Moderator	**Interaction P value**	**Subgroup**	**CON**	**INT**	**Estimate**
SES	0.221	High	-3.0 (-5.9 to -0.0)	3.5 (0.4 to 6.6)	6.5 (2.2 to 10.7)
		Low or medium	-3.2 (-5.3 to -1.1)	0.1 (-1.8 to 2.0)	3.3 (0.5 to 6.1)
Sex	0.986	Boy	-3.4 (-5.6 to -1.6)	0.4 (-1.9 to 2.6)	4.0 (1.0 to 7.0)
		Girl	-2.3 (-5.3 to 0.8)	1.7 (-0.5 to 4.0)	4.0 (0.2 to 7.8)
Weight status	0.252	Healthy weight and underweight	-2.6 (-4.6 to -0.6)	0.7 (-1.2 to 2.3)	3.3 (0.6 to 6.0)
		Overweight and obese	-4.4 (-7.5 to -1.4)	1.9 (-1.3 to 5.1)	6.4 (1.9 to 10.8)
Mental health status	0.483	Close to average and slightly raised	-3.3 (-5.1 to -1.5)	0.4 (-1.3 to 2.2)	3.7 (1.2 to 6.3)
		High to very high	-1.9 (-6.0 to 2.2)	4.1 (0.0 to 8.2)	6.0 (0.2 to 11.7)
CRF status	0.478	Health risk and needs improvement	-0.5 (-3.2 to 2.2)	2.5 (-0.3 to 5.3)	3.0 (-0.9 to 6.9)
		Healthy fitness zone	-4.5 (-6.6 to -2.5)	0.2 (-1.7 to 2.1)	4.7 (1.9 to 7.6)

Note. INT = intervention; CON = control; SES = socio-economic status based on household postcode; CRF = cardiorespiratory fitness; CI = confidence interval

[1] Adjusted difference at 6-months = [(INT post-test mean minus INT baseline mean) minus (CON post-test mean minus CON baseline mean)].

Supplementary Table 6. Effect modification of hair cortisol concentrations at 6-months

			Within group mean change (95% CI) (6-month minus baseline)		Adjusted difference[1] (INT v. CON)
Moderator	**Interaction P value**	**Subgroup**	**CON**	**INT**	**Estimate**
SES	0.139	High	5.20 (-0.05 to 10.45)	-3.13 (-7.80 to 1.53)	-8.34 (-15.36 to -1.32)
		Low or medium	2.00 (-0.22 to 4.21)	-0.58 (-2.65 to 1.50)	-2.57 (-5.61 to 0.46)
Sex	0.467	Boy	2.45 (-0.33 to 5.22)	-0.37 (-3.14 to 2.40)	-2.82 (-6.74 to 1.10)
		Girl	2.62 (-0.68 to 5.92)	-2.35 (-5.12 to 0.41)	-4.97 (-9.28 to -0.67)
Weight status	0.049	Healthy weight and underweight	2.12 (-0.39 to 4.63)	0.02 (-2.23 to 2.27)	-2.10 (-5.47 to 1.26)
		Overweight and obese	3.44 (-0.46 to 7.34)	-5.13 (-8.97 to -1.30)	-8.57 (-14.05 to -3.10)
Mental health status	0.087	Close to average and slightly raised	2.15 (-0.16 to 4.47)	-0.60 (-2.75 to 1.56)	-2.75 (-5.91 to 0.41)
		High to very high	4.01 (-1.11 to 9.13)	-5.34 (-9.92 to -0.76)	-9.35 (-16.22 to -2.47)
CRF status	0.429	Health risk and needs improvement	1.35 (-2.75 to 5.45)	-4.68 (-8.61 to -0.75)	-6.03 (-11.71 to -0.35)
		Healthy fitness zone	2.83 (0.22 to 5.44)	-0.53 (-2.83 to 1.77)	-3.36 (-6.83 to 0.12)

Note. INT = intervention; CON = control; SES = socio-economic status based on household postcode; CRF = cardiorespiratory fitness; CI = confidence interval

[1] Adjusted difference at 6-months = [(INT post-test mean minus INT baseline mean) minus (CON post-test mean minus CON baseline mean)].

Supplementary Table 7. Effect modification of internalising problems at 6-months

			Within group mean change (95% CI) (6-month minus baseline)		Adjusted difference[1] (INT v. CON)
Moderator	**Interaction P value**	**Subgroup**	**CON**	**INT**	**Estimate**
SES	0.793	High	0.14 (-0.35 to 0.63)	0.09 (-0.44 to 0.61)	-0.05 (-0.77 to 0.67)
		Low or medium	0.15 (-0.21 to 0.51)	-0.02 (-0.36 to 0.32)	-0.17 (-0.66 to 0.32)
Sex	0.501	Boy	0.19 (-0.18 to 0.55)	-0.10 (-0.50 to 0.31)	-0.28 (-0.83 to 0.26)
		Girl	0.10 (-0.37 to 0.57)	0.09 (-0.30 to 0.49)	0.00 (-0.61 to 0.61)
Weight status	0.010	Healthy weight and underweight	-0.12 (-0.47 to 0.23)	0.10 (-0.22 to 0.42)	0.22 (-0.26 to 0.69)
		Overweight and obese	0.70 (0.18 to 1.22)	-0.28 (-0.85 to 0.30)	-0.97 (-1.75 to -0.20)
Mental health status	0.156	Close to average and slightly raised	0.42 (0.12 to 0.73)	0.35 (0.06 to 0.64)	-0.07 (-0.49 to 0.35)
		High to very high	-0.96 (-1.57 to -0.36)	-1.76 (-2.44 to -1.08)	-0.80 (-1.70 to 0.11)
CRF status	0.853	Health risk and needs improvement	0.19 (-0.31 to 0.69)	0.01 (-0.50 to 0.51)	-0.19 (-0.90 to 0.52)
		Healthy fitness zone	0.23 (-0.17 to 0.62)	-0.05 (-0.41 to 0.32)	-0.27 (-0.81 to 0.26)

Note. INT = intervention; CON = control; SES = socio-economic status based on household postcode; CRF = cardiorespiratory fitness; CI = confidence interval

[1] Adjusted difference at 6-months = [(INT post-test mean minus INT baseline mean) minus (CON post-test mean minus CON baseline mean)].

Supplementary Table 8. Effect modification of perceived stress at 6-months

			Within group mean change (95% CI) (6-month minus baseline)		Adjusted difference[1] (INT v. CON)
Moderator	**Interaction P value**	**Subgroup**	**CON**	**INT**	**Estimate**
SES	0.241	High	-0.27 (-1.34 to 0.79)	-1.10 (-2.26 to 0.05)	-0.83 (-2.40 to 0.74)
		Low or medium	-0.61 (-1.40 to 0.17)	-0.31 (-1.04 to 0.42)	0.30 (-0.77 to 1.37)
Sex	0.425	Boy	-0.41 (-1.21 to 0.39)	-0.82 (-1.70 to 0.06)	-0.41 (-1.60 to 0.78)
		Girl	-0.59 (-1.61 to 0.43)	-0.27 (-1.13 to 0.59)	0.32 (-1.01 to 1.65)
Weight status	0.032	Healthy weight and underweight	-0.69 (-1.45 to 0.07)	-0.10 (-0.81 to 0.60)	0.59 (-0.44 to 1.63)
		Overweight and obese	-0.17 (-1.30 to 0.97)	-1.74 (-2.99 to -0.49)	-1.57 (-3.26 to 0.12)
Mental health status	0.077	Close to average and slightly raised	-0.66 (-1.37 to 0.04)	-0.30 (-0.96 to 0.37)	0.37 (-0.60 to 1.34)
		High to very high	0.16 (-1.23 to 1.55)	-1.54 (-3.09 to 0.02)	-1.69 (-3.78 to 0.39)
CRF status	0.271	Health risk and needs improvement	0.15 (-0.93 to 1.22)	-0.46 (-1.55 to 0.64)	-0.60 (-2.14 to 0.93)
		Healthy fitness zone	-1.02 (-1.87 to -0.17)	-0.54 (-1.32 to 0.23)	0.48 (-0.67 to 1.62)

Note. INT = intervention; CON = control; SES = socio-economic status based on household postcode; CRF = cardiorespiratory fitness; CI = confidence interval

[1] Adjusted difference at 6-months [(INT post-test mean minus INT baseline mean) minus (CON post-test mean minus CON baseline mean)].

Supplementary Table 9. Changes in cognitive outcomes at 6- and 12-month follow-up between participants randomised to control or the B2L intervention

Secondary outcomes	No of clusters (participants)		Mean change from baseline (95% CI)		Adjusted difference in follow-up[1]	
	CON	INT	CON	INT	Coefficient (95% CI)	P value
Flanker congruent, accuracy (%): 6-months	10 (320)	10 (326)	4.20 (3.31, 5.09)	4.29 (3.49, 5.09)	0.45 (-0.72, 1.63)	0.449
Flanker congruent, accuracy (%): 12-months	10 (327)	10 (328)	3.97 (2.94, 5.00)	4.79 (3.79, 5.80)	0.66 (-0.52, 1.85)	0.273
Flanker incongruent, accuracy (%): 6-months	10 (320)	10 (326)	9.68 (8.25, 11.11)	8.75 (7.58, 9.93)	-0.54 (-2.35, 1.28)	0.563
Flanker incongruent, accuracy (%): 12-months	10 (327)	10 (328)	11.81 (10.06, 13.56)	11.51 (10.03, 12.98)	0.04 (-1.91, 1.99)	0.967
Flanker interference, accuracy (%): 6-months	10 (320)	10 (326)	-5.48 (-6.77, -4.18)	-4.47 (-5.50, -3.44)	0.81 (-0.80, 2.41)	0.324
Flanker interference, accuracy (%): 12-months	10 (327)	10 (328)	-7.84 (-9.32, -6.35)	-6.71 (-7.87, -5.56)	0.62 (-1.05, 2.30)	0.466
Flanker congruent, RT (%): 6-months	10 (320)	10 (326)	1.82 (-3.12, 6.76)	7.67 (2.88, 12.46)	5.91 (-0.82, 12.64)	0.086
Flanker congruent, RT (%): 12-months	10 (327)	10 (328)	5.09 (-0.64, 10.82)	5.90 (0.55, 11.25)	0.22 (-6.93, 7.38)	0.951
Flanker incongruent, RT (%): 6-months	10 (320)	10 (326)	1.20 (-4.98, 7.37)	2.70 (-2.43, 7.83)	2.70 (-5.07, 10.47)	0.496
Flanker incongruent, RT (%): 12-months	10 (327)	10 (328)	-4.42 (-11.05, 2.22)	-4.90 (-10.55, 0.75)	-2.41 (-10.52, 5.69)	0.560
Flanker interference, RT (%): 6-months	10 (320)	10 (326)	-0.62 (-4.64, 3.40)	-4.97 (-7.95, -1.99)	-2.48 (-7.25, 2.29)	0.308
Flanker interference, RT (%): 12 months	10 (327)	10 (328)	-9.51 (-13.16, -5.86)	-10.80 (-14.26, -7.35)	-2.36 (-7.20, 2.47)	0.339
2-back non-target, accuracy (%): 6-months	10 (328)	10 (337)	5.03 (3.46, 6.60)	4.24 (2.87, 5.61)	-1.08 (-3.12, 0.96)	0.298
2-back non-target, accuracy (%): 12-months	10 (332)	10 (337)	4.83 (2.91, 6.75)	4.56 (2.72, 6.41)	-0.27 (-2.69, 2.15)	0.825
2-back target, accuracy (%): 6-months	10 (328)	10 (337)	5.94 (4.23, 7.64)	6.65 (5.09, 8.21)	0.81 (-1.44, 3.06)	0.481
2-back target, accuracy (%): 12-months	10 (332)	10 (337)	7.82 (5.42, 10.22)	7.39 (5.05, 9.74)	0.05 (-2.79, 2.89)	0.971
d-prime: 6-months	10 (328)	10 (337)	-0.22 (-0.33, -0.12)	-0.11 (-0.21, -0.01)	0.12 (-0.03, 0.26)	0.109
d-prime: 12-months	10 (332)	10 (337)	0.61 (0.46, 0.77)	0.58 (0.43, 0.74)	-0.01 (-0.20, 0.18)	0.907

Secondary outcomes	No of clusters (participants)		Mean change from baseline (95% CI)		Adjusted difference in follow-up[1]	
	CON	INT	CON	INT	Coefficient (95% CI)	P value
2-back non-target, RT (ms): 6-months	10 (328)	10 (337)	-61.33 (-83.33, -39.33)	-62.06 (-82.28, -41.84)	-1.96 (-31.07, 27.16)	0.895
2-back non-target, RT (ms): 12-months	10 (332)	10 (337)	-83.28 (-116.48, -50.08)	-90.89 (-123.02, -58.76)	-18.58 (-55.68, 18.51)	0.326
2-back target, RT (ms): 6-months	10 (328)	10 (337)	-53.55 (-73.24, -33.87)	-40.16 (-60.06, -20.26)	11.10 (-16.31, 38.51)	0.428
2-back target, RT (ms): 12-months	10 (332)	10 (337)	-57.83 (-88.40, -27.26)	-56.70 (-88.50, -24.91)	-7.10 (-42.13, 27.94)	0.691

Note. RT = reaction time; ms = milliseconds; INT = intervention; CON = control; CI = confidence interval. Participants were included in the analysis if their overall mean flanker accuracy (i.e., congruent and incongruent) was higher than 50% and if their mean d-prime score was greater than 0 for the 1- and 2-back conditions. At baseline (37 cases), 6-month (13 cases) and 12-months (11 cases) flanker accuracy and reaction values were removed. At baseline (8 cases), 6-month (3 cases) and 12-months (2 cases) n-back accuracy and reaction values were removed.

[1]Adjusted difference in secondary outcomes at 6- and 12-months = [(INT post-test mean minus INT baseline mean) minus (CON post-test mean minus CON baseline mean)]. P value adjusted for cluster effect, and randomisation pair.

Supplementary Table 10. Effect modification of flanker accuracy interference at 6-months

			Within group mean change (95% CI) (6-month minus baseline)		Adjusted difference[1] (INT v. CON)
Moderator	**Interaction P value**	**Subgroup**	**CON**	**INT**	**Estimate**
SES	0.689	High	-5.26 (-7.21 to -3.32)	-4.92 (-7.05 to -2.79)	0.34 (-2.54 to 3.23)
		Low or medium	-5.23 (-6.66 to -3.80)	-4.18 (-5.50 to -2.85)	1.05 (-0.90 to 3.00)
Sex	0.336	Boy	-5.73 (-7.20 to -4.25)	-5.84 (-7.43 to -4.24)	-0.11 (-2.28 to 2.06)
		Girl	-4.49 (-6.30 to -2.68)	-3.02 (-4.57 to -1.48)	1.47 (-0.92 to 3.85)
Weight status	0.392	Healthy weight and underweight	-5.67 (-7.05 to -4.29)	-4.38 (-5.68 to -3.08)	1.29 (-0.61 to 3.19)
		Overweight and obese	-4.19 (-6.30 to -2.07)	-4.47 (-6.71 to -2.23)	-0.29 (-3.37 to 2.79)
Mental health status	0.725	Close to average and slightly raised	-5.09 (-6.39 to -3.79)	-4.43 (-5.66 to -3.21)	0.66 (-1.13 to 2.44)
		High to very high	-5.75 (-8.26 to -3.24)	-4.35 (-7.10 to -1.60)	1.40 (-2.32 to 5.12)
CRF status	0.494	Health risk and needs improvement	-4.20 (-6.18 to -2.22)	-3.73 (-5.67 to -1.78)	0.47 (-2.30 to 3.25)
		Healthy fitness zone	-6.60 (-8.17 to -5.03)	-4.91 (-6.35 to -3.48)	1.69 (-0.44 to 3.82)

Note. INT = intervention; CON = control; SES = socio-economic status based on household postcode; CRF = cardiorespiratory fitness; CI = confidence interval

[1] Adjusted difference at 6-months = [(INT post-test mean minus INT baseline mean) minus (CON post-test mean minus CON baseline mean)].

Supplementary Table 11. Effect modification of flanker reaction time interference at 6-months

			Within group mean change (95% CI) (6-month minus baseline)		Adjusted difference[1] (INT v. CON)
Moderator	**Interaction P value**	**Subgroup**	**CON**	**INT**	**Estimate**
SES	0.151	High	0.66 (-5.12 to 6.43)	-6.99 (-13.35 to -0.62)	-7.64 (-16.24 to 0.95)
		Low or medium	-2.51 (-6.76 to 1.75)	-2.56 (-6.50 to 1.38)	-0.06 (-5.86 to 5.75)
Sex	0.243	Boy	-1.46 (-5.86 to 2.95)	-6.99 (-11.76 to -2.22)	-5.53 (-12.02 to 0.96)
		Girl	-0.98 (-6.40 to 4.44)	-0.77 (-5.40 to 3.85)	0.21 (-6.92 to 7.33)
Weight status	0.803	Healthy weight and underweight	-0.30 (-4.42 to 3.82)	-3.26 (-7.15 to 0.62)	-2.97 (-8.63 to 2.69)
		Overweight and obese	-3.75 (-10.04 to 2.54)	-5.35 (-12.02 to 1.32)	-1.60 (-10.77 to 7.57)
Mental health status	0.880	Close to average and slightly raised	-2.16 (-6.01 to 1.70)	-4.36 (-8.01 to -0.71)	-2.20 (-7.51 to 3.11)
		High to very high	1.62 (-5.83 to 9.07)	-1.53 (-9.69 to 6.64)	-3.14 (-14.20 to 7.91)
CRF status	0.497	Health risk and needs improvement	0.99 (-4.88 to 6.87)	-2.69 (-8.49 to 3.10)	-3.69 (-11.94 to 4.57)
		Healthy fitness zone	-3.76 (-8.44 to 0.92)	-3.85 (-8.12 to 0.43)	-0.08 (-6.42 to 6.26)

Note. INT = intervention; CON = control; SES = socio-economic status based on household postcode; CRF = cardiorespiratory fitness; CI = confidence interval

[1] Adjusted difference at 6-months = [(INT post-test mean minus INT baseline mean) minus (CON post-test mean minus CON baseline mean)].

Supplementary Table 12. Effect modification of 2-back d-prime at 6-months

			Within group mean change (95% CI) (6-month minus baseline)		Adjusted difference[1] (INT v. CON)
Moderator	**Interaction P value**	**Subgroup**	**CON**	**INT**	**Estimate**
SES	0.096	High	-0.16 (-0.34 to 0.01)	-0.24 (-0.43 to -0.06)	-0.08 (-0.33 to 0.17)
		Low or medium	-0.25 (-0.38 to -0.12)	-0.07 (-0.19 to 0.05)	0.18 (0.01 to 0.35)
Sex	0.547	Boy	-0.23 (-0.36 to -0.10)	-0.07 (-0.21 to 0.07)	0.16 (-0.03 to 0.35)
		Girl	-0.20 (-0.37 to -0.04)	-0.13 (-0.27 to 0.01)	0.07 (-0.14 to 0.29)
Weight status	0.013	Healthy weight and underweight	-0.15 (-0.27 to -0.03)	-0.15 (-0.26 to -0.03)	0.00 (-0.16 to 0.17)
		Overweight and obese	-0.38 (-0.56 to -0.19)	0.03 (-0.17 to 0.23)	0.41 (0.14 to 0.68)
Mental health status	0.700	Close to average and slightly raised	-0.22 (-0.34 to -0.11)	-0.10 (-0.21 to 0.01)	0.12 (-0.03 to 0.28)
		High to very high	-0.21 (-0.43 to 0.02)	-0.15 (-0.40 to 0.09)	0.05 (-0.28 to 0.38)
CRF status	0.108	Health risk and needs improvement	-0.31 (-0.48 to -0.14)	0.00 (-0.17 to 0.16)	0.30 (0.07 to 0.54)
		Healthy fitness zone	-0.18 (-0.31 to -0.04)	-0.12 (-0.24 to 0.00)	0.06 (-0.12 to 0.24)

Note. INT = intervention; CON = control; SES = socio-economic status based on household postcode; CRF = cardiorespiratory fitness; CI = confidence interval

[1] Adjusted difference at 6-months = [(INT post-test mean minus INT baseline mean) minus (CON post-test mean minus CON baseline mean)].

Supplementary Table 13: Intraclass correlation values expressing the similarity of individual observations within the same schools

Outcome	School variance (Level 3)	Student variance (Level 2)	Error variance (Level 1)	ICC
Cardiorespiratory fitness (laps)	15.8646	506.84	79.6235	0.02634
Push-ups	0.1522	61.1099	12.9233	0.00205
Standing long jump	42.1937	1187.69	116.03	0.03135
Hair cortisol concentrations	1.9148	0.1470	61.8951	0.02994
Perceived stress	0	22.2860	13.8743	0
Internalising problems	0	7.0399	2.9027	0
Externalising problems	0	7.8641	3.0561	0
Steps per day (school hours)	394434	542616	1332405	0.17380
Steps per day (weekday)	72613	2291422	1353060	0.01953
Steps per day (weekend day)	0	3100164	6255686	0
MVPA mins/day (school hours)	0.4643	44.0410	29.0537	0.00631
MVPA mins/day (weekday)	0	123.91	64.5551	0
MVPA mins/day (weekend day)	0	104.76	237.53	0

Note. MVPA = moderate-to-vigorous physical activity; ICC = intraclass correlation coefficient reflecting similarity of individual observations in the same classes. Some Level 3 variance estimates are 0 due to estimation of negligible or negative variances at Level 3, after accounting for variation at Levels 1 and 2, resulting in ICC estimates of 0.

Supplementary Table 14: Intraclass correlation values expressing the similarity of individual observations within the same classes

Outcome	Class variance (Level 3)	Student variance (Level 2)	Error variance (Level 1)	ICC
Cardiorespiratory fitness (laps)	31.0660	492.17	79.6281	0.05153
Push-ups	2.4018	58.9615	12.9248	0.03233
Standing long jump	65.3322	1164.61	116.03	0.04854
Hair cortisol concentrations	2.5205	0	61.5490	0.03934
Perceived stress	0	22.2858	13.8744	0
Internalising problems	0.07044	6.9716	2.9019	0.00708
Externalising problems	0	7.8651	3.0558	0
Steps per day (school hours)	477833	454396	1324904	0.21170
Steps per day (weekday)	148419	2212208	1356017	0.03993
Steps per day (weekend day)	0	3104281	6252301	0
MVPA mins/day (school hours)	3.7410	41.2045	28.9541	0.05062
MVPA mins/day (weekday)	3.8264	120.29	64.5087	0.02029
MVPA mins/day (weekend day)	0	104.76	237.52	0

Note. MVPA = moderate-to-vigorous physical activity; ICC = intraclass correlation coefficient reflecting similarity of individual observations in the same classes. Some Level 3 variance estimates are 0 due to estimation of negligible or negative variances at Level 3, after accounting for variation at Levels 1 and 2, resulting in ICC estimates of 0.

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School-based physical activity intervention for older adolescents: rationale and study protocol for the Burn 2 Learn cluster randomised controlled trial

Angus A Leahy,[1,2] Narelle Eather,[1,2] Jordan J Smith,[1,2] Charles Hillman,[3,4] Philip J Morgan,[1,2] Michael Nilsson,[5] Chris Lonsdale,[6] Ronald C Plotnikoff,[1,2] Michael Noetel,[6,7] Elizabeth Holliday,[8] Tatsuya T Shigeta,[3] Sarah A Costigan,[1,2,9] Frederick R Walker,[10] Sarah Young,[1,2] Sarah R Valkenborghs,[1,10] Prajwal Gyawali,[10] Nigel Harris,[11] Sarah G Kennedy,[1,2] David R Lubans[1,2]

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For numbered affiliations see end of article.

Correspondence to
Professor David R Lubans;
david.lubans@newcastle.edu.au

ABSTRACT

Introduction This trial aims to investigate the impact of a school-based physical activity programme, involving high-intensity interval training (HIIT), on the physical, mental and cognitive health of senior school students.

Methods and analysis The Burn 2 Learn (B2L) intervention will be evaluated using a two-arm parallel group cluster randomised controlled trial with allocation occurring at the school level (to treatment or wait-list control). Schools will be recruited in two cohorts from New South Wales, Australia. The trial will aim to recruit ~720 senior school students (aged 16–18 years) from 20 secondary schools (ie, 10 schools per cohort). A range of implementation strategies will be provided to teachers (eg, training, equipment and support) to facilitate the delivery of HIIT sessions during scheduled classes. In phase I and II (3 months each), teachers will facilitate the delivery of at least two HIIT sessions/week during lesson-time. In phase III (6 months), students will be encouraged to complete sessions outside of lesson-time (teachers may continue to facilitate the delivery of B2L sessions during lesson-time). Study outcomes will be assessed at baseline, 6 months (primary end point) and 12 months. Cardiorespiratory fitness (shuttle run test) is the primary outcome. Secondary outcomes include: vigorous physical activity, muscular fitness, cognition and mental health. A subsample of students will (i) provide hair samples to determine their accumulated exposure to stressful events and (ii) undergo multimodal MRI to examine brain structure and function. A process evaluation will be conducted (ie, recruitment, retention, attendance and programme satisfaction).

Ethics and dissemination This study has received approval from the University of Newcastle (H-2016–0424) and the NSW Department of Education (SERAP: 2017116) human research ethics committees.

Trial registration number ACTRN12618000293268; Pre-results.

Strengths and limitations of this study

- Strengths of this study include the cluster randomised controlled trial design and adequate power to detect changes in primary and secondary outcomes.
- The measurement and analysis of the potential mechanisms responsible for the effects of physical activity on cognitive and mental health are strengths of this study.
- Focus on the factors influencing implementation and intervention fidelity are additional study strengths.
- As the majority of assessments will take place in the schools, it is not possible to assess fitness parameters using gold standard measures.

INTRODUCTION

Physical inactivity has been described as a global pandemic,[1] and global estimates suggest that <20% of adolescents are sufficiently active.[2] Furthermore, physical activity declines dramatically during the teenage years (~7% each year from age 11 to 19 years),[3] and Australian data indicate only 6% of older adolescents (15–17 years) are satisfying current physical activity guidelines of 60 min of moderate-to-vigorous physical activity per day.[4] Recent data gathered from Australian secondary schools indicates that adolescent girls are less likely to meet physical activity recommendations in comparison to boys.[5] Of additional concern, evidence suggests a decline in young people's cardiorespiratory fitness (CRF), which is an important predictor of overall health status,[6] has occurred since the 1970s.[7 8] While previous studies have noted small-to-moderate

associations between physical activity and CRF in young people,[9] the relationship is stronger when activity of vigorous intensity is examined independently.

Adolescents who participate in physical activity of sufficient volume and intensity to improve their CRF will experience metabolic and cognitive benefits. For example, a recent longitudinal study involving a large sample of adolescents found that cardiometabolic risk declined in a dose-response manner with increasing vigorous physical activity in adolescents (healthy adolescents accumulated at least 7 min of vigorous activity each day), but not with increased volume of light or moderate physical activity.[10] Both vigorous activity and CRF are also important for young people's mental[11 12] and cognitive health.[13 14] Recent systematic reviews have concluded that participating in physical activity can improve young people's cognitive control and academic performance,[14 15] but the underlying neurobiological, psychosocial and behavioural mechanisms not well understood.[16]

Schools are ideal settings for the delivery of physical activity programmes because they have access to young people as well as the necessary facilities and equipment, and availability of qualified staff.[17] School-based physical activity interventions targeting children (aged 5–11 years) and young adolescents (aged 12–15 years) have had mixed success.[18 19] Efficacy studies usually produce positive findings, but the promising findings from small-scale studies are rarely seen in large-scale effectiveness trials.[20] Focusing on organisational change (ie, supportive school policies) and providing professional development for teachers can lead to improvements in physical activity and fitness in children[21 22] and younger adolescents.[23–26] However, it is relatively unknown if school-based interventions are effective with older adolescents (ie, senior school students [aged 16–18 years]) because few randomised controlled trials (RCTs) have been conducted with this population.[19]

Conducting and evaluating health promotion interventions with older adolescents is challenging, in part, due to the pressures associated with standardised testing at the end of secondary school and university entrance examinations. The focus on academic performance in the final years of secondary schooling and a lack of support from school administrators are major barriers to physical activity promotion in schools.[17 27 28] The success and sustainability of physical activity interventions is largely dependent on 'buy in' from school principals and teachers, which may wane over time in the face of competing time demands. As enhancing students' academic performance is the core business of schools, providing evidence for the impact of vigorous physical activity on cognitive and academic outcomes may provide a novel 'hook' for schools to implement physical activity interventions. Nevertheless, school-based physical activity interventions need to be time efficient because lack of time is the most commonly cited implementation barrier cited by teachers.[27]

High-intensity interval training (HIIT) is a time efficient strategy for improving metabolic health in adolescents and adults,[29 30] and typically consists of short, yet intense bouts of vigorous activity interspersed with brief periods of rest or light activity. Previous studies have shown HIIT can improve CRF (unstandardised mean difference=2.6 mL/kg/min, 95% CI=1.8 to 3.3), reduce body mass index (BMI, −0.6 kg/m^2, 95% CI=−0.9 to −0.4) and improve metabolic markers (ie, insulin sensitivity and fasting plasma insulin) in adolescents.[30 31] For most adolescents, the 'all out' maximal type of HIIT (ie, 100% of heart rate max) may not be palatable and such an approach has limited potential as a public health strategy.[32] Alternatively, there is emerging evidence for the efficacy of less demanding HIIT protocols (eg, 85% of heart rate max), although most experimental studies have been conducted in laboratory settings over short periods of time (~8 weeks).[31] Importantly, there is scope for developing novel HIIT protocols that retain the health-enhancing effects, and satisfy adolescents' desire for enjoyment and variety.[33–35]

We recently conducted the first 'teacher-facilitated' HIIT intervention for older adolescents, the Burn 2 Learn (B2L) pilot RCT.[36] School teachers were asked to provide at least two opportunities during the school week for students (n=68) to complete HIIT sessions during class time. The programme achieved high levels of recruitment (85%) and retention (90%) over the 14-week study period. Adherence to sessions was lower than prescribed (1.9 sessions/week during school) due to disruptions within the school (eg, examinations). Overall programme satisfaction was high among both students and teachers. Favourable intervention effects were found for CRF, lower-body muscular power (increases) and psychological distress (decrease) in the hypothesised directions. Our pilot study demonstrated that teachers can successfully facilitate the delivery of HIIT during the school day to improve older adolescents' fitness and well-being. However, it is unclear whether these positive findings can be replicated on a larger scale.

Study objectives

The primary aim of this trial is to determine the effect of the B2L intervention on older adolescents' CRF (primary outcome). Secondary outcomes of the trial include muscular fitness, body composition, mental health and cognitive control. This study will also test a range of potential neurobiological, psychosocial and behavioural mechanisms responsible for the effects of physical activity on cognitive and mental health. Finally, a detailed process evaluation will be conducted to determine if the intervention was delivered as intended and the factors influencing implementation.

METHODS

Study design

The trial is registered with the Australian New Zealand Clinical Trials Registry (ACTRN12617000544370) and the design, conduct and reporting will adhere

to the Consolidated Standards of Reporting Trials[37] and Template for Intervention Description and Replication[38] checklists. The B2L intervention will be evaluated using a two-arm parallel group cluster RCT with an intervention group and wait-list control group. Assessments will be conducted at baseline, 6 months (primary end point) and 12 months from baseline (secondary end point). The RCT will include two cohorts, one starting in 2018 (10 schools; 5 intervention and 5 control), and the other starting in 2019 (10 schools; 5 intervention and 5 control) and finishing in 2020. Baseline data collection will occur in the school term preceding the intervention delivery (ie, term 1 [February to April 2018 and 2019]). The intervention delivery will occur in terms 2 and 3 (May to September 2018, 2019). Post-test data collection (ie, 6-month follow-up) will commence midway through term 3 and continue until the end of term (August to September 2018 and 2019), with final follow-up assessments (ie, 12-month follow-up) being completed in term 1 of the following year (February to April 2019 and 2020).

School recruitment and selection

New South Wales (NSW) government secondary schools that include senior school students (ie, grades 11 and 12, students aged 16–18 years) will be eligible to participate in the study. In cohort 1, eligible secondary schools located within 90 min drive from the University of Newcastle will be invited to participate. In cohort 2, eligible secondary schools located within 150 min drive from the University of Newcastle will be recruited. The selected geographical regions (ie, Hunter-Central Coast, Sydney, Northern Sydney, Western Sydney and New England) are broadly representative of urban and regional secondary schools in NSW.

Schools will be recruited via presentations at conferences and meetings (eg, regional meetings of the NSW Principals' Association) and emails sent directly to eligible schools (ie, school principals and grade 11 coordinators). Once schools have expressed an interest in the study, our Project Manager will meet with the school representative(s) and explain the study requirements. At this time, schools will be asked to identify a minimum of two grade 11 teachers willing to facilitate the delivery of scheduled B2L sessions during school hours. There are no restrictions regarding the teaching discipline (eg, mathematics, English, health and physical education) of grade 11 teachers eligible to participate in the study.

Participants

Two grade 11 teachers per school (B2L school champions) who agree to facilitate the delivery of B2L during scheduled class time. Eligible participants will be grade 11 students who are taught by one of the B2L school champions. Of note, students consenting to participate in the trial, are consenting to participate in the evaluation component (ie, completion of study measures). Students with a health or medical condition that would preclude participation in vigorous physical activity will be excluded from the study, but will still participate in normal lessons adapted by the B2L school champion. We will aim to recruit ~36 students (ie, 2 classes) per school.

Sample size calculation

Power calculations were based on the primary outcome of CRF, assessed using the Progressive Aerobic Cardiovascular Endurance Run (PACER) test.[39] Baseline post-test correlation (r=0.90) and SD=29 values were obtained from our pilot trial, and conservative intraclass correlation coefficient values of 0.20 and 0.03 were used to account for clustering at the class and school levels, respectively.[40] To detect a clinically meaningful baseline-adjusted between-group difference of 6 laps[33 41] with 80% power at a 5% significance level will require 280 students per treatment group (ie, 2 classes of 14 students from each of 10 schools). Inflating the sample size to 18 students per class, or 360 students per treatment arm (ie, total sample of 720 students) allows for a potential drop-out rate of 20% at our primary study end point (ie, 6 months).

Blinding and randomisation

Randomisation will occur once 10 schools (cohort 1) have been recruited and completed baseline assessments. The same process will be repeated for cohort 2. Pairs of schools will be matched based on the following characteristics: geographic location (ie, region, rural/urban, coastal/inland), school area-level socioeconomic status (ie, using the Socio-Economic Indexes For Areas Index of Relative Socio-Economic Disadvantage),[42] schools' student population educational advantage (ie, using the Index of Community Socio-Educational Advantage) and where possible, proposed class delivery (eg, mathematics, English and personal development, health and physical education). Schools will be randomised by an independent researcher using a computer-based random number generator, such that one school from each pair will be allocated to the intervention condition and the other to the control condition. Using this approach, each school will have an equal chance of being allocated to the intervention condition, while maintaining an appropriate balance of school characteristics across the two conditions. Schools randomised to the intervention condition will deliver the B2L programme during the study period, whereas schools allocated to the control condition will continue with usual school practice (ie, normal curricular lessons) for the duration of the study period (ie, until completion of 12-month study assessments). Schools allocated to control group will then receive the intervention following final study assessments (ie, the following year). The decision to use a wait-list control design, rather than an attention-matched placebo, was based on the following. First, the research team will have little contact with students, as the programme will be delivered by teachers during their regularly scheduled lessons. Second, for our findings to have greater external validity, it is important that our control group reflects 'usual practice'. Finally, based on our previous studies, a

wait-list control group is acceptable for schools and the majority of our school-based trials have achieved high levels of retention (80%–90%).[24 43 44]

Intervention delivery, components and implementation strategies

The B2L intervention will be delivered in three phases: phase I) *getting started,* phase II) *maintaining student interest* and phase III) *moving towards independence*. In phases I and II (term 2–term 3; May–September 2018 and 2019), school champions will be tasked with facilitating the delivery of at least two HIIT sessions/week during lesson-time. During phase I, school champions will attend a 1-day professional learning workshop led by the research team. The workshop will focus on providing the school champions with the knowledge and skills needed to introduce students to HIIT and develop their competency. Phase II will involve a greater emphasis on student responsibility and control, and introduce additional intervention resources (ie, new HIIT task cards) to maintain student interest. In phase III (term 4/term 1; October–April 2018/2019 and 2019/2020), students will be encouraged to complete sessions outside of lesson-time (teachers may continue to facilitate the delivery of B2L sessions during lesson-time).

The HIIT sessions will involve a combination of aerobic (eg, shuttle runs, jumping jacks, boxing, dancing) and body weight muscle-strengthening exercises (eg, push-ups, squat jumps and walking lunges), and have been designed to be fun and engaging as well as vigorous in nature. Participants will be able to select from a variety of predesigned HIIT task cards which will be released across the phases of the programme to promote variety and sustain participant interest. Phase I) *getting started*: (i) Gym HIIT—combination of aerobic (eg, skipping) and strength exercises (eg, squat jumps), (ii) Sport HIIT—using sports equipment (eg, shuttle run while dribbling a basketball), (iii) Class HIIT—exercises that can be performed in a standard classroom (eg, running on the spot, tricep dips), (iv) Quick HIIT—using Tabata protocol (eg, 20 s intense work, followed by 10 s rest). Phase II) *maintaining student interest*: (i) Hip-hop HIIT—high-intensity hip-hop dance movements, (ii) Combat HIIT—involves boxing/mixed martial arts movements (eg, front kicks), (iii) Brain HIIT—activities that encourage thinking while participating in high-intensity activity, (iv) Rumble HIIT—high-intensity rough and tumble exercises (eg, partner knee taps) combined with aerobic activity, (v) Custom HIIT—participants design their own HIIT workout. Phase III) *moving towards independence*: (i) Beach HIIT—using the natural coastal environment (eg, sand shuttle runs and surfer style get-ups), (ii) Park HIIT—exercise sessions adapted for the park setting (eg, triceps dips using park benches).

A common criticism of public health research is the development of interventions that are not 'scalable' and unlikely to be adopted and implemented in real-world settings.[45] The B2L intervention has been designed in consultation with the NSW Department of Education and guided by the Consolidated Framework for Implementation Research[46] to maximise scalability and sustainability. A summary of the B2L intervention components are provided in table 1. The multicomponent intervention will target schools, principals, teachers, students and parents using: (i) an information seminar delivered by school champions, (ii) school-based physical activity sessions for two school terms, (iii) smartphone application and heart rate monitors and (iv) information for parents (ie, print or e-newsletters). A range of implementation strategies were designed to support the delivery of the B2L programme (table 2) and include the following: (i) intervention characteristics, (ii) outer setting (ie, educational authorities), (iii) inner setting (ie, schools), (iv) characteristics of teachers and (v) implementation process.

Theoretical framework for the intervention

Several theoretical frameworks have been used to guide intervention design. First, Beets *et al* theory of expanded, extended and enhanced opportunities[47] suggests that the extension and enhancement of existing physical activity opportunities, as well as the creation of new opportunities (ie, expansion) are needed to increase youth physical activity levels. For the current study, the provision of an entirely new opportunity for physical activity (ie, expansion) was considered necessary, as the majority of secondary schools in NSW do not provide mandatory physical activity for senior students. During phases I and II of the intervention, the HIIT sessions will be facilitated during scheduled class-time, therefore adopting a compulsory application of theory of expanded, extended and enhanced opportunities. In the third phase, students will be encouraged to complete two to three sessions per week within or beyond the school day. During this phase, students will be encouraged to self-monitor their participation in HIIT sessions using the B2L smartphone app.

With reference to self-determination theory, B2L HIIT sessions have been developed with a focus on enhancing students' autonomous motivation for vigorous physical activity within and beyond the school setting by satisfying their basic psychological needs for autonomy (feeling in control), competence (feeling capable) and relatedness (feeling connected with others).[48] Teachers will learn to facilitate the B2L sessions using the Supportive, Active, Autonomous, Fair and Enjoyable (SAAFE) physical activity delivery principles (table 3).[49] Participants' need for autonomy will be satisfied by providing opportunities for choice within sessions (eg, type of activity, music playing and training partner) and explaining the rationale for the programme in an information seminar. The introductory seminar will reinforce the importance of exercise for cognitive health and academic performance, which may be salient outcomes for students during this period of their schooling. Competence will be satisfied using positive and specific feedback from teachers, an explicit focus on effort over performance (via heart rate feedback), and through the provision of resources designed to support the development of exercise skills. Teachers will be encouraged to

Leahy AA, *et al*. *BMJ Open* 2019;**9**:e026029. doi:10.1136/bmjopen-2018-026029

Table 1 Intervention components and implementation evaluation

Level	Intervention component	Dose	Description	Implementation evaluation
Teacher	1) Professional learning workshop	1×5 hour workshop	Professional development workshop for teachers responsible for facilitating the delivery of the B2L programme in their school (hereafter referred to as school champions). The workshop will be delivered by members of the research team (ie, the Principal Investigator and certain Chief Investigators), and will cover information and current evidence on the impact of vigorous physical activity and cardiorespiratory fitness on cognitive functioning and academic performance as well as adolescent mental health. Teachers will participate in practical exercise sessions, where they will be taught about HIIT, and they will also be shown how to use the 'B2L' resources (ie, HIIT task cards, smartphone application). A condensed online version of the workshop will be provided for school champions unable to attend the face-to-face workshop.	▶ Workshop evaluation questionnaire (following workshop completion by school champions). ▶ Postprogramme implementation questionnaire (school champions) developed for the current study based on an existing questionnaire.[97]
	2) Action plan	Once	At the completion of the B2L professional development workshop, teachers will be required to complete an action plan. This will include: timeline, necessary actions, potential barriers and solutions.	▶ Research team will sign-off once completed by school champions in the penultimate session of the workshop.
	3) Session observations	Three observations	The research team will conduct two B2L session observations using the SAAFE observation checklist and provide feedback to the school champions. The school champions will also be asked to observe one B2L session conducted by another school champion at their school.	▶ SAAFE observations[49] conducted by research team in terms 2 and 3. ▶ SAAFE observation conducted by peer teacher in term 2.
	4) Support from research team	Ongoing	The research team will create a B2L WhatsApp group and invite school champions to join. School champions will be encouraged to use the online messaging platform to share challenges and successful strategies.	▶ Postprogramme implementation questionnaire (school champions). ▶ Analysis of WhatsApp engagement.
School	5) Presentation to school staff	1×15 min	School champions will design a tailored presentation, using predesigned programme resources (ie, videos, presentation slides), to be delivered to school faculty during a regularly scheduled staff meeting. The purpose of the presentation is to inform staff of the objectives and details of the B2L programme, and to promote a supportive school climate.	▶ Research team will confirm staff presentation during meeting with school principal.
	6) Equipment	Once	Schools will be provided with a small equipment pack to assist in the delivery of the B2L programme (~\$A2500) including: 1×heart rate monitor/student, 1×Bluetooth speaker for playing music during sessions, 1×WASP device (connect Ant+ to WiFi) and a selection of sports equipment (eg, balls, cones).	▶ Postprogramme implementation questionnaire (school champions).
	7) Technique and HIIT session cards	1×set/school champion	B2L technique cards (ie, describing key components to perform each exercise) and HIIT session cards (ie, describing the various HIIT workouts).	▶ Postprogramme implementation questionnaire (school champions).

Continued

Table 1 Continued

Level	Intervention component	Dose	Description	Implementation evaluation
Student	8) Interactive seminar	1×2 hour seminar	Participating students will attend an interactive seminar delivered by the school champion, but supported by a member of the research team (present on the day of delivery). The interactive seminar will provide an overview of the B2L programme and will address relevant information regarding physical activity, mental health and cognition, using a PowerPoint presentation and embedded videos designed specifically for this project. During this introductory session, students will participate in a practical HIIT session using the B2L smartphone application.	▶ Postprogramme evaluation questionnaire (students)—satisfaction.
	9) HIIT sessions	3/week	Sessions will be run at school during curricular time, supported by programme resources and the B2L app. In phases I and II, teachers will be asked to facilitate the delivery of at least two exercise sessions/week across two school terms (ie, 16 weeks) during regularly scheduled lessons. Participants will be able to select from a variety of predesigned HIIT workouts including: Gym HIIT, Sport HIIT, Class HIIT, Quick HIIT, Hip-hop HIIT, Combat HIIT, Brain HIIT, Rumble HIIT and Custom HIIT. Each exercise session will last approximately 10–15 min in duration. In addition, students will be encouraged to complete additional sessions before or after school, during recess or lunch and during free/study periods using the B2L app. In phase III, students will be encouraged to complete sessions outside of lesson-time (teachers may continue to facilitate the delivery of B2L sessions during lesson-time). Students will also be encouraged to continue the exercise sessions during the school holiday breaks. Two additional HIIT workouts will be provided during this phase (Beach HIIT, Park HIIT) which use the natural environment. Students will be able to select from predesigned HIIT workouts, which may be delivered between 8 and 16 intervals (30 s work, 30 s rest; 1:1 work-to-rest ratio). A shorter option (ie, 8 intervals; 20 s work, 10 s rest; 2:1 work-to-rest ratio; 4 min) will also be provided. Although recommendations will be provided, teachers and students will have the capacity to modify the work-to-rest ratios and number of intervals. Students will be provided with Bluetooth heart rate monitoring technology (Wahoo TICKR), which will connect with the B2L app to display concurrent heart rate data. Students will be encouraged to reach a target intensity of 85% of age-predicted heart rate max. HIIT sessions will include variety and choice of activities to enhance motivation, and will be student self-directed. School champions will facilitate the exercise sessions, but are not expected to guide/deliver the sessions themselves.	▶ Students' attendance at the activity sessions will be tracked using the B2L app and via teacher recording. ▶ Average heart rate during sessions. ▶ Postprogramme evaluation questionnaire—session preference, barriers to participation (students).
	10) Smartphone app	Ongoing	A smartphone app has been developed to enable students to complete the B2L sessions at school and home. Android and iOS versions of the app are available. The app includes: (i) descriptions and depictions of exercise sessions, (ii) options for 'solo' or 'group' sessions (for up to six users per device), (iii) timer, audible prompts and display of heart rate using Bluetooth-synced commercial heart rate monitors (Wahoo brand) during HIIT sessions, (iv) personalised reports outlining heart rate (ie, in bpm and % of maximum) achieved overall, and during each work interval across the session, (v) display of HIIT session log on app dashboard to aid self-monitoring and goal setting. A teacher version of the B2L app will also be developed to enable whole class heart rate monitoring for use during scheduled class sessions.	▶ Postprogramme evaluation questionnaire—satisfaction (students). ▶ B2L app usage and engagement—number of sessions completed, average heart rate.
Parent	11) e-Newsletters for parents	2×e-newsletters	Parents of intervention group students will receive two e-newsletters containing information on the benefits of physical activity for academic performance and mental health and strategies to support their children's participation in physical activity during school holiday periods. The e-newsletters will include video content, and will be emailed to parents, unless there is a preferred parental contact method provided by the school.	▶ Postprogramme evaluation questionnaire (student).

B2L, Burn 2 Learn; HIIT, high-intensity interval training; SAAFE, Supportive, Active, Autonomous, Fair, Enjoyable teaching principles.

Table 2 Strategies used to facilitate implementation in the B2L intervention

Domains	Constructs	Strategies
Intervention characteristics	Evidence strength and quality	B2L intervention resources and evidence from two pilot studies.
	Adaptability	Flexible intervention delivery model (ie, during class-time, breaks, before or after school) requiring minimal access to facilities (ie, can be done in the classroom) and equipment (ie, body weight exercises).
	Complexity	Time efficient, student-directed intervention requiring only two or three 10 min sessions per week.
	Design quality and packaging	Intervention resources developed by professional graphic designer.
Outer setting (educational authorities)	Partnerships and investment	Partnership with the NSW Department of Education.
	External policy and incentives	Professional learning accreditation with NSW Educational Standards Authority.
	Peer pressure	Media attention from the pilot study.
Inner setting (schools)	School culture	Interactive seminar for teachers (20 min) and short videos for parents.
	Leadership engagement	Meeting with school principal to ensure commitment to the programme.
	Resources and facilities	Schools provided with B2L session cards, heart rate monitors, WASP device (connect Ant+ to WiFi) and Bluetooth speaker (~$A2500). B2L sessions designed to be completed by students in a variety of settings.
	Relative priority	Promoted to schools as strategy to improve cognitive function and mental health. Alignment with stage 6 curricular material.
	Organisational incentives	Teacher professional learning workshop accredited with NSW Education Standards Authority.
Characteristics of individuals (teachers)	Self-efficacy, knowledge and beliefs	Full day professional development workshop provided for teachers. Online version of workshop available.
	Perceived barriers	Designed to be time efficient, and motivating for students, through the SAAFE teaching principles.
Implementation process	Planning for implementation	Teachers required to complete an action plan to support B2L implementation in their school.
	Champions	Recruitment of two school champions at each intervention school.
	External change agents	Research team member allocated to each intervention school. Weekly SMS reminders to implement B2L sessions using messaging service (eg, WhatsApp).
	Evaluation and feedback	B2L session observations and feedback provided by research team.

B2L, Burn 2 Learn; NSW, New South Wales; SAAFE, Supportive, Active, Autonomous, Fair, Enjoyable teaching principles.

adopt practices that support relatedness and group cohesion during HIIT sessions (ie, encouraging supportive behaviour among students such as 'high fives' and partner work).[50]

Measures and data collection

Apart from multimodal MRI, all assessments will be conducted at the study schools on the same day by trained research assistants, who will be blinded to group allocation at all time-points. Demographic information and self-report measures will be collected using electronic tablets under exam-like conditions. Cognitive testing will occur on university laptops and participants will receive instructions and practice prior to performing each of the cognitive tasks. Self-report and cognitive measures will occur prior to fitness assessments in a randomised order. Anthropometric assessments will be conducted in a sensitive manner by same-sex research staff when possible. Research assistants will provide a brief verbal description and demonstration of each fitness test prior to commencement. The timing for participants to complete all measures is approximately 90 min.

Primary outcome

Cardiorespiratory fitness

CRF will be assessed using the PACER FITNESSGRAM testing procedures. This test is the most widely accepted field-based measure of CRF, demonstrating high reliability and validity.[51] A 20 m course will be set up on a hard surface with participants instructed to run back and forth between two sets of lines while keeping pace with a prerecorded cadence (indicated by a single beep for each

Table 3 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. ► Encourage supportive behaviour among students.
Active	Sessions are highly active	► Commence sessions quickly. ► Minimise talk and instruction time. ► Encourage students to exercise at high-intensity.
Autonomous	Sessions involve elements of choice	► Provide students with opportunities of choice (eg, music, partner, activity). ► Minimise controlling language (eg, ordering students around). ► Remind students about the benefits of high-intensity activity.
Fair	Sessions provide all students with opportunities to experience success	► Encourage self-comparison rather than peer-comparison. ► Encourage students to modify exercises to personal fitness and ability level. ► Treat all students equally and fairly (ie, high expectations for all).
Enjoyable	Sessions are designed to be enjoyable and engaging for all students	► Play motivational music during exercise sessions. ► Provide students with a variety of HIIT workout options. ► Encourage students to reflect on their postexercise affect (ie, how they are feeling).

SAAFE, Supportive, Active, Autonomous, Fair, Enjoyable teaching principles.

20 m shuttle). The test begins at a slow pace (8.5 km/hour), and increases by 0.5 km/hour with each passing minute (as indicated by a triple beep). The test ends when participants fail to complete a shuttle (20 m lap) before the beep sounds, on two consecutive shuttles, or on volitional failure. Verbal encouragement will be provided by test administrators in order to maximise participant motivation. The last successful stage will be recorded and converted into the number of 20 m laps completed, which will constitute the primary outcome measure. The total number of laps will be used to estimate maximal aerobic capacity (ie, VO_2 max), using the following equation: 45.619+(0.353×PACER laps)−(1.121×age).[52] Estimated VO_2 max will be used to classify participants into fitness zones according to criterion-referenced age-specific and sex-specific cut-offs developed by the Cooper Institute.[53]

Secondary outcomes

Physical activity

Participants will be instructed to wear an ActiGraph GT9X Link accelerometer on their non-dominant wrist for 24 hours/day (even when bathing, swimming and sleeping) for a period of seven consecutive days. Weekday and weekend day (ie, mean minutes per day) physical activity will be calculated separately, using existing thresholds for categorising physical activity into light, moderate and vigorous intensity.[54]

Muscular fitness

Upper body muscular endurance will be assessed using the 90-degree push-up test.[39] Using a cadence of 40 beats per minute, participants lower themselves in a controlled manner until a 90-degree angle is formed at the elbow before pushing back up. The test concludes when the participant either fails to lower themselves to the required depth on two non-consecutive repetitions (warning verbalised by assessor, repetitions counted), fails to maintain movement in time with the metronome, fails to maintain appropriate technique (back straight) or on volitional failure of the test. Lower body muscular power will be assessed using the standing long jump test.[55] From a standing position behind a line marked at zero centimetres, participants perform a maximal long jump taking off and landing with two feet, simultaneously. The test will be performed twice, with the maximal distance jumped recorded as the participant's final score. Both measures of muscular fitness demonstrate high validity and reliability in adolescents.[56 57]

Body composition

Body weight and height will be measured using a portable digital scale (A&D Medical UC-352-BLE Digital Scales) and a portable stadiometer (Seca 213 Portable Height Measuring Rod Stadiometer), respectively. Both weight and height will be measured twice to reduce the risk of measurement error. A third measurement will occur should there be a difference of >0.1 kg for weight, and >0.3 cm for height between the first and second measurement. BMI will be calculated using the standard formula (weight [kg]/height [m^2]). Age-specific and sex-specific BMI z-scores will be calculated and participants will be classified into weight categories according to International Obesity Task Force cut-offs.[58]

Cognitive control

Using a laptop, specialised software (PsychoPy)[59] will be used to assess working memory and inhibition. A modified version of an Eriksen flanker task will be used

to measure inhibition, which is a reliable and valid measure in youth.[60] In this task, participants are required to respond (using specific keys) to the direction of the centrally presented arrow among either 'congruent' or 'incongruent' flanking arrows. Congruent trials consist of five horizontal arrows facing the same direction (ie, <<<<< or >>>>>), while incongruent trials consist of the central arrow facing the opposite direction to the four flanking arrows (ie,<<><< or >><>>). Participants are challenged with a random sequence of congruent and incongruent trials and instructed to identify the direction of the centrally presented, target arrow as quickly and accurately as possible. Following instructions, participants will be presented with a practice block consisting of 25 trials to familiarise themselves with the test. If participants achieve below satisfactory overall accuracy (<70%), they will complete another practice block of 25 trials, and the test administrator will confirm their understanding of the test. Participants then complete an experimental block consisting of 150 trials (with an equal distribution of congruent and incongruent). Stimuli are presented for 100 ms, with a randomly allocated interstimulus interval of 900, 1050 or 1200 ms separating each trial. Response time (ie, the time in ms taken by the participant to press the key associated with the direction of the target arrow) and response accuracy (ie, the percentage of trials for which the participant correctly indicated the direction of the target arrow) and will be recorded. An interference score (ie, the difference in performance outcomes between congruent and incongruent trials) will also be calculated for both accuracy and response time. A lower interference score demonstrates higher inhibitory control.

Working memory will be assessed using a serial n-back task, which is a widely used and reliable measure.[61 62] Two task conditions (ie, 1-back and 2-back) will be evaluated which differ in the degree of cognitive demand. In these tasks, participants are presented with a series of six basic shapes (ie, square, star, circle, cross, crescent, triangle) and required to recall (using specific keys) whether the shape currently displayed (trial 'n') matches the shape immediately prior (1-back, 'n-1'), or two shapes prior (2-back, 'n-2'). For each trial (within each n-back condition), participants are required to indicate whether the shape is a match (ie, target) or not a match (ie, non-target). Shapes are presented for a duration of 250 ms following a fixed interstimulus interval of 2500 ms. Following task instructions, participants will complete a practice block consisting of 20 trials to ensure understanding. If overall accuracy is below 70%, participants will complete another practice block, and the test administrator will confirm their understanding of the test. Each task condition (ie, 1-back, 2-back) consists of two blocks of randomised target (n=24) and non-target (n=48) trials, and are presented in a counterbalanced order. Response time and accuracy will be recorded for both target shapes (ie, correctly identifying a match) and non-target shapes (ie, correctly identifying a non-match). Additionally, the relative proportion of 'hits' (correct target trials) to 'false alarms' (incorrect selection on target trial), otherwise known as the d-prime score, will be calculated for both task conditions.[63] A higher d-prime score reflects a greater capacity to differentiate target from non-target shapes when performing the n-back tasks, thereby indicating greater working memory.

Stress

Objectively measured stress will be determined by examining the build-up of cortisol within the hair shaft using a sample taken from the vertex at the rear of the head. As human hair grows at a rate of approximately 1 cm per month, each cm is considered to reflect life stressors experienced by the individual over the last month.[64] Cortisol concentrations will be determined from the 3 cm hair segment (maximum) most proximal to the scalp. This will represent the cumulative stress level in the past 2–3 months. Interindividual variation in hair growth rate can be factored into analyses by measuring hair growth at the initial sampling site 1 month later. The intraindividual stability (r=0.68–0.79)[65] and validity of hair cortisol as a retrospective index of stress are supported in the literature in adults[66 67] and adolescents.[68] Perceived stress will be self-reported using the Perceived Stress Scale, which is designed to assess the degree to which situations in one's life are stressful.[69] Participants will be required to respond to the 10-item questionnaire in relation to the previous month (eg, *"In the last month, how often have you felt you were on top of things?"*). 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.

Psychological difficulties

The Strengths and Difficulties Questionnaire will be used to assess psychological distress.[70] The questionnaire consists of 25 items, covering 2 subscales (ie, strengths and difficulties). The strengths subscale consists of one domain (prosocial behaviour (eg, "*I try to be nice to other people. I care about their feelings*"), and the difficulties subscale consists of four domains: emotional symptoms (eg, "*I worry a lot*"), conduct problems (eg, "*I get very angry and often lose my temper*"), hyperactivity (eg, "*I am restless, I cannot stay still for long*") and peer problems (eg, "*I would rather be alone than with people of my own age*"). For each item, participants respond using a 3-point scale (ie, *'not true'=0, 'somewhat true'=1* and *'certainly true'=2*). For each of the five domains the score can range from 0 to 10. A difficulties composite score will be obtained by adding the scores of all four difficulty domains, with a possible range from 0 to 40. Lower scores indicate fewer psychological difficulties.

Autonomous motivation

Motivation for physical activity will be assessed using the 'Behavioural Regulations in Exercise Questionnaire'.[71] The identified (eg, "*I value the benefits of exercise*"), and

intrinsic (eg, "*I exercise because it's fun*") regulation subscales will be used. 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

Friends' and teachers' support for exercise will be assessed via the 'Adolescent Psychological Need Support in Exercise Questionnaire'.[72] Items assess needs satisfaction during exercise across the three psychological needs identified within self-determination theory, namely autonomy support (eg, "*I feel that they understand why I choose to exercise*"), relatedness support (eg, "*I feel they care about me*") and competence support (eg, "*They display confidence in my exercise ability*"). Participants respond using a 7-point Likert scale ranging from *1 'strongly disagree' to 7 'strongly agree'*.

Psychological well-being

Well-being is assessed using the validated Warwick-Edinburgh Mental Well-being Scale.[73] The 14-item questionnaire requires participants to reflect on their experiences over the last 2 weeks. Items are scored on a 5-point scale ranging from 1 '*none of the time*' to 5 '*all of the time*', and summed across all to produce a well-being composite (possible range=14–70).

Perceived fitness

Perceived physical fitness will be self-reported using the International Fitness Scale (IFIS).[74] Participants are required to report perceptions of their 'general fitness' and four specific subcomponents of health-related fitness. The 5-item instrument is scored on a scale ranging from 1 *'very poor'* to 5 *'very good'*. The validity and test-retest reliability of the IFIS has been found to be acceptable among a sample of youth aged 9–12 years.[74]

HIIT self-efficacy

Self-efficacy for HIIT will be assessed using a 6-item scale developed for the current study. The scale uses the common stem "*If you really wanted to, how confident are you that you can…*" and participants respond as follows: *1 'not at all confident' to 10 'completely confident'*. Sample item '*maintain a high level of effort right through to the end of a HIIT session*'. The mean of the 6-items will be calculated.

Brain structure and function

To further elucidate exercise-induced neural changes, a target subsample of approximately 60 students (ie, 15 students per school from 4 schools; 2×intervention group, 2×control group) identified as being in the bottom 50% of students from their school for CRF (using their baseline PACER test result) will undergo multimodal MRI. We have undertaken a systematic review of neuroimaging studies that have examined associations between physical activity, CRF or muscular fitness, and brain structure/function. Preliminary findings from this review informed our multimodal MRI protocol to explore changes in the following areas: (i) structural MRI (T1-weighted and T2-weighted imaging) to identify volumetric changes in white and grey matter of the hippocampus,[75–77] frontal regions/prefrontal cortex,[75] anterior cingulate cortex[78] and basal ganglia[79]; (ii) diffusion tensor imaging will be used to identify changes in white matter structural connectivity of the superior longitudinal fasciculus and corpus callosum; (iii) resting state functional MRI will be used to assess changes in activation of the default mode network, cognitive control network, saliency network,[80] hippocampus and prefrontal cortex[81 82]; (iv) magnetic resonance spectroscopy will be used to identify changes in brain metabolite concentrations (ie, gamma-aminobutyric acid, N-acetyl aspartate, ATP and glutamate/glutamine) in the hippocampus and frontal regions/prefrontal cortex.

On-task behaviour

Cohort 2 schools will be invited to participate in a substudy to determine the acute effect of the B2L intervention on students' behaviour in the classroom. Classroom observations will be conducted by trained research assistants at baseline and mid-intervention (weeks 5–8) using established methods.[83 84] During each 30 min observation period (starting 5 min after students enter the classroom), research assistants will assess the on-task and off-task behaviour of six randomly selected students (5 min per student). For each lesson, two observers will randomly select 12 students (ie, 6 boys and 6 girls) and the order in which they are observed (teachers and students will not know who is being observed). Observers will listen to an MP3 audio file via headphones, which will inform them when to observe and record (in 15 s intervals). After each 10 s interval, the observers will record the student's behaviour by circling an appropriate code (ie, actively engaged, passively engaged, off-task motor, off-task verbal or off-task passive) using an observation sheet. After 15 s, the observer will then focus on the next student and repeat this process five times until the six students have been observed 20 times. On-task behaviour includes times when the child is actively engaged in an academic activity (eg, reading, writing or performing the designated task) or passively engaged (ie, sitting quietly and listening to the teacher). Off-task behaviour includes times when the student is not engaged in the designated task and can be classified as off-task motor (ie, walking around the class), off-task verbal (ie, talking) or off-task passive (ie, passively not attending to the assigned academic activity). Time spent on-task and off-task during the lesson will be expressed as a percentage of total lesson-time. Two trained research assistants will be responsible for conducting all observations and inter-rater reliability scores will be established in the training phase.

Process evaluation

A detailed process evaluation will be conducted to determine intervention fidelity. Process measures will include: (i) students' mean heart rate from the HIIT sessions (measured using Bluetooth heart rate monitoring technology), (ii) teacher attendance and satisfaction with

the professional learning workshop and curriculum materials (workshop evaluation questionnaires), (iii) students' satisfaction with all intervention components (student evaluation questionnaire), (iv) number of practical sessions delivered (school champion logs and session observations), (v) teachers' implementation questionnaire (adapted from an existing questionnaire),[85] (vi) student engagement (objective usage data) with the app and (vii) practical session fidelity (three observations per teacher) using the SAAFE observation checklist.[49]

Statistical analyses

Analyses of the primary and secondary outcomes will be conducted using linear mixed models in IBM SPSS Statistics for Windows, V.20.0 (IBM, Armonk, New York, USA), with alpha levels set at $p<0.05$. The models will be used to assess the impact of treatment (B2L or control), time (treated as categorical with levels baseline, 6 and 12 months) and the group-by-time interaction, using random effects to account for the clustered nature of the data. Although randomisation will occur at the school level, statistical analyses will be adjusted for the clustering of effects at the class level, as students from each school are nested in classes. Previous school-based studies have demonstrated that clustering at the school level is negligible after adjusting for clustering at the class level.[86 87] However, we will test this assumption and additionally adjust our analyses for school-level clustering if required.[88] Several potential moderators of intervention effects will be explored using interaction tests.[89] Subgroup analyses will be conducted for the following variables if the significance of the group-by-moderator interaction is ≤0.10: socioeconomic status (low, medium, high), sex (male, female), baseline weight status (not overweight, overweight/obese), baseline psychological distress (using established cut-offs from the Strengths and Difficulties Questionnaire) and baseline CRF (using FITNESSGRAM fitness standards). Compared with complete-case analyses, mixed models include available data for all participants in the analysis and are thus both more efficient and robust to bias. Mixed model analyses are consistent with the intention-to-treat principle, assuming the data are missing at random.[90] The validity of this assumption will be explored by assessing relationships between missingness and observed values of covariates and previous outcomes. A range of sensitivity analyses will be conducted (eg, multiple imputation and complete-case analysis). In addition to our primary analysis (ie, intention-to-treat) and sensitivity analyses, we will also conduct two per-protocol analyses (ie, at the class and student levels, respectively). After consideration of typical school disruptions (ie, sporting events, school excursions, exams, etc), we estimate that a minimum of 28 exercise sessions offered over the duration of phases I and II is achievable for schools, and sufficient to observe effects for our primary outcome at the primary end point (ie, 6 months). Therefore, our class-level per-protocol analysis will include only students from classes in which at least 28 school-based sessions were offered. For our student-level per-protocol analysis, we will include only those students who achieved an average heart rate of 80% of their age-predicted maximum (220-age) across the intervention period (up until our primary end point), using heart-rate data drawn from the B2L smartphone app.

Patient and public involvement

The need for a time efficient physical activity intervention for older adolescents was identified through consultation with the NSW Department of Education School Sport Unit, who provided initial funding to evaluate the feasibility of the B2L intervention. The pilot study was conducted in two secondary schools in Newcastle (n=68 students) and participants (ie, students and teachers) were invited to provide feedback on the intervention and suggestions for further improvement. This feedback was then used to refine the B2L intervention components (eg, B2L smartphone app) and implementation strategies (eg, professional learning for teachers).

The findings of the RCT will be published in peer-reviewed journals and the NSW Department of Education and all participating schools will receive a report outlining the study findings at the conclusion of the trial. Burden of the intervention was not assessed prior to commencing the trial; teacher and student experiences in the intervention will be determined using a detailed process evaluation questionnaire at post-test.

DISCUSSION

Despite the importance of physical activity and fitness for adolescents' physical and mental health, increasing time demands and academic pressures in the final years of schooling often drive older adolescents to sacrifice time usually spent being active. Although schools are well equipped to promote physical activity to adolescents, secondary schools in NSW do not schedule mandatory physical activity opportunities (eg, physical education, co-curricular school sport) for senior school students (ie, grades 11 and 12). Lack of physical activity may contribute to the high levels of stress, anxiety and depression observed in older adolescents.[91–93] The B2L intervention will be promoted to schools, teachers, students and parents as a strategy to improve older adolescents' cognitive control and academic performance (rather than focusing on the metabolic health benefits).

Phases I and II of the B2L intervention aim to provide grade 11 students with additional physical activity opportunities embedded within the school day in order to increase fitness and physical activity levels. Phase III will provide an opportunity to explore fitness and behaviour change once the scheduled sessions are no longer facilitated by teachers. We hypothesise that intervention group participants' fitness levels will decrease during this period, but remain higher than control group participants. Providing older adolescents with the knowledge, skills and opportunities to engage in HIIT may compliment

their participation in other types of leisure-time physical activity. It is therefore important to ensure that students are equipped with the necessary tools in order to engage in self-directed physical activity, outside of the school setting. Self-efficacy (ie, a belief in one's capability or competence within a specific context) is consistently identified as a central determinant of human motivation, and exercise adherence.[94] B2L has also been guided by self-determination theory and designed to satisfy students' basic psychological needs for autonomy (eg, providing choice/allowing students to feel in control), competence (eg, incorporating technique cards to develop correct exercise form) and relatedness (eg, encouraging social connection and encouragement from others), ultimately impacting on students' autonomous motivation.

Poor implementation may explain why so many school-based physical activity interventions fail to reach their potential. Lack of time has been noted as the greatest barrier to implementation by teachers[27] and providing robust evidence for the positive effects of vigorous physical activity on cognitive and mental health outcomes may provide the impetus for schools to make mandatory physical activity for older adolescents. While several studies have established that HIIT can be successfully delivered in schools,[95] previous studies have used research staff members or external providers to deliver HIIT sessions, which is neither 'scalable' nor 'sustainable'. Although we do not have funding to conduct an economic evaluation, incorporating short breaks into the school day appears to be a cost-effective way to increase young people's activity levels.[96]

ETHICS AND DISSEMINATION

School principals, teachers, parents and students all provided informed written consent prior to enrolment. It is not expected that participants will be at any greater risk of adverse events than they would be when participating in other types of school-based physical activity. However, the teacher handbook includes a section for teachers to report any injuries or adverse events that may occur. Any amendments to the study protocols will be publicly available via the Australian and New Zealand Clinical Trials Registry (trial number: ACTRN12615000360516). Data management procedures will be conducted by DRL and SK. All entered data will be de-identified using participant codes and will be stored electronically in a password-protected drive at the University of Newcastle. Quality checks of entered data will be completed by AL (ie, range checks). Access to the final trial dataset will comply with the conditions of the ethics committee approval and will be at the discretion of the lead investigator, DRL.

Author affiliations
[1]Priority Research Centre for Physical Activity and Nutrition, University of Newcastle, Callaghan, New South Wales, Australia
[2]Faculty of Education and Arts, University of Newcastle, Callaghan, New South Wales, Australia
[3]Department of Psychology, Northeastern University, Boston, Massachusetts, USA
[4]Department of Physical Therapy, Movement and Rehabilitation Sciences, Northeastern University, Boston, Massachusetts, USA
[5]Centre for Rehab Innovations(CRI), School of Biomedical Sciences and Pharmacy and the Priority Research Centre for Stroke and Brain Injury, Hunter Medical Research Institute (HMRI), University of Newcastle, Callaghan, New South Wales, Australia
[6]Institute for Positive Psychology and Education, Faculty of Health Sciences, Australian Catholic University, Strathfield, New South Wales, Australia
[7]School of Behavioural and Health Sciences, Faculty of Health Sciences, Australian Catholic University, Strathfield, New South Wales, Australia
[8]School of Medicine and Public Health, University of Newcastle, Callaghan, New South Wales, Australia
[9]School of Exercise and Nutrition Sciences, Deakin University, Geelong, Victoria, Australia
[10]School of Biomedical Sciences and Pharmacy, University of Newcastle, Callaghan, New South Wales, Australia
[11]Auckland University of Technology, Human Potential Centre, Auckland, New Zealand

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