Original research

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

Accepted 17 November 2020

To cite: Lubans DR, Smith JJ, Eather N, *et al*. *Br J Sports Med* Epub ahead of print: [*please include* Day Month Year]. doi:10.1136/bjsports-2020-103277

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.

Trial registration number Australian New Zealand Clinical Trials Registry (ACTRN12618000293268).

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

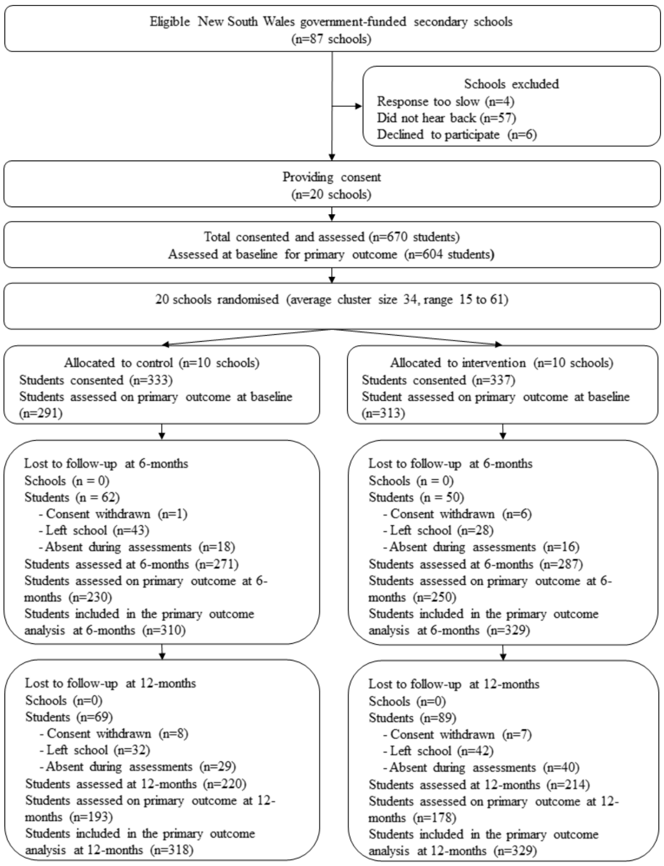

Figure 1 Consolidated Standards of Reporting Trials flow diagram.

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	230 (69.5)	239 (71.3)	469 (70.4)
European	28 (8.5	39 (11.6)	67 (10.1)
African	3 (0.9)	3 (0.9)	6 (0.9)
Asian	18 (5.4)	21 (6.3)	39 (5.9)
Middle Eastern	3 (0.9)	4 (1.2)	7 (1.1)
Other	49 (14.8)	29 (8.7)	78 (11.6)
Indigenous decent, n (%)*			
Yes	37 (11.2)	24 (7.2)	61 (9.2)
No	294 (88.8)	311 (92.8)	605 (90.8)
Socioeconomic status, n (%)†			
Low	48 (14.5)	81 (24.3)	129 (19.4)
Medium	170 (51.4)	169 (50.8)	339 (51.1)
High	113 (34.1)	83 (24.9)	196 (29.5)
Weight status, n (%)‡			
Underweight	16 (4.9)	10 (3.0)	26 (3.9)
Healthy weight	207 (63.1)	238 (71.5)	445 (67.3)
Overweight	72 (22.0)	62 (18.6)	134 (20.3)
Obese	33 (10.1)	23 (6.9)	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

Acknowledgements We would like to thank the participating schools, students and teachers for their support and cooperation throughout the project. We would also like to thank the NSW Department of Education, with special thanks to Ross Morrison, Sue Meade, Peter Banks, James Boyer, Darren Lang and Renee West. We would like to thank FAQ Interactive for their work developing the B2L app. Tara Finn, Sarah Young and Mark Babic are acknowledged for their assistance in data collection.

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.

Funding The study was funded by the National Health and Medical Research Council (APP1120518) and the New South Wales Department of Education School Sport Unit. DRL is supported by a National Health and Medical Research Council Research Fellowship (APP1154507).

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

REFERENCES

1 Raghuveer G, Hartz J, Lubans DR, *et al*. Cardiorespiratory fitness in youth: an important marker of health: a scientific statement from the American heart association. *Circulation* 2020;142:e101–18.
2 Adegboye ARA, Anderssen SA, Froberg K, *et al*. Recommended aerobic fitness level for metabolic health in children and adolescents: a study of diagnostic accuracy. *Br J Sports Med* 2011;45:722–8.
3 Ruiz JR, Castro-Piñero J, Artero EG, *et al*. Predictive validity of health-related fitness in youth: a systematic review. *Br J Sports Med* 2009;43:909–23.
4 Henriksson P, Shiroma EJ, Henriksson H, *et al*. Fit for life? low cardiorespiratory fitness in adolescence is associated with a higher burden of future disability. *Br J Sports Med* 2020. doi:10.1136/bjsports-2020-102605
5 Ruggero CJ, Petrie T, Sheinbein S, *et al*. Cardiorespiratory fitness may Help in protecting against depression among middle school adolescents. *J Adolesc Health* 2015;57:60–5.
6 Åberg MAI, Waern M, Nyberg J, *et al*. Cardiovascular fitness in males at age 18 and risk of serious depression in adulthood: Swedish prospective population-based study. *Br J Psychiatry* 2012;201:352–9.
7 Tomkinson GR, Lang JJ, Tremblay MS. Temporal trends in the cardiorespiratory fitness of children and adolescents representing 19 high-income and upper middle-income countries between 1981 and 2014. *Br J Sports Med* 2019;53:478–86.
8 Lang JJ, Tomkinson GR, Janssen I, *et al*. Making a case for cardiorespiratory fitness surveillance among children and youth. *Exerc Sport Sci Rev* 2018;46:66–75.
9 Costigan SA, Eather N, Plotnikoff RC, *et al*. High-Intensity interval training for improving health-related fitness in adolescents: a systematic review and meta-analysis. *Br J Sports Med* 2015;49:1253–61.
10 Batacan RB, Duncan MJ, Dalbo VJ, *et al*. Effects of high-intensity interval training on cardiometabolic health: a systematic review and meta-analysis of intervention studies. *Br J Sports Med* 2017;51:494–503.
11 Biddle SJH, Batterham AM. High-Intensity interval exercise training for public health: a big hit or shall we hit it on the head? *Int J Behav Nutr Phys Act* 2015;12:95.
12 Leahy AA, Eather N, Smith JJ, *et al*. Feasibility and preliminary efficacy of a teacher-facilitated high-intensity interval training intervention for older adolescents. *Pediatr Exerc Sci* 2019;31:107–17.
13 Dumith SC, Gigante DP, Domingues MR, *et al*. Physical activity change during adolescence: a systematic review and a pooled analysis. *Int J Epidemiol* 2011;40:685–98.
14 Hardman K, Murphy C, Routen A, *et al*. *World-Wide survey of school physical education*. 3rd Ed. Paris, France: United Nations Educational, Scientific, and Cultural Organization, 2013.
15 Leahy AA, Eather N, Smith JJ, *et al*. School-based physical activity intervention for older adolescents: rationale and study protocol for the Burn 2 Learn cluster randomised controlled trial. *BMJ Open* 2019;9:e026029–e29.
16 Campbell MK, Elbourne DR, Altman DG, *et al*. Consort statement: extension to cluster randomised trials. *BMJ* 2004;328:702–8.
17 Hoffmann TC, Glasziou PP, Boutron I, *et al*. Better reporting of interventions: template for intervention description and replication (TIDieR) checklist and guide. *BMJ* 2014;348:g1687.
18 Cooper Institute for Aerobics Research. *Fitnessgram: test administration manual*. Champaign, IL: Human Kinetics, 1999.
19 Heo M, Leon AC. Statistical power and sample size requirements for three level hierarchical cluster randomized trials. *Biometrics* 2008;64:1256–62.
20 Weston KL, Azevedo LB, Bock S, *et al*. Effect of novel, school-based high-intensity interval training (HIT) on cardiometabolic health in adolescents: Project FFAB (Fun Fast Activity Blasts) - An exploratory controlled before-and-after trial. *PLoS One* 2016;11:e0159116.
21 Costigan SA, Eather N, Plotnikoff RC, *et al*. Preliminary efficacy and feasibility of embedding high intensity interval training into the school day: a pilot randomized controlled trial. *Prev Med Rep* 2015;2:973–9.
22 Damschroder LJ, Aron DC, Keith RE, *et al*. Fostering implementation of health services research findings into practice: a consolidated framework for advancing implementation science. *Implement Sci* 2009;4:50.
23 Castro-Piñero J, Artero EG, España-Romero V, *et al*. Criterion-related validity of field-based fitness tests in youth: a systematic review. *Br J Sports Med* 2010;44:934–43.
24 Chandler JL, Brazendale K, Beets MW, *et al*. Classification of physical activity intensities using a wrist-worn accelerometer in 8-12-year-old children. *Pediatr Obes* 2016;11:120–7.
25 Stalder T, Steudte S, Miller R, *et al*. Intraindividual stability of hair cortisol concentrations. *Psychoneuroendocrinology* 2012;37:602–10.
26 Lubans DR, Morgan P, Callister R, *et al*. Test-retest reliability of a battery of field-based health-related fitness measures for adolescents. *J Sports Sci* 2011;29:685–93.
27 Ruiz JR, Castro-Piñero J, España-Romero V, *et al*. Field-based fitness assessment in young people: the alpha health-related fitness test battery for children and adolescents. *Br J Sports Med* 2011;45:518–24.
28 Cole TJ, Lobstein T. Extended International (IOTF) body mass index cut-offs for thinness, overweight and obesity. *Pediatr Obes* 2012;7:284–94.
29 Peirce J, Gray JR, Simpson S, *et al*. PsychoPy2: experiments in behavior made easy. *Behav Res Methods* 2019;51:195–203.
30 Diamond A. Executive functions. *Annu Rev Psychol* 2013;64:135–68.
31 Cohen S, Kamarck T, Mermelstein R. A global measure of perceived stress. *J Health Soc Behav* 1983;24:385–96.
32 Mellor D. Normative data for the Strengths and Difficulties Questionnaire in Australia. *Aust Psychol* 2005;40:215–22.
33 Tennant R, Hiller L, Fishwick R, *et al*. The Warwick-Edinburgh mental well-being scale (WEMWBS): development and UK validation. *Health Qual Life Outcomes* 2007;5:63.
34 Eather N, Beauchamp MR, Rhodes RE, *et al*. Development and evaluation of the High-Intensity Interval Training Self-Efficacy Questionnaire. *J Sport Exerc Psychol* 2020;42:114–22.
35 Markland D, Tobin V. A modification to the Behavioural Regulation in Exercise Questionnaire to include an assessment of amotivation. *Journal of Sport and Exercise Psychology* 2004;26:191–6.
36 Goodman A, Lamping DL, Ploubidis GB. When to use broader internalising and externalising subscales instead of the hypothesised five subscales on the Strengths and Difficulties Questionnaire (SDQ): data from British parents, teachers and children. *J Abnorm Child Psychol* 2010;38:1179–91.
37 Mahar MT, Welk GJ, Rowe DA. Estimation of aerobic fitness from PACER performance with and without body mass index. *Meas Phys Educ Exerc Sci* 2018;22:239–49.
38 Perry AC, Rosenblatt ES, Kempner L, *et al*. The effects of an exercise physiology program on physical fitness variables, body satisfaction, and physiology knowledge. *J Strength Cond Res* 2002;16:219–26.
39 Kargarfard M, Kelishadi R, Ziaee V, *et al*. The impact of an after-school physical activity program on health-related fitness of mother/daughter pairs: Caspian study. *Prev Med* 2012;54:219–23.
40 Bayne-Smith M, Fardy PS, Azzollini A, *et al*. Improvements in heart health behaviors and reduction in coronary artery disease risk factors in urban teenaged girls through a school-based intervention: the path program. *Am J Public Health* 2004;94:1538–43.
41 Noonan V, Dean E. Submaximal exercise testing: clinical application and interpretation. *Phys Ther* 2000;80:782–807.
42 Minatto G, Barbosa Filho VC, Berria J, *et al*. School-based interventions to improve cardiorespiratory fitness in adolescents: systematic review with meta-analysis. *Sports Med* 2016;46:1273–92.
43 Jago R, McMurray RG, Drews KL, *et al*. Healthy intervention: fitness, physical activity, and metabolic syndrome results. *Med Sci Sports Exerc* 2011;43:1513–22.
44 Brazendale K, Beets MW, Weaver RG, *et al*. Understanding differences between summer vs. school obesogenic behaviors of children: the structured days hypothesis. *Int J Behav Nutr Phys Act* 2017;14:100.
45 Delgado-Floody P, Espinoza-Silva M, García-Pinillos F, *et al*. Effects of 28 weeks of high-intensity interval training during physical education classes on cardiometabolic risk factors in Chilean schoolchildren: a pilot trial. *Eur J Pediatr* 2018;177:1019–27.
46 Troiano RP, McClain JJ, Brychta RJ, *et al*. Evolution of accelerometer methods for physical activity research. *Br J Sports Med* 2014;48:1019–23.
47 Rowlands AV, Sherar LB, Fairclough SJ, *et al*. A data-driven, meaningful, easy to interpret, standardised accelerometer outcome variable for global surveillance. *J Sci Med Sport* 2019;22:1132–8.
48 Borde R, Smith JJ, Sutherland R, *et al*. Methodological considerations and impact of school-based interventions on objectively measured physical activity in adolescents: a systematic review and meta-analysis. *Obes Rev* 2017;18:476–90.
49 McCrabb S, Lane C, Hall A, *et al*. Scaling-up evidence-based obesity interventions: a systematic review assessing intervention adaptations and effectiveness and quantifying the scale-up penalty. *Obes Rev* 2019;20:964–82.
50 Patalay P, Gage SH. Changes in millennial adolescent mental health and health-related behaviours over 10 years: a population cohort comparison study. *Int J Epidemiol* 2019;48:1650–64.
51 Keyes KM, Gary D, O'Malley PM, *et al*. Recent increases in depressive symptoms among US adolescents: trends from 1991 to 2018. *Soc Psychiatry Psychiatr Epidemiol* 2019;54:987–96.
52 Högberg B, Strandh M, Hagquist C. Gender and secular trends in adolescent mental health over 24 years–The role of school-related stress. *Social Science & Medicine* 2020;112890.
53 Kjaer M. Regulation of hormonal and metabolic responses during exercise in humans. *Exerc Sport Sci Rev* 1992;20:161–84.
54 Mücke M, Ludyga S, Colledge F, *et al*. Influence of regular physical activity and fitness on stress reactivity as measured with the Trier social stress test protocol: a systematic review. *Sports Med* 2018;48:2607–22.
55 Leahy AA, Mavilidi MM, Smith JJ, *et al*. Review of high-intensity interval training for cognitive and mental health in youth. *Med Sci Sports Exerc* 2020;52:2224–34.
56 Spruit A, Assink M, van Vugt E, *et al*. The effects of physical activity interventions on psychosocial outcomes in adolescents: a meta-analytic review. *Clin Psychol Rev* 2016;45:56–71.
57 Bailey AP, Hetrick SE, Rosenbaum S, *et al*. Treating depression with physical activity in adolescents and young adults: a systematic review and meta-analysis of randomised controlled trials. *Psychol Med* 2018;48:1068–83.