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# BMJ Open

## A school-based physical activity intervention for older adolescents: Rationale and study protocol for the Burn 2 Learn cluster randomised controlled trial

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Keywords:	Physical fitness, Adolescents, Physical activity, Behaviour change, Resistance training, Cognition

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3 **A school-based physical activity intervention for older adolescents: Rationale and study**  
4 **protocol for the Burn 2 Learn cluster randomised controlled trial**  
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13 Training; Mental health; Cognition

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## ABSTRACT

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

**Methods and analysis:** The 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 from 20 secondary schools (i.e., 10 schools per cohort). A range of implementation strategies will be provided to teachers (e.g., training, equipment, and support) to facilitate the delivery of HIIT sessions during scheduled classes. In Phase 1 and 2 (3-months each), teachers will facilitate the delivery of at least two HIIT sessions/week during lesson-time. In Phase 3 (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 endpoint) and 12-months. Cardiorespiratory fitness (shuttle run test) is the primary outcome. Secondary outcomes include: vigorous physical activity, muscular fitness, cognition, and mental health. Subgroup analyses will be performed on random subsamples assessing cortisol concentrations in hair, and multi-modal magnetic resonance imaging. A process evaluation will be conducted (i.e., recruitment, retention, attendance, and program 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:** Australian New Zealand Clinical Trials Registry Number: ACTRN12618000293268.

### 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.

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## 1 INTRODUCTION

2 Physical inactivity has been described as a global pandemic,<sup>1</sup> and global estimates suggest  
3 that less than 20% of adolescents are sufficiently active.<sup>2</sup> Furthermore, physical activity  
4 declines dramatically during the teenage years (~7% each year from age 11 to 19 years),<sup>3</sup> and  
5 Australian data indicate only 6% of older adolescents (15-17 years) are satisfying current  
6 physical activity guidelines of 60 minutes of moderate-to-vigorous physical activity (MVPA)  
7 per day.<sup>4</sup> Of additional concern, evidence suggests a decline in young people's  
8 cardiorespiratory fitness (CRF), which is an important predictor of overall health status,<sup>5</sup> has  
9 occurred since the 1970s.<sup>6,7</sup> While previous studies have noted small-to-moderate  
10 associations between physical activity and CRF in young people,<sup>8</sup> the relationship is stronger  
11 when activity of vigorous intensity is examined independently.

12 Adolescents who participate in physical activity of sufficient volume and intensity to  
13 improve their CRF will experience metabolic and cognitive benefits. For example, a recent  
14 longitudinal study involving a large sample of adolescents found that cardio-metabolic risk  
15 declined in a dose-response manner with increasing vigorous physical activity in adolescents  
16 (healthy adolescents participated in  $\geq 7$ mins/day of vigorous activity), but not with increased  
17 volume of light or moderate physical activity.<sup>9</sup> Both vigorous activity and CRF are also  
18 important for young people's mental<sup>10,11</sup> and cognitive health.<sup>12,13</sup> Recent systematic reviews  
19 have concluded that participating in physical activity can improve young people's cognitive  
20 control and academic performance<sup>13,14</sup>, but the underlying neurobiological, psychosocial and  
21 behavioural mechanisms not well understood.<sup>15</sup>

22 Schools are ideal settings for the delivery of physical activity programs because they  
23 have access to young people as well as the necessary facilities and equipment, and  
24 availability of qualified staff.<sup>16</sup> School-based physical activity interventions targeting children  
25 (ages 5 to 11 years) and young adolescents (ages 12 to 15 years) have had mixed success.<sup>17,18</sup>  
26 Efficacy studies usually produce positive findings, but the promising findings from small-  
27 scale studies are rarely seen in large-scale effectiveness trials.<sup>19</sup> Focusing on organisational  
28 change (i.e., supportive school policies) and providing professional development for teachers  
29 can lead to improvements in physical activity and fitness in children<sup>20,21</sup> and younger  
30 adolescents.<sup>22-25</sup> However, it is relatively unknown if school-based interventions are effective  
31 with older adolescents (i.e., senior school students [16-18 years]) because few randomised  
32 controlled trials (RCTs) have been conducted with this population.<sup>18</sup>

33 Conducting and evaluating health promotion interventions with older adolescents is  
34 challenging, in part, due to the pressures associated with standardised testing at the end of



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3 35 secondary school and university entrance examinations. The focus on academic performance  
4 36 in the final years of secondary schooling and a lack of support from school administrators are  
5 37 major barriers to physical activity promotion in schools.<sup>16 26 27</sup> The success and sustainability  
6 38 of physical activity interventions is largely dependent upon 'buy in' from school principals  
7 39 and teachers, which may wane over time in the face of competing time demands. As  
8 40 enhancing students' academic performance is the core business of schools, providing  
9 41 evidence for the impact of vigorous physical activity on cognitive and academic outcomes  
10 42 may provide a novel 'hook' for schools to implement physical activity interventions.  
11 43 Nevertheless, school-based physical activity interventions need to be time efficient because  
12 44 lack of time is the most commonly cited implementation barrier cited by teachers.<sup>26</sup>

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19 45 High-intensity interval training (HIIT) is a time efficient strategy for improving  
20 46 metabolic health in adolescents and adults,<sup>28 29</sup> and typically consists of short, yet intense  
21 47 bouts of vigorous activity interspersed with brief periods of rest or light activity. Previous  
22 48 studies have shown HIIT can improve CRF (unstandardised mean difference = 2.6  
23 49 mL/kg/min, 95% CI = 1.8 to 3.3), reduce body mass index (-.6 kg/m<sup>2</sup>, 95% CI = -.9 to -.4),  
24 50 and improve metabolic markers (i.e., insulin sensitivity and fasting plasma insulin) in  
25 51 adolescents.<sup>29</sup> For most adolescents, the 'all out' maximal type of HIIT (i.e., 100% of heart  
26 52 rate max.) may not be palatable and such an approach has limited potential as a public health  
27 53 strategy.<sup>30</sup> Alternatively, there is emerging evidence for the efficacy of less demanding HIIT  
28 54 protocols (e.g., 85% of heart rate max.), albeit that most experimental studies have been  
29 55 conducted in laboratory settings over short periods of time (~8 weeks).<sup>31</sup> Importantly, there is  
30 56 scope for developing novel HIIT protocols that retain the health-enhancing effects, but also  
31 57 satisfy adolescents' desire for enjoyment and variety.<sup>32 33 34</sup>

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40 58 We recently conducted the first 'teacher-facilitated' HIIT intervention for older  
41 59 adolescents, the Burn 2 Learn (B2L) pilot RCT.<sup>35</sup> School teachers were asked to provide at  
42 60 least two opportunities during the school week for students (N = 68) to complete HIIT  
43 61 sessions during class time. The program achieved high levels of recruitment (85%) and  
44 62 retention (90%) over the 14-week study period. Adherence to sessions was lower than  
45 63 prescribed (1.9 sessions/week during school) due to disruptions within the school (e.g.,  
46 64 examinations). Overall program satisfaction was high among both students and teachers.  
47 65 Intervention effects were found for CRF, lower-body muscular power and psychological  
48 66 distress. Our pilot study demonstrated that teachers can successfully facilitate the delivery of  
49 67 HIIT during the school day to improve older adolescents' fitness and wellbeing. However, it  
50 68 is unclear whether these positive findings can be replicated on a larger scale.

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## 70 **Study objectives**

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

## 79 **METHODS**

### 80 **Study design**

81 The trial is registered with the Australian New Zealand Clinical Trials Registry  
82 (ACTRN12617000544370) and the design, conduct and reporting will adhere to CONSORT  
83 <sup>36</sup> and TIDier <sup>37</sup> checklists. The B2L intervention will be evaluated using a two-arm parallel  
84 group cluster RCT with an intervention group and wait-list control group. Assessments will  
85 be conducted at baseline, 6-months (primary endpoint) and 12-months from baseline  
86 (secondary endpoint). The RCT will include two cohorts, one starting in 2018 (10 schools; 5  
87 intervention and 5 control), and the other starting in 2019 (10 schools; 5 intervention and 5  
88 control) and finishing in 2020. Baseline data collection will occur in the school term  
89 preceding the intervention delivery (i.e., Term 1 [February to April, 2018 and 2019]. The  
90 intervention delivery will occur in Terms 2 and 3 [May to September, 2018, 2019]. Post-test  
91 data collection (i.e., 6-month follow-up) will commence midway through Term 3 and  
92 continue until the end of term (August to September, 2018 and 2019), with final follow-up  
93 assessments (i.e., 12-month follow-up) being completed in Term 1 of the following year  
94 (February to April, 2019 and 2020).

### 96 **School recruitment and selection**

97 New South Wales (NSW) government secondary schools that include senior school students  
98 (i.e., Grades 11 and 12, students aged 16-18) will be eligible to participate in the study. In  
99 Cohort 1, eligible secondary schools located within 90 minutes' drive from the University of  
100 Newcastle, will be invited to participate. In Cohort 2, eligible secondary schools located  
101 within 150 minutes' drive from the University of Newcastle, will be recruited. The selected  
102 geographical regions (i.e., Hunter-Central Coast, Sydney, Northern Sydney, Western Sydney,

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3 103 and New England) are broadly representative of urban and regional secondary schools in  
4 104 NSW.

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6 105 Schools will be recruited via presentations at conferences and meetings (e.g., regional  
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8 106 meetings of the NSW Principals' Association) and emails sent directly to eligible schools  
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10 107 (i.e., school Principals and Grade 11 Coordinators). Once schools have expressed an interest  
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12 108 in the study, our Project Manager will meet with the school representative(s) and explain the  
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14 109 study requirements. At this time, schools will be asked to identify a minimum of two Grade  
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16 110 11 teachers willing to facilitate the delivery of scheduled B2L sessions during school hours.  
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18 111 There are no restrictions regarding the teaching discipline (e.g., Mathematics, English, Health  
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20 112 and Physical Education) of Grade 11 teachers eligible to participate in the study.  
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### 23 114 **Participants**

24 115 Two Grade 11 teachers per school (B2L school champions) who agree to facilitate the  
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26 116 delivery of B2L during scheduled class time. Eligible participants will be Grade 11 students  
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28 117 who are taught by one of the B2L school champions. Of note, students consenting to  
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30 118 participate in the trial, are consenting to participate in the evaluation component (i.e.,  
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32 119 completion of study measures). Students with a health or medical condition that would  
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34 120 preclude participation in vigorous physical activity will be excluded from the study, but will  
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36 121 still participate in normal lessons adapted by the B2L school champion. We will aim to  
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38 122 recruit ~36 students (i.e., 2 classes) per school.  
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### 41 124 **Sample size calculation**

42 125 Power calculations were based on the primary outcome of cardiorespiratory fitness (CRF),  
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44 126 assessed using the Progressive Aerobic Cardiovascular Endurance Run (PACER) test<sup>38</sup>.  
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46 127 Baseline post-test correlation ( $r = .90$ ) and standard deviation ( $SD=29$ ) values were obtained  
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48 128 from our pilot trial, and conservative ICC values of .20 and .03 were used to account for  
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50 129 clustering at the class- and school-levels, respectively.<sup>39</sup> To detect a clinically meaningful  
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52 130 baseline-adjusted between-group difference of 6 laps<sup>32 40</sup> with 80% power at a 5%  
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54 131 significance level will require 280 students per treatment group (i.e., 2 classes of 14 students  
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56 132 from each of 10 schools). Inflating the sample size to 18 students per class, or 360 students  
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58 133 per treatment arm (i.e., total sample of 720 students) allows for a potential drop-out rate of  
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60 134 20% at our primary study endpoint (i.e., 6-months).  
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### 63 136 **Blinding and randomisation**

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3 137 Randomisation will occur once 10 schools (Cohort 1) have been recruited and completed  
4 138 baseline assessments. The same process will be repeated for Cohort 2. Pairs of schools will  
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6 139 be matched based on the following characteristics: geographic location (i.e., region,  
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8 140 rural/urban, coastal/inland), school area-level socio-economic status (i.e., using the Socio-  
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10 141 Economic Indexes For Areas [SEIFA] Index of Relative Socio-Economic Disadvantage),<sup>41</sup>  
11 142 schools' student population educational advantage (i.e., using the Index of Community Socio-  
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13 143 Educational Advantage [ICSEA]) and where possible, proposed class delivery (e.g.,  
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15 144 Mathematics, English, and Personal Development, Health and Physical Education). Schools  
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17 145 will be randomised by an independent researcher using a computer-based random number  
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19 146 generator, such that one school from each pair will be allocated to the intervention condition  
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21 147 and the other to the control condition. Using this approach, each school will have an equal  
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23 148 chance of being allocated to the intervention condition, whilst maintaining an appropriate  
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25 149 balance of school characteristics across the two conditions. Schools randomised to the  
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27 150 intervention condition will deliver the B2L program during the study period, whereas schools  
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29 151 allocated to the control condition will continue with usual school practice (i.e., normal  
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31 152 curricular lessons) for the duration of the study period (i.e., until completion of 12-month  
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33 153 study assessments). Schools allocated to control group will then receive the intervention  
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35 154 following final study assessments (i.e., the following year). The decision to use a wait-list  
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37 155 control design, rather than an attention-matched placebo, was based on the following. First,  
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39 156 the research team will have little contact with students, as the program will be delivered by  
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41 157 teachers during their regularly scheduled lessons. Second, for our findings to have greater  
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43 158 external validity, it is important that our control group reflects 'usual practice'. Finally, based  
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45 159 on our previous studies, a wait-list control group is acceptable for schools and the majority of  
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47 160 our school-based trials have achieved high levels of retention (80-90%).<sup>23 42 43</sup>  
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### 162 **Intervention delivery, components and implementation strategies**

163 The B2L intervention will be delivered in three phases: Phase 1) *Getting started*, Phase 2)  
164 *Maintaining student interest*, and Phase 3) *Moving towards independence*. In Phases 1 and 2  
165 (Term 2-Term 3; May-September, 2018 and 2019), school champions will be tasked with  
166 facilitating the delivery of at least two HIIT sessions/week during lesson time. During Phase  
167 1, the focus will be on introducing students to HIIT and developing their competency. Phase  
168 2 will involve a greater emphasis on student responsibility and control, and introduce  
169 additional intervention resources (i.e., new HIIT task cards) to maintain student interest. In  
170 Phase 3 (Term 4/Term 1; October-April 2018/2019 and 2019/2020), students will be

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3 171 encouraged to complete sessions outside of lesson time (teachers may continue to facilitate  
4 172 the delivery of B2L sessions during lesson-time).

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6 173 A common criticism of public health research is the development of interventions that  
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8 174 are not ‘scalable’ and unlikely to be adopted and implemented in real world settings.<sup>44</sup> The  
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10 175 B2L intervention has been designed in consultation with the NSW Department of Education  
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12 176 and guided by the Consolidated Framework for Implementation Research<sup>45</sup> to maximise  
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14 177 scalability and sustainability. A summary of the B2L intervention components are provided  
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16 178 in Table 1. The multi-component intervention will target schools, principals, teachers,  
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18 179 students and parents using: (i) an information seminar delivered by school champions, (ii)  
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20 180 school-based physical activity sessions for two school terms, (iii) smartphone application and  
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22 181 heart rate monitors and (iv) information for parents (i.e., print or e-newsletters). A range of  
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24 182 implementation strategies were designed to support the delivery of the B2L program (Table  
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26 183 2) and include the following: (i) intervention characteristics, (ii) outer setting (i.e.,  
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28 184 educational authorities), (iii) inner setting (i.e., schools), (iv) characteristics of teachers, and  
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30 185 (v) implementation process.

### 31 186 32 187 **Theoretical framework for the intervention**

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34 188 Several theoretical frameworks have been used to guide intervention design. Firstly, Beets  
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36 189 and colleagues’ theory of expanded, extended, and enhanced opportunities<sup>46</sup> suggests that the  
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38 190 extension and enhancement of existing physical activity opportunities, as well as the creation  
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40 191 of new opportunities (i.e., expansion) are needed to increase youth physical activity levels.  
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42 192 For the current study, the provision of an entirely new opportunity for physical activity (i.e.,  
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44 193 expansion) was considered necessary, as the majority of secondary schools in NSW do not  
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46 194 provide mandatory physical activity for senior students. During Phases 1 and 2 of the  
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48 195 intervention, the HIIT sessions will be facilitated during scheduled class-time, therefore  
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50 196 adopting a compulsory application of Theory of Expanded, Extended, and Enhanced  
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52 197 Opportunities. In the third phase, students will be encouraged to complete two to three  
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54 198 sessions per week within or beyond the school day. During this phase, students will be  
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56 199 encouraged to self-monitor their participation in HIIT sessions using the B2L smartphone  
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58 200 app.

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60 201 With reference to self-determination theory, B2L HIIT sessions have been developed  
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203 202 with a focus on enhancing students’ autonomous motivation for vigorous physical activity  
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205 203 within and beyond the school setting by satisfying their basic psychological needs for  
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207 204 autonomy (feeling in control), competence (feeling capable) and relatedness (feeling

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3 205 connected with others).<sup>47</sup> Teachers will learn to facilitate the B2L sessions using the SAAFE  
4 206 (Supportive, Active, Autonomous, Fair and Enjoyable) physical activity delivery principles  
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6 207 (see Table 3).<sup>48</sup> Participants' need for autonomy will be satisfied by providing opportunities  
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8 208 for choice within sessions (e.g., type of activity, music playing, and training partner) and  
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10 209 explaining the rationale for the program in an information seminar. The introductory seminar  
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12 210 will reinforce the importance of exercise for cognitive health and academic performance,  
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14 211 which may be salient outcomes for students during this period of their schooling.  
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16 212 Competence will be satisfied using positive and specific feedback from teachers, an explicit  
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18 213 focus on effort over performance (via heart rate feedback), and through the provision of  
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20 214 resources designed to support the development of exercise skills. Teachers will be  
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22 215 encouraged to adopt practices that support relatedness and group cohesion during HIIT  
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24 216 sessions (i.e., encouraging supportive behaviour among students such as 'high fives' and  
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26 217 partner work)<sup>49</sup>.

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### 219 **Measures and data collection**

220 Apart from multi-modal magnetic resonance imaging, all assessments will be conducted at  
221 the study schools by trained research assistants, who will be blinded to group allocation at all  
222 time-points. Demographic information and self-report measures will be collected using  
223 electronic tablets under exam-like conditions. Anthropometric assessments will be conducted  
224 in a sensitive manner by same-sex research staff when possible. Cognitive testing will occur  
225 before fitness assessments. Participants will receive instructions and practice prior to  
226 performing each of the cognitive tasks. Research assistants will provide a brief verbal  
227 description and demonstration of each fitness test prior to commencement.

228

### 229 **Primary outcome**

230 *Cardiorespiratory fitness*. CRF will be assessed using the Progressive Aerobic  
231 Cardiovascular Endurance Run (PACER), using FITNESSGRAM® testing procedures. This  
232 test is the most widely accepted field-based measure of CRF, demonstrating high reliability  
233 and validity.<sup>50</sup> A 20 m course will be set up on a hard surface with participants instructed to  
234 run back and forth between two sets of lines while keeping pace with a pre-recorded cadence  
235 (indicated by a single beep for each 20 m shuttle). The test begins at a slow pace (8.5 km/h),  
236 and increases by 0.5 km/h with each passing minute (as indicated by a triple beep). The test  
237 ends when participants fail to complete a shuttle (20 m lap) before the beep sounds, on two  
238 consecutive shuttles, or upon volitional failure. Verbal encouragement will be provided by

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3 239 test administrators in order to maximise participant motivation. The last successful stage will  
4 240 be recorded and converted into the number of 20 m laps completed, which will constitute the  
5 241 primary outcome measure. The total number of laps will be used to estimate maximal aerobic  
6 242 capacity (i.e.,  $\text{VO}_2$  max), using the following equation:  $20.41012 + (\text{PACER laps} \times$   
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8 243  $0.41304)$ .<sup>51</sup> Estimated  $\text{VO}_2$  max will be used to classify participants into fitness zones  
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11 244 according to criterion-referenced age- and sex-specific cut-offs developed by the Cooper  
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13 245 Institute.<sup>52</sup>  
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## 16 247 **Secondary outcomes**

17 248 *Physical activity.* Participants will be instructed to wear an ActiGraph GT9X Link  
18 249 accelerometer on their non-dominant wrist for 24 hours per day (even when bathing,  
19 250 swimming and sleeping) for a period of seven consecutive days. Weekday and weekend day  
20 251 (i.e., mean minutes per day) physical activity will be calculated separately, using existing  
21 252 thresholds for categorising physical activity into light, moderate and vigorous intensity.  
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23 253 *Muscular fitness.* Upper body muscular endurance will be assessed using the 90-degree push-  
24 254 up test.<sup>38</sup> Using a cadence of 40 beats per minute, participants lower themselves in a  
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26 255 controlled manner until a 90-degree angle is formed at the elbow before pushing back up. The  
27 256 test concludes when the participant either fails to lower themselves to the required depth on  
28 257 two non-consecutive repetitions (warning verbalised by assessor, repetitions counted), fails to  
29 258 maintain movement in time with the metronome, fails to maintain appropriate technique  
30 259 (back straight), or upon volitional failure of the test. Lower body muscular power will be  
31 260 assessed using the standing long jump test.<sup>53</sup> From a standing position behind a line marked  
32 261 at zero centimetres, participants perform a maximal long jump taking off and landing with  
33 262 two feet, simultaneously. The test will be performed twice, with the maximal distance jumped  
34 263 recorded as the participant's final score. Both measures of muscular fitness demonstrate high  
35 264 validity and reliability in adolescents.<sup>54 55</sup>  
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46 266 *Body composition.* Body weight and height will be measured using a portable digital scale  
47 267 (A&D Medical UC-352-BLE Digital Scales) and a portable stadiometer (Seca 213 Portable  
48 268 Height Measuring Rod Stadiometer), respectively. Body mass index (BMI) will be calculated  
49 269 using the standard formula ( $\text{weight}[\text{kg}]/\text{height}[\text{m}]^2$ ). Age- and sex-specific BMI z-scores will  
50 270 be calculated and participants will be classified into weight categories according to  
51 271 International Obesity Task Force cut-offs.<sup>56</sup>  
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3 273 *Cognitive control.* Using a laptop, specialised software (PsychoPy)<sup>57</sup> will be used to assess  
4 274 working memory and inhibition. A modified version of an Eriksen flanker task will be used  
5 275 to measure inhibition, which is a reliable and valid measure in youth.<sup>58</sup> In this task  
6 276 participants are required to respond (using specific keys) to the direction of the centrally  
7 277 presented arrow among either ‘congruent’ or ‘incongruent’ flanking arrows. Congruent trials  
8 278 consist of five horizontal arrows facing the same direction (i.e., <<<<< or >>>>>), while  
9 279 incongruent trials consist of the central arrow facing the opposite direction to the four  
10 280 flanking arrows (i.e., <<<<< or >>>>>). Participants are challenged with a random sequence  
11 281 of congruent and incongruent trials and instructed to identify the direction of the centrally  
12 282 presented, target arrow as quickly and accurately as possible. Following instructions,  
13 283 participants will be presented with a practice block consisting of 25 trials to familiarise  
14 284 themselves with the test. If participants achieve below satisfactory overall accuracy (<70%),  
15 285 they will complete another practice block of 25 trials, and the test administrator will confirm  
16 286 their understanding of the test. Participants then complete an experimental block consisting of  
17 287 150 trials (with an equal distribution of congruent and incongruent). Stimuli are presented for  
18 288 100 milliseconds (ms), with a randomly allocated inter-stimulus interval of 900, 1050, or  
19 289 1200 ms separating each trial. Response time (i.e., the time in ms taken by the participant to  
20 290 press the key associated with the direction of the target arrow) and response accuracy (i.e.,  
21 291 the percentage of trials for which the participant correctly indicated the direction of the target  
22 292 arrow) and will be recorded. An interference score (i.e., the difference in performance  
23 293 outcomes between congruent and incongruent trials) will also be calculated for both accuracy  
24 294 and response time. A lower interference score demonstrates higher inhibitory control.

25 295 Working memory will be assessed using a serial n-back task, which is a widely used and  
26 296 reliable measure.<sup>59 60</sup> Two task conditions (i.e., 1-back and 2-back) will be evaluated which  
27 297 differ in the degree of cognitive demand. In these tasks, participants are presented with a  
28 298 series of six basic shapes (i.e., square, star, circle, cross, crescent, triangle) and required to  
29 299 recall (using specific keys) whether the shape currently displayed (trial ‘n’) matches the  
30 300 shape immediately prior (1-back, ‘n-1’), or two shapes prior (2-back, ‘n-2’). For each trial  
31 301 (within each n-back condition) participants are required to indicate whether the shape is a  
32 302 match (i.e., target) or not a match (i.e., non-target). Shapes are presented for a duration of 250  
33 303 ms following a fixed inter-stimulus interval of 2500 ms. Following task instructions,  
34 304 participants will complete a practice block consisting of 20 trials to ensure understanding. If  
35 305 overall accuracy is below 70%, participants will complete another practice block, and the test  
36 306 administrator will confirm their understanding of the test. Each task condition (i.e., 1-back, 2-



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3 307 back) consists of two blocks of randomised target (n=24) and non-target (n=48) trials, and are  
4 308 presented in a counterbalanced order. Response time and accuracy will be recorded for both  
5 309 target shapes (i.e., correctly identifying a match) and non-target shapes (i.e., correctly  
6 310 identifying a non-match). Additionally, the relative proportion of ‘hits’ (correct target trials)  
7 311 to ‘false alarms’ (incorrect selection on target trial), otherwise known as the d-prime score,  
8 312 will be calculated for both task conditions.<sup>61</sup> A higher d-prime score reflects a greater  
9 313 capacity to differentiate target from non-target shapes when performing the n-back tasks,  
10 314 thereby indicating greater working memory.  
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18 316 *Stress.* Objectively measured stress will be determined by examining the build-up of cortisol  
19 317 within the hair shaft using a sample taken from the vertex at the rear of the head. As human  
20 318 hair grows at a rate of approximately 1 cm per month, each cm is considered to reflect life  
21 319 stressors experienced by the individual over the last month.<sup>62</sup> Cortisol concentrations will be  
22 320 determined from the 3-cm hair segment (maximum) most proximal to the scalp. This will  
23 321 represent the cumulative stress level in the past two to three months. Inter-individual  
24 322 variation in hair growth rate can be factored into analyses by measuring hair growth at the  
25 323 initial sampling site one month later. The intra-individual stability ( $r = .68-.79$ )<sup>63</sup> and validity  
26 324 of hair cortisol as a retrospective index of stress are supported in the literature in adults<sup>64 65</sup>  
27 325 and adolescents<sup>66</sup>. Perceived stress will be self-reported using the Perceived Stress Scale,  
28 326 which is designed to assess the degree to which situations in one’s life are stressful<sup>67</sup>.  
29 327 Participants will be required to respond to the 10-item questionnaire in relation to the  
30 328 previous month (e.g., “*In the last month, how often have you felt you were on top of*  
31 329 *things?*”). Responses are scored on a 5-point scale ranging from 0 “*Never*” to 4 “*Very often*”  
32 330 and then summing across all scale items. Higher scores indicate a greater degree of subjective  
33 331 stress experienced by participants.  
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45 333 *Psychological difficulties.* The Strengths and Difficulties Questionnaire will be used to assess  
46 334 psychological distress.<sup>68</sup> The questionnaire consists of 25 items, covering 2 subscales (i.e.,  
47 335 strengths and difficulties). The strengths subscale consists of one domain (prosocial  
48 336 behaviour [e.g., “*I try to be nice to other people. I care about their feelings.*”), and the  
49 337 difficulties subscale consists of four domains: emotional symptoms (e.g., “*I worry a lot.*”),  
50 338 conduct problems (e.g., “*I get very angry and often lose my temper.*”), hyperactivity (e.g., “*I*  
51 339 *am restless, I cannot stay still for long.*”), and peer problems (e.g., “*I would rather be alone*  
52 340 *than with people of my own age.*”). For each item, participants respond using a three-point  
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3 341 scale (i.e., “Not true” = 0, “Somewhat true” = 1, and “Certainly true” = 2). For each of the  
4 342 five domains the score can range from 0 to 10. A difficulties composite score will be obtained  
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6 343 by adding the scores of all four difficulty domains, with a possible range from 0 to 40. Lower  
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8 344 scores indicate fewer psychological difficulties.

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11 346 *Autonomous motivation.* Motivation for physical activity will be assessed using the  
12 347 ‘Behavioural Regulations in Exercise Questionnaire’.<sup>69</sup> The identified (e.g., “I value the  
13 348 benefits of exercise”), and intrinsic (e.g., “I exercise because it’s fun”) regulation subscales  
14 349 will be used. Responses are scored on a 5-point scale ranging from 0 “Not true for me” to 4  
15 350 “Very true for me”.

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18 352 *Basic psychological needs satisfaction.* Friends’ and teachers’ support for exercise will be  
19 353 assessed via the ‘Adolescent Psychological Need Support in Exercise Questionnaire’.<sup>70</sup> Items  
20 354 assess needs satisfaction during exercise across the three psychological needs identified  
21 355 within self-determination theory, namely autonomy support (e.g., “I feel that they understand  
22 356 why I choose to exercise”), relatedness support (e.g., “I feel they care about me”), and  
23 357 competence support (e.g., “They display confidence in my exercise ability”). Participants  
24 358 respond using a 7-point Likert scale ranging from 1 “Strongly disagree” to 7 “Strongly  
25 359 agree”.

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27 361 *Psychological well-being.* Well-being is assessed using the validated Warwick-Edinburgh  
28 362 Mental Wellbeing Scale.<sup>71</sup> The 14-item questionnaire requires participants to reflect on their  
29 363 experiences over the last two weeks. Items are scored on a 5-point scale ranging from 1  
30 364 “None of the time” to 5 “All of the time”, and summed across all to produce a well-being  
31 365 composite (possible range = 14 to 70).

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34 367 *Perceived fitness.* Perceived physical fitness will be self-reported using the International  
35 368 Fitness Scale.<sup>72</sup> Participants are required to report perceptions of their ‘general fitness’ and  
36 369 four specific sub-components of health-related fitness. The 5-item instrument is scored on a  
37 370 scale ranging from 1 “Very poor” to 5 “Very good”. The validity and test-retest reliability of  
38 371 the IFIS has been found to be acceptable among a sample of 9-12 year old youth.<sup>72</sup>

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41 373 *HIIT self-efficacy.* Self-efficacy for HIIT will be assessed using a 6-item scale developed for  
42 374 the current study. The scale uses the common stem “If you really wanted to, how confident

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3 375 *are you that you can...*” and participants respond as follows: 1 “*Not at all confident*” to 10  
4 376 “*Completely confident*”. Sample item- “*maintain a high level of effort right through to the*  
5 377 *end of a HIIT session*”. The mean of the 6-items will be calculated.  
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9 379 *Brain structure and function.* To further elucidate exercise-induced neural changes, a target  
10 380 sub-sample of approximately 60 students (i.e., 15 students per school from 4 schools; 2 x  
11 381 intervention group, 2 x control group) identified as being in the bottom 50% of students from  
12 382 their school for CRF (using their baseline PACER test result) will undergo multi-modal  
13 383 magnetic resonance imaging. We have undertaken a systematic review of neuroimaging  
14 384 studies that have examined associations between physical activity, CRF or muscular fitness,  
15 385 and brain structure/function. Preliminary findings from this review informed our multi-modal  
16 386 magnetic resonance imaging protocol to explore changes in the following areas: (i) structural  
17 387 magnetic resonance imaging (T1 and T2-weighted imaging) to identify volumetric changes in  
18 388 white and grey matter of the hippocampus,<sup>73-75</sup> frontal regions/prefrontal cortex,<sup>73</sup> anterior  
19 389 cingulate cortex,<sup>76</sup> and basal ganglia<sup>77</sup>; (ii) diffusion tensor imaging will be used to identify  
20 390 changes in white matter structural connectivity of the superior longitudinal fasciculus and  
21 391 corpus callosum. (iii) resting state functional magnetic resonance imaging will be used to  
22 392 assess changes in activation of the default mode network, cognitive control network, saliency  
23 393 network,<sup>78</sup> hippocampus, and prefrontal cortex<sup>79 80</sup>; (iv) magnetic resonance spectroscopy will  
24 394 be used to identify changes in brain metabolite concentrations (i.e., gamma-aminobutyric  
25 395 acid, N-acetyl Aspartate, adenosine tri-phosphate, and glutamate/glutamine) in the  
26 396 hippocampus and frontal regions/prefrontal cortex.  
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#### 398 **Process evaluation**

399 A detailed process evaluation will be conducted to determine intervention fidelity. Process  
400 400 measures will include: (i) students’ mean heart rate from the HIIT sessions (measured using  
401 401 Bluetooth heart rate monitoring technology), (ii) teacher attendance and satisfaction with the  
402 402 professional learning workshop and curriculum materials (workshop evaluation  
403 403 questionnaires), (iii) students’ satisfaction with all intervention components (student  
404 404 evaluation questionnaire), (iv) number of practical sessions delivered (school champion logs  
405 405 and session observations), (v) teachers’ implementation questionnaire (adapted from an  
406 406 existing questionnaire)<sup>81</sup>, (vi) student engagement (objective usage data) with the app, and  
407 407 (vii) practical session fidelity (3 observations per teacher) using the SAAFE observation  
408 408 checklist.<sup>48</sup>  
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3 4094 410 **Statistical analyses**

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6 411 Analyses of the primary and secondary outcomes will be conducted using linear mixed  
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8 412 models in IBM SPSS Statistics for Windows, Version 20.0 (2010 SPSS Inc., IBM Company  
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10 413 Armonk, NY), with alpha levels set at  $p < 0.05$ . The models will be used to assess the impact  
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12 414 of treatment (B2L or control), time (treated as categorical with levels baseline, 6- and 12-  
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14 415 months) and the group-by-time interaction, using random effects to account for the clustered  
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16 416 nature of the data. Although randomisation will occur at the school level, statistical analyses  
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18 417 will be adjusted for the clustering of effects at the class level, as students from each school  
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20 418 are nested in classes. Previous school-based studies have demonstrated that clustering at the  
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22 419 school-level is negligible after adjusting for clustering at the class-level.<sup>82 83</sup> However, we  
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24 420 will test this assumption and additionally adjust our analyses for school-level clustering if  
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26 421 required<sup>84</sup>. Several potential moderators of intervention effects will be explored using  
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28 422 interaction tests. Subgroup analyses will be conducted for the following variables if the  
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30 423 significance of the group-by-moderator interaction is  $\leq .10$ . Socio-economic status (Low,  
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32 424 Medium, High), sex (male, female), baseline weight status (not overweight,  
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34 425 overweight/obese), baseline psychological distress (using established cut-offs from the  
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36 426 Strengths and Difficulties Questionnaire), and baseline CRF (using FITNESSGRAM fitness  
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38 427 standards).  
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40 428 principle, assuming the data are missing at random<sup>85</sup>. The validity of this assumption will be  
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42 429 explored by assessing relationships between missingness and observed values of covariates  
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44 430 and previous outcomes. A range of sensitivity analyses will be conducted (e.g., multiple  
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46 431 imputation and complete-case analysis). In addition to our primary analysis (i.e., intention-to-  
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48 432 treat) and sensitivity analyses, we will also conduct two per-protocol analyses (i.e., at the  
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50 433 class and student levels, respectively). After consideration of typical school disruptions (i.e.,  
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52 434 sporting events, school excursions, exams etc.), we estimate that a minimum of 28 exercise  
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54 435 sessions offered over the duration of Phases 1 and 2 is achievable for schools, and sufficient  
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56 436 to observe effects for our primary outcome at the primary end point (i.e., 6-months).  
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58 437 Therefore, our class-level per-protocol analysis will include only students from classes in  
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60 438 which at least 28 school-based sessions were offered. For our student-level per-protocol  
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440 439 analysis, we will include only those students who achieved an average heart-rate of 80% of  
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442 440 their age-predicted maximum across the intervention period (up until our primary endpoint),  
using heart-rate data drawn from the B2L smartphone app.

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### 443 **Patient and public involvement**

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

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

### 457 **DISCUSSION**

458 Despite the importance of physical activity and fitness for adolescents' physical and mental  
459 health, increasing time demands and academic pressures in the final years of schooling often  
460 drive older adolescents to sacrifice time usually spent being active. Although schools are well  
461 equipped to promote physical activity to adolescents, secondary schools in NSW do not  
462 schedule mandatory physical activity opportunities (e.g., physical education, co-curricular  
463 school sport) for senior school students (i.e., Grades 11 and 12). Lack of physical activity  
464 may contribute to the high levels of stress, anxiety, and depression observed in older  
465 adolescents.<sup>86-88</sup> The B2L intervention will be promoted to schools, teachers, students and  
466 parents as a strategy to improve older adolescents' cognitive control and academic  
467 performance (rather than focusing on the metabolic health benefits).

468 Beets and colleagues recently proposed the Theory of Expanded, Extended, and  
469 Enhanced Opportunities for physical activity promotion in youth.<sup>46</sup> The authors suggest that  
470 the provision of new opportunities (i.e., expansion) to be physically active, (such as teacher-  
471 facilitated HIIT sessions) is needed to increase young people's activity levels. Phases 1 and 2  
472 of the B2L intervention aim to provide Grade 11 students with additional physical activity  
473 opportunities embedded within the school day in order to increase fitness and physical  
474 activity levels. Phase 3 will provide an opportunity to explore fitness and behaviour change  
475 once the scheduled sessions are no longer facilitated by teachers. We hypothesize that

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3 476 intervention group participants' fitness levels will decrease during this period, but remain  
4 477 higher than control group participants. Providing older adolescents with the knowledge,  
5 478 skills, and opportunities to engage in HIIT may compliment their participation in other types  
6 479 of leisure-time physical activity. It is therefore important to ensure that students are equipped  
7 480 with the necessary tools in order to engage in self-directed physical activity, outside of the  
8 481 school setting. Self-efficacy (i.e., a belief in one's capability or competence within a specific  
9 482 context) is consistently identified as a central determinant of human motivation, and exercise  
10 483 adherence.<sup>89</sup> B2L has also been guided by self-determination theory and designed to satisfy  
11 484 students' basic psychological needs for autonomy (e.g., providing choice/allowing students to  
12 485 feel in control), competence (e.g., incorporating technique cards to develop correct exercise  
13 486 form), and relatedness (e.g., encouraging social connection and encouragement from others),  
14 487 ultimately impacting on students' autonomous motivation.

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22 488 Poor implementation may explain why so many school-based physical activity  
23 489 interventions fail to reach their potential. Lack of time has been noted as the greatest barrier  
24 490 to implementation by teachers<sup>90</sup> and providing robust evidence for the positive effects of  
25 491 vigorous physical activity on cognitive and mental health outcomes may provide the impetus  
26 492 for schools to make mandatory physical activity for older adolescents. While several studies  
27 493 have established that HIIT can be successfully delivered in schools,<sup>91</sup> previous studies have  
28 494 used research staff members or external providers to deliver HIIT sessions, which is neither  
29 495 'scalable' nor 'sustainable'. Although we do not have funding to conduct an economic  
30 496 evaluation, incorporating short breaks into the school day appears to be a cost-effective way  
31 497 to increase young people's activity levels.<sup>92</sup>

## 32 498 33 34 35 36 37 38 39 40 41 499 **ETHICS AND DISSEMINATION**

42 500 Ethics approval for the RCT was obtained from the Human Research Ethics Committee of the  
43 501 University of Newcastle, Australia (H-2016-0424) and the NSW Department of Education  
44 502 and Communities (SERAP: 2017116). School Principals, teachers, parents and students all  
45 503 provided informed written consent prior to enrolment. It is not expected that participants will  
46 504 be at any greater risk of adverse events than they would be when participating in other types  
47 505 of school-based physical activity. However, the teacher handbook includes a section for  
48 506 teachers to report any injuries or adverse events that may occur. Any amendments to the  
49 507 study protocols will be publicly available via the Australian and New Zealand Clinical Trials  
50 508 Registry (Trial number: ACTRN12615000360516). Data management procedures will be

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3 509 conducted by DRL and SK. All entered data will be de-identified using participant codes and  
4 510 will be stored electronically in a password protected drive at the University of Newcastle.  
5 511 Quality checks of entered data will be completed by AL (i.e., range checks). Access to the  
6 512 final trial dataset will comply with the conditions of the ethics committee approval and will  
7 513 be at the discretion of the lead investigator, DRL.  
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11 514

12 515 **Contributors:** DRL, CH, PJM, RCP, MN, CL, NE and JJS secured funding for the project.

13 516 All authors contributed intellectually to the study design and research methodology, or will  
14 517 be directly involved in the collection and management of data. AL and DRL were responsible  
15 518 for drafting the manuscript. All authors provided critical review and endorsed the final  
16 519 version of the manuscript.  
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21 521 **Competing interests:** None declared.  
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For peer review only

780 **Table 1:** Intervention components and implementation evaluation

Level	Intervention component	Dose	Description	Implementation evaluation
TEACHER	1) Professional learning workshop	1 x 5 hour workshop	Professional development workshop for teachers responsible for facilitating the delivery of the B2L program in their school (hereafter referred to as school champions). The workshop will be delivered by members of the research team (i.e., 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 high-intensity interval training (HIIT), and they will also be shown how to use the 'Burn 2 Learn' resources (i.e., HIIT task cards, smartphone application). A condensed online version of the workshop will be provided for school champions that could not attend the face-to-face workshop.	<ul style="list-style-type: none"> <li>• Workshop evaluation questionnaire (following workshop completion by school champions)</li> <li>• Post-program implementation questionnaire (school champions) developed for the current study based on an existing questionnaire<sup>93</sup>.</li> </ul>
	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.	<ul style="list-style-type: none"> <li>• Research team will sign-off once completed by school champions in the penultimate session of the workshop.</li> </ul>
	3) Session observations	3 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.	<ul style="list-style-type: none"> <li>• SAAFE observations<sup>48</sup> conducted by research team in Terms 2 and 3.</li> <li>• SAAFE observation conducted by peer teacher in Term 2.</li> </ul>

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	4) Support from research team	On-going	The research team will create a Burn 2 Learn WhatsApp group and invite school champions to join. School champions will be encouraged to use the on-line messaging platform to share challenges and successful strategies.	<ul style="list-style-type: none"> <li>• Post-program implementation questionnaire (school champions)</li> <li>• Analysis of WhatsApp engagement</li> </ul>
SCHOOL	5) Presentation to school staff	1 x 15 minutes	School champions will design a tailored presentation, scaffolded by pre-designed program resources (i.e., 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 program, and to promote a supportive school climate.	<ul style="list-style-type: none"> <li>• Research team will confirm staff presentation during meeting with school principal.</li> </ul>
	6) Equipment	Once	Schools will be provided with a small equipment pack to assist in the delivery of the Burn 2 Learn program (~AUD\$2500) including: 1 x heart rate monitor/student, 1 x Bluetooth speaker for playing music during sessions and a selection of sports equipment (e.g., balls, cones).	<ul style="list-style-type: none"> <li>• Post-program implementation questionnaire (school champions)</li> </ul>
	7) Technique and HIIT session cards	1 x set/school champion	B2L technique cards (i.e., describing key components to perform each exercise) and HIIT session cards (i.e., describing the various HIIT workouts).	<ul style="list-style-type: none"> <li>• Post-program implementation questionnaire (school champions)</li> </ul>
STUDENT	8) Interactive seminar	1 x 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 Burn 2 Learn program 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	<ul style="list-style-type: none"> <li>• Post-program evaluation questionnaire (students)- satisfaction</li> </ul>

			<p>introductory session, students will participate in a practical HIIT session using the Burn 2 Learn smartphone application.</p>	
	9) HIIT sessions	3/week	<p>Sessions will be run at school during curricular time, supported by program resources and the B2L app. In Phases 1 and 2, teachers will be asked to facilitate the delivery of at least two exercise sessions/week across 2 school terms (i.e., 16 weeks) during regularly scheduled lessons. Each exercise session will last approximately 10-15 minutes 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 3, 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. The HIIT sessions will involve a combination of aerobic (e.g., shuttle runs, jumping jacks, boxing, dancing) and body weight muscle-strengthening exercises (e.g., push-ups, squat jumps and walking lunges), and have been designed to be fun and engaging as well as vigorous in nature. Students will be able to select from pre-designed HIIT workouts, which may be delivered for between 8-16 intervals (30 seconds work, 30 seconds rest; 1:1 work to rest ratio). A shorter option (i.e., 8 intervals; 20 seconds work, 10 seconds rest; 2:1 work to rest ratio; 4 minutes) will also be provided. 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</p>	<ul style="list-style-type: none"> <li>• Students' attendance at the activity sessions will be tracked using the B2L app and via teacher recording.</li> <li>• Average heart rate during sessions</li> <li>• Post-program evaluation questionnaire- session preference, barriers to participation (students)</li> </ul>

			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.	
	10) Smartphone app	On-going	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 6 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 (i.e., 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.	<ul style="list-style-type: none"> <li>• Post-program evaluation questionnaire- satisfaction (students)</li> <li>• Burn 2 Learn app usage and engagement- number of sessions completed, average heart rate</li> </ul>
PARENT	11) e-newsletters for parents	2 x 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.	<ul style="list-style-type: none"> <li>• Post-program evaluation questionnaire (student)</li> </ul>

781 **Table 2:** Strategies used to facilitate implementation in the Burn 2 Learn intervention

Domains	Constructs	Strategies
<b>Intervention characteristics</b>	Evidence strength and quality	B2L intervention resources and evidence from 2 pilot studies
	Adaptability	Flexible intervention delivery model (i.e., during class-time, breaks, before or after school) requiring minimal access to facilities (i.e., can be done in the classroom) and equipment (i.e., body weight exercises).
	Complexity	Time efficient, student-directed intervention requiring only two or three 10 minute sessions per week.
	Design quality and packaging	Intervention resources developed by professional graphic designer.
<b>Outer setting (Educational authorities)</b>	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.
<b>Inner setting (Schools)</b>	School culture	Interactive seminar (20 minutes), B2L promotional posters for schools, short video for parents.
	Leadership engagement	Meeting with School Principal to ensure commitment to the program.
	Resources and facilities	Schools provided with B2L session cards, heart rate monitors and Bluetooth speaker (~\$2,000AUS). B2L sessions designed to be completed by students in a variety of settings (e.g., classroom, playground, sports hall).
	Relative priority	Promoted to schools as strategy to improve cognitive function and mental health. Alignment with Stage 6 curricular material.
	Organizational incentives	Teacher professional learning workshop accredited with New South Wales Education Standards Authority.
<b>Characteristics of individuals (Teachers)</b>	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.
<b>Implementation process</b>	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 (e.g., What's App).
	Evaluation and feedback	B2L session observations and feedback provided by research team.

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For peer review only

784 **Table 3: SAAFE principles and example strategies**

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<b>Principle</b>	<b>Definition</b>	<b>Example strategies</b>
Supportive	Sessions are designed to facilitate a supportive environment	<ul style="list-style-type: none"> <li>• Provide constructive feedback</li> <li>• Praise effort and improvement</li> <li>• Encourage supportive behaviour among students</li> </ul>
Active	Sessions involve a high level of movement	<ul style="list-style-type: none"> <li>• Commence sessions quickly</li> <li>• Minimise talk and instruction time</li> <li>• Encourage students to exercise at high-intensity</li> </ul>
Autonomous	Sessions involve elements of choice	<ul style="list-style-type: none"> <li>• Provide students with opportunities of choice (e.g., music, partner, activity)</li> <li>• Minimise controlling language (e.g., ordering students around)</li> <li>• Remind students about the benefits of high intensity activity</li> </ul>
Fair	Sessions provided all students with an opportunity to experience success	<ul style="list-style-type: none"> <li>• Encourage self-comparison rather than peer-comparison</li> <li>• Encourage students to modify exercises to personal fitness and ability level</li> <li>• Treat all students equally and fairly (i.e., high expectations for all)</li> </ul>
Enjoyable	Sessions are designed to be enjoyable and engaging for all students	<ul style="list-style-type: none"> <li>• Play motivational music during exercise sessions</li> <li>• Provide students with a variety of HIIT workout options</li> <li>• Encourage students to reflect on their post exercise affect (i.e., how they are feeling)</li> </ul>

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# BMJ Open

## A school-based physical activity intervention for older adolescents: Rationale and study protocol for the Burn 2 Learn cluster randomised controlled trial

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	Physical Activity and Nutrition, Faculty of Education and Arts
<b>Primary Subject Heading</b> :	Public health
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3 **A school-based physical activity intervention for older adolescents: Rationale and study**  
4 **protocol for the Burn 2 Learn cluster randomised controlled trial**  
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13 Training; Mental health; Cognition  
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## ABSTRACT

**Introduction:** This trial aims to investigate the impact of a school-based physical activity program, involving high-intensity interval training (HIIT), on the physical and mental 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 (i.e., 10 schools per cohort). A range of implementation strategies will be provided to teachers (e.g., training, equipment, and support) to facilitate the delivery of HIIT sessions during scheduled classes. In Phase 1 and 2 (3-months each), teachers will facilitate the delivery of at least two HIIT sessions/week during lesson-time. In Phase 3 (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 endpoint) 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 multi-modal magnetic resonance imaging to examine brain structure and function. A process evaluation will be conducted (i.e., recruitment, retention, attendance, and program 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:** Australian New Zealand Clinical Trials Registry Number: ACTRN12618000293268.

### 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.

## 1 INTRODUCTION

2 Physical inactivity has been described as a global pandemic,<sup>1</sup> and global estimates suggest  
3 that less than 20% of adolescents are sufficiently active.<sup>2</sup> Furthermore, physical activity  
4 declines dramatically during the teenage years (~7% each year from age 11 to 19 years),<sup>3</sup> and  
5 Australian data indicate only 6% of older adolescents (15-17 years) are satisfying current  
6 physical activity guidelines of 60 minutes of moderate-to-vigorous physical activity (MVPA)  
7 per day.<sup>4</sup> Recent data gathered from Australian secondary schools indicates that adolescent  
8 girls were less likely to meet physical activity recommendations in comparison to boys.<sup>5</sup> Of  
9 additional concern, evidence suggests a decline in young people's cardiorespiratory fitness  
10 (CRF), which is an important predictor of overall health status,<sup>6</sup> has occurred since the  
11 1970s.<sup>7,8</sup> While previous studies have noted small-to-moderate associations between physical  
12 activity and CRF in young people,<sup>9</sup> the relationship is stronger when activity of vigorous  
13 intensity is examined independently.

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

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

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3 35 Conducting and evaluating health promotion interventions with older adolescents is  
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5 36 challenging, in part, due to the pressures associated with standardised testing at the end of  
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7 37 secondary school and university entrance examinations. The focus on academic performance  
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9 38 in the final years of secondary schooling and a lack of support from school administrators are  
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11 39 major barriers to physical activity promotion in schools.<sup>17 27 28</sup> The success and sustainability  
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13 40 of physical activity interventions is largely dependent upon ‘buy in’ from school principals  
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15 41 and teachers, which may wane over time in the face of competing time demands. As  
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17 42 enhancing students’ academic performance is the core business of schools, providing  
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19 43 evidence for the impact of vigorous physical activity on cognitive and academic outcomes  
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21 44 may provide a novel ‘hook’ for schools to implement physical activity interventions.  
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23 45 Nevertheless, school-based physical activity interventions need to be time efficient because  
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25 46 lack of time is the most commonly cited implementation barrier cited by teachers.<sup>27</sup>

24 47 High-intensity interval training (HIIT) is a time efficient strategy for improving  
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26 48 metabolic health in adolescents and adults,<sup>29 30</sup> and typically consists of short, yet intense  
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28 49 bouts of vigorous activity interspersed with brief periods of rest or light activity. Previous  
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30 50 studies have shown HIIT can improve CRF (unstandardised mean difference = 2.6  
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32 51 mL/kg/min, 95% CI = 1.8 to 3.3), reduce body mass index (-.6 kg/m<sup>2</sup>, 95% CI = -.9 to -.4),  
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34 52 and improve metabolic markers (i.e., insulin sensitivity and fasting plasma insulin) in  
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36 53 adolescents.<sup>30</sup> For most adolescents, the ‘all out’ maximal type of HIIT (i.e., 100% of heart  
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38 54 rate max.) may not be palatable and such an approach has limited potential as a public health  
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40 55 strategy.<sup>31</sup> Alternatively, there is emerging evidence for the efficacy of less demanding HIIT  
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42 56 protocols (e.g., 85% of heart rate max.), albeit that most experimental studies have been  
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44 57 conducted in laboratory settings over short periods of time (~8 weeks).<sup>32</sup> Importantly, there is  
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46 58 scope for developing novel HIIT protocols that retain the health-enhancing effects, but also  
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48 59 satisfy adolescents’ desire for enjoyment and variety.<sup>33 34 35</sup>

46 60 We recently conducted the first ‘teacher-facilitated’ HIIT intervention for older  
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48 61 adolescents, the Burn 2 Learn (B2L) pilot RCT.<sup>36</sup> School teachers were asked to provide at  
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50 62 least two opportunities during the school week for students (N = 68) to complete HIIT  
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52 63 sessions during class time. The program achieved high levels of recruitment (85%) and  
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54 64 retention (90%) over the 14-week study period. Adherence to sessions was lower than  
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56 65 prescribed (1.9 sessions/week during school) due to disruptions within the school (e.g.,  
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58 66 examinations). Overall program satisfaction was high among both students and teachers.  
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60 67 Favourable intervention effects were found for CRF, lower-body muscular power (increases)  
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69 68 and psychological distress (decrease) in the hypothesised directions. Our pilot study



69 demonstrated that teachers can successfully facilitate the delivery of HIIT during the school  
70 day to improve older adolescents' fitness and wellbeing. However, it is unclear whether these  
71 positive findings can be replicated on a larger scale.

### 73 **Study objectives**

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

## 82 **METHODS**

### 83 **Study design**

84 The trial is registered with the Australian New Zealand Clinical Trials Registry  
85 (ACTRN12617000544370) and the design, conduct and reporting will adhere to  
86 CONSORT<sup>37</sup> and TIDier<sup>38</sup> checklists. The B2L intervention will be evaluated using a two-  
87 arm parallel group cluster RCT with an intervention group and wait-list control group.  
88 Assessments will be conducted at baseline, 6-months (primary endpoint) and 12-months from  
89 baseline (secondary endpoint). The RCT will include two cohorts, one starting in 2018 (10  
90 schools; 5 intervention and 5 control), and the other starting in 2019 (10 schools; 5  
91 intervention and 5 control) and finishing in 2020. Baseline data collection will occur in the  
92 school term preceding the intervention delivery (i.e., Term 1 [February to April, 2018 and  
93 2019]. The intervention delivery will occur in Terms 2 and 3 [May to September, 2018,  
94 2019]. Post-test data collection (i.e., 6-month follow-up) will commence midway through  
95 Term 3 and continue until the end of term (August to September, 2018 and 2019), with final  
96 follow-up assessments (i.e., 12-month follow-up) being completed in Term 1 of the  
97 following year (February to April, 2019 and 2020).

### 99 **School recruitment and selection**

100 New South Wales (NSW) government secondary schools that include senior school students  
101 (i.e., Grades 11 and 12, students aged 16-18) will be eligible to participate in the study. In  
102 Cohort 1, eligible secondary schools located within 90 minutes' drive from the University of

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3 103 Newcastle, will be invited to participate. In Cohort 2, eligible secondary schools located  
4 104 within 150 minutes' drive from the University of Newcastle, will be recruited. The selected  
5 105 geographical regions (i.e., Hunter-Central Coast, Sydney, Northern Sydney, Western Sydney,  
6 106 and New England) are broadly representative of urban and regional secondary schools in  
7 107 NSW.

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12 108 Schools will be recruited via presentations at conferences and meetings (e.g., regional  
13 109 meetings of the NSW Principals' Association) and emails sent directly to eligible schools  
14 110 (i.e., school Principals and Grade 11 Coordinators). Once schools have expressed an interest  
15 111 in the study, our Project Manager will meet with the school representative(s) and explain the  
16 112 study requirements. At this time, schools will be asked to identify a minimum of two Grade  
17 113 11 teachers willing to facilitate the delivery of scheduled B2L sessions during school hours.  
18 114 There are no restrictions regarding the teaching discipline (e.g., Mathematics, English, Health  
19 115 and Physical Education) of Grade 11 teachers eligible to participate in the study.  
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## 27 117 **Participants**

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29 118 Two Grade 11 teachers per school (B2L school champions) who agree to facilitate the  
30 119 delivery of B2L during scheduled class time. Eligible participants will be Grade 11 students  
31 120 who are taught by one of the B2L school champions. Of note, students consenting to  
32 121 participate in the trial, are consenting to participate in the evaluation component (i.e.,  
33 122 completion of study measures). Students with a health or medical condition that would  
34 123 preclude participation in vigorous physical activity will be excluded from the study, but will  
35 124 still participate in normal lessons adapted by the B2L school champion. We will aim to  
36 125 recruit ~36 students (i.e., 2 classes) per school.  
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## 44 127 **Sample size calculation**

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46 128 Power calculations were based on the primary outcome of cardiorespiratory fitness (CRF),  
47 129 assessed using the Progressive Aerobic Cardiovascular Endurance Run (PACER) test<sup>39</sup>.  
48 130 Baseline post-test correlation ( $r = .90$ ) and standard deviation ( $SD=29$ ) values were obtained  
49 131 from our pilot trial, and conservative ICC values of .20 and .03 were used to account for  
50 132 clustering at the class- and school-levels, respectively.<sup>40</sup> To detect a clinically meaningful  
51 133 baseline-adjusted between-group difference of 6 laps<sup>33 41</sup> with 80% power at a 5%  
52 134 significance level will require 280 students per treatment group (i.e., 2 classes of 14 students  
53 135 from each of 10 schools). Inflating the sample size to 18 students per class, or 360 students  
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3 136 per treatment arm (i.e., total sample of 720 students) allows for a potential drop-out rate of  
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5 137 20% at our primary study endpoint (i.e., 6-months).  
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### 8 139 **Blinding and randomisation**

10 140 Randomisation will occur once 10 schools (Cohort 1) have been recruited and completed  
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12 141 baseline assessments. The same process will be repeated for Cohort 2. Pairs of schools will  
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14 142 be matched based on the following characteristics: geographic location (i.e., region,  
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16 143 rural/urban, coastal/inland), school area-level socio-economic status (i.e., using the Socio-  
17  
18 144 Economic Indexes For Areas [SEIFA] Index of Relative Socio-Economic Disadvantage),<sup>42</sup>  
19  
20 145 schools' student population educational advantage (i.e., using the Index of Community Socio-  
21  
22 146 Educational Advantage [ICSEA]) and where possible, proposed class delivery (e.g.,  
23  
24 147 Mathematics, English, and Personal Development, Health and Physical Education). Schools  
25  
26 148 will be randomised by an independent researcher using a computer-based random number  
27  
28 149 generator, such that one school from each pair will be allocated to the intervention condition  
29  
30 150 and the other to the control condition. Using this approach, each school will have an equal  
31  
32 151 chance of being allocated to the intervention condition, whilst maintaining an appropriate  
33  
34 152 balance of school characteristics across the two conditions. Schools randomised to the  
35  
36 153 intervention condition will deliver the B2L program during the study period, whereas schools  
37  
38 154 allocated to the control condition will continue with usual school practice (i.e., normal  
39  
40 155 curricular lessons) for the duration of the study period (i.e., until completion of 12-month  
41  
42 156 study assessments). Schools allocated to control group will then receive the intervention  
43  
44 157 following final study assessments (i.e., the following year). The decision to use a wait-list  
45  
46 158 control design, rather than an attention-matched placebo, was based on the following. First,  
47  
48 159 the research team will have little contact with students, as the program will be delivered by  
49  
50 160 teachers during their regularly scheduled lessons. Second, for our findings to have greater  
51  
52 161 external validity, it is important that our control group reflects 'usual practice'. Finally, based  
53  
54 162 on our previous studies, a wait-list control group is acceptable for schools and the majority of  
55  
56 163 our school-based trials have achieved high levels of retention (80-90%).<sup>24 43 44</sup>  
57  
58 164

### 53 165 **Intervention delivery, components and implementation strategies**

55 166 The B2L intervention will be delivered in three phases: Phase 1) *Getting started*, Phase 2)  
56  
57 167 *Maintaining student interest*, and Phase 3) *Moving towards independence*. In Phases 1 and 2  
58  
59 168 (Term 2-Term 3; May-September, 2018 and 2019), school champions will be tasked with  
60  
169 facilitating the delivery of at least two HIIT sessions/week during lesson time. During Phase

1  
2  
3 170 1, school champions will attend a one day professional learning workshop led by the research  
4  
5 171 team. The workshop will focus on providing the school champions with the knowledge and  
6  
7 172 skills needed to introduce students to HIIT and develop their competency. Phase 2 will  
8  
9 173 involve a greater emphasis on student responsibility and control, and introduce additional  
10  
11 174 intervention resources (i.e., new HIIT task cards) to maintain student interest. In Phase 3  
12  
13 175 (Term 4/Term 1; October-April 2018/2019 and 2019/2020), students will be encouraged to  
14  
15 176 complete sessions outside of lesson time (teachers may continue to facilitate the delivery of  
16  
17 177 B2L sessions during lesson-time).

17 178 The HIIT sessions will involve a combination of aerobic (e.g., shuttle runs, jumping  
18  
19 179 jacks, boxing, dancing) and body weight muscle-strengthening exercises (e.g., push-ups,  
20  
21 180 squat jumps and walking lunges), and have been designed to be fun and engaging as well as  
22  
23 181 vigorous in nature. Participants will be able to select from a variety of pre-designed HIIT task  
24  
25 182 cards which will be released across the phases of the program to promote variety and sustain  
26  
27 183 participant interest. Phase 1) *Getting started*: (i) Gym HIIT - combination of aerobic (e.g.,  
28  
29 184 skipping) and strength exercises (e.g., squat jumps), (ii) Sport HIIT - utilising sports  
30  
31 185 equipment (e.g., shuttle run while dribbling a basketball), (iii) Class HIIT - exercises that can  
32  
33 186 be performed in a standard classroom (e.g., running on the spot, tricep dips), (iv) Quick HIIT  
34  
35 187 - utilising Tabata protocol (e.g., 20s intense work, followed by 10s rest). Phase 2)  
36  
37 188 *Maintaining student interest*: (i) Hip-Hop HIIT - high-intensity hip-hop dance movements,  
38  
39 189 (ii) Combat HIIT - involves boxing/mixed martial arts movements (e.g., front kicks), (iii)  
40  
41 190 Brain HIIT - activities that encourage thinking while participating in high-intensity activity,  
42  
43 191 (iv) Rumble HIIT - high-intensity rough and tumble exercises (e.g., partner knee taps)  
44  
45 192 combined with aerobic activity, (v) Custom HIIT - participants design their own HIIT  
46  
47 193 workout. Phase 3) *Moving towards independence*: (i) Beach HIIT - utilising the natural  
48  
49 194 coastal environment (e.g., sand shuttle runs and surfer style get-ups), (ii) Park HIIT - exercise  
50  
51 195 sessions adapted for the park setting (e.g., triceps dips using park benches).

48 196 A common criticism of public health research is the development of interventions that  
49  
50 197 are not 'scalable' and unlikely to be adopted and implemented in real world settings.<sup>45</sup> The  
51  
52 198 B2L intervention has been designed in consultation with the NSW Department of Education  
53  
54 199 and guided by the Consolidated Framework for Implementation Research<sup>46</sup> to maximise  
55  
56 200 scalability and sustainability. A summary of the B2L intervention components are provided  
57  
58 201 in Table 1. The multi-component intervention will target schools, principals, teachers,  
59  
60 202 students and parents using: (i) an information seminar delivered by school champions, (ii)  
203 203 school-based physical activity sessions for two school terms, (iii) smartphone application and

1  
2  
3 204 heart rate monitors and (iv) information for parents (i.e., print or e-newsletters). A range of  
4  
5 205 implementation strategies were designed to support the delivery of the B2L program (Table  
6  
7 206 2) and include the following: (i) intervention characteristics, (ii) outer setting (i.e.,  
8  
9 207 educational authorities), (iii) inner setting (i.e., schools), (iv) characteristics of teachers, and  
10 208 (v) implementation process.

11  
12 209

### 13 210 **Theoretical framework for the intervention**

14  
15 211 Several theoretical frameworks have been used to guide intervention design. Firstly, Beets  
16  
17 212 and colleagues' theory of expanded, extended, and enhanced opportunities<sup>47</sup> suggests that the  
18  
19 213 extension and enhancement of existing physical activity opportunities, as well as the creation  
20  
21 214 of new opportunities (i.e., expansion) are needed to increase youth physical activity levels.  
22  
23 215 For the current study, the provision of an entirely new opportunity for physical activity (i.e.,  
24  
25 216 expansion) was considered necessary, as the majority of secondary schools in NSW do not  
26  
27 217 provide mandatory physical activity for senior students. During Phases 1 and 2 of the  
28  
29 218 intervention, the HIIT sessions will be facilitated during scheduled class-time, therefore  
30  
31 219 adopting a compulsory application of Theory of Expanded, Extended, and Enhanced  
32  
33 220 Opportunities. In the third phase, students will be encouraged to complete two to three  
34  
35 221 sessions per week within or beyond the school day. During this phase, students will be  
36  
37 222 encouraged to self-monitor their participation in HIIT sessions using the B2L smartphone  
38  
39 223 app.

40  
41 224 With reference to self-determination theory, B2L HIIT sessions have been developed  
42  
43 225 with a focus on enhancing students' autonomous motivation for vigorous physical activity  
44  
45 226 within and beyond the school setting by satisfying their basic psychological needs for  
46  
47 227 autonomy (feeling in control), competence (feeling capable) and relatedness (feeling  
48  
49 228 connected with others).<sup>48</sup> Teachers will learn to facilitate the B2L sessions using the SAAFE  
50  
51 229 (Supportive, Active, Autonomous, Fair and Enjoyable) physical activity delivery principles  
52  
53 230 (see Table 3).<sup>49</sup> Participants' need for autonomy will be satisfied by providing opportunities  
54  
55 231 for choice within sessions (e.g., type of activity, music playing, and training partner) and  
56  
57 232 explaining the rationale for the program in an information seminar. The introductory seminar  
58  
59 233 will reinforce the importance of exercise for cognitive health and academic performance,  
60  
234 which may be salient outcomes for students during this period of their schooling.  
235 Competence will be satisfied using positive and specific feedback from teachers, an explicit  
236 focus on effort over performance (via heart rate feedback), and through the provision of  
237 resources designed to support the development of exercise skills. Teachers will be

1  
2  
3 238 encouraged to adopt practices that support relatedness and group cohesion during HIIT  
4  
5 239 sessions (i.e., encouraging supportive behaviour among students such as ‘high fives’ and  
6  
7 240 partner work).<sup>50</sup>

8  
9 241

## 10 242 **Measures and data collection**

11 243 Apart from multi-modal magnetic resonance imaging, all assessments will be conducted at  
12 244 the study schools on the same day by trained research assistants, who will be blinded to group  
13  
14 245 allocation at all time-points. Demographic information and self-report measures will be  
15  
16 246 collected using electronic tablets under exam-like conditions. Cognitive testing will occur on  
17  
18 247 University laptops and participants will receive instructions and practice prior to performing  
19  
20 248 each of the cognitive tasks. Self-report and cognitive measures will occur prior to fitness  
21  
22 249 assessments in a randomised order. Anthropometric assessments will be conducted in a  
23  
24 250 sensitive manner by same-sex research staff when possible. Research assistants will provide a  
25  
26 251 brief verbal description and demonstration of each fitness test prior to commencement. The  
27  
28 252 timing for participants to complete all measures is approximately 90 minutes.

29 253

## 30 254 **Primary outcome**

31 255 *Cardiorespiratory fitness*. CRF will be assessed using the Progressive Aerobic  
32  
33 256 Cardiovascular Endurance Run (PACER), using FITNESSGRAM® testing procedures. This  
34  
35 257 test is the most widely accepted field-based measure of CRF, demonstrating high reliability  
36  
37 258 and validity.<sup>51</sup> A 20 m course will be set up on a hard surface with participants instructed to  
38  
39 259 run back and forth between two sets of lines while keeping pace with a pre-recorded cadence  
40  
41 260 (indicated by a single beep for each 20 m shuttle). The test begins at a slow pace (8.5 km/h),  
42  
43 261 and increases by 0.5 km/h with each passing minute (as indicated by a triple beep). The test  
44  
45 262 ends when participants fail to complete a shuttle (20 m lap) before the beep sounds, on two  
46  
47 263 consecutive shuttles, or upon volitional failure. Verbal encouragement will be provided by  
48  
49 264 test administrators in order to maximise participant motivation. The last successful stage will  
50  
51 265 be recorded and converted into the number of 20 m laps completed, which will constitute the  
52  
53 266 primary outcome measure. The total number of laps will be used to estimate maximal aerobic  
54  
55 267 capacity (i.e., VO<sub>2</sub> max), using the following equation:  $45.619 + (0.353 * \text{Pacer laps}) -$   
56  
57 268  $(1.121 * \text{Age})$ .<sup>52</sup> Estimated VO<sub>2</sub> max will be used to classify participants into fitness zones  
58  
59 269 according to criterion-referenced age- and sex-specific cut-offs developed by the Cooper  
60  
270 Institute.<sup>53</sup>

271

## 272 **Secondary outcomes**

273 *Physical activity.* Participants will be instructed to wear an ActiGraph GT9X Link  
274 accelerometer on their non-dominant wrist for 24 hours per day (even when bathing,  
275 swimming and sleeping) for a period of seven consecutive days. Weekday and weekend day  
276 (i.e., mean minutes per day) physical activity will be calculated separately, using existing  
277 thresholds for categorising physical activity into light, moderate and vigorous intensity.<sup>54</sup>  
278 *Muscular fitness.* Upper body muscular endurance will be assessed using the 90-degree push-  
279 up test.<sup>39</sup> Using a cadence of 40 beats per minute, participants lower themselves in a  
280 controlled manner until a 90-degree angle is formed at the elbow before pushing back up. The  
281 test concludes when the participant either fails to lower themselves to the required depth on  
282 two non-consecutive repetitions (warning verbalised by assessor, repetitions counted), fails to  
283 maintain movement in time with the metronome, fails to maintain appropriate technique  
284 (back straight), or upon volitional failure of the test. Lower body muscular power will be  
285 assessed using the standing long jump test.<sup>55</sup> From a standing position behind a line marked  
286 at zero centimetres, participants perform a maximal long jump taking off and landing with  
287 two feet, simultaneously. The test will be performed twice, with the maximal distance jumped  
288 recorded as the participant's final score. Both measures of muscular fitness demonstrate high  
289 validity and reliability in adolescents.<sup>56 57</sup>

290

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

300

301 *Cognitive control.* Using a laptop, specialised software (PsychoPy)<sup>59</sup> will be used to assess  
302 working memory and inhibition. A modified version of an Eriksen flanker task will be used  
303 to measure inhibition, which is a reliable and valid measure in youth.<sup>60</sup> In this task  
304 participants are required to respond (using specific keys) to the direction of the centrally  
305 presented arrow among either 'congruent' or 'incongruent' flanking arrows. Congruent trials

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3 306 consist of five horizontal arrows facing the same direction (i.e., <<<<< or >>>>>), while  
4  
5 307 incongruent trials consist of the central arrow facing the opposite direction to the four  
6  
7 308 flanking arrows (i.e., <<◇<< or >>◇>>). Participants are challenged with a random sequence  
8  
9 309 of congruent and incongruent trials and instructed to identify the direction of the centrally  
10  
11 310 presented, target arrow as quickly and accurately as possible. Following instructions,  
12  
13 311 participants will be presented with a practice block consisting of 25 trials to familiarise  
14  
15 312 themselves with the test. If participants achieve below satisfactory overall accuracy (<70%),  
16  
17 313 they will complete another practice block of 25 trials, and the test administrator will confirm  
18  
19 314 their understanding of the test. Participants then complete an experimental block consisting of  
20  
21 315 150 trials (with an equal distribution of congruent and incongruent). Stimuli are presented for  
22  
23 316 100 milliseconds (ms), with a randomly allocated inter-stimulus interval of 900, 1050, or  
24  
25 317 1200 ms separating each trial. Response time (i.e., the time in ms taken by the participant to  
26  
27 318 press the key associated with the direction of the target arrow) and response accuracy (i.e.,  
28  
29 319 the percentage of trials for which the participant correctly indicated the direction of the target  
30  
31 320 arrow) and will be recorded. An interference score (i.e., the difference in performance  
32  
33 321 outcomes between congruent and incongruent trials) will also be calculated for both accuracy  
34  
35 322 and response time. A lower interference score demonstrates higher inhibitory control.

323 Working memory will be assessed using a serial n-back task, which is a widely used  
324 and reliable measure.<sup>61 62</sup> Two task conditions (i.e., 1-back and 2-back) will be evaluated  
325 which differ in the degree of cognitive demand. In these tasks, participants are presented with  
326 a series of six basic shapes (i.e., square, star, circle, cross, crescent, triangle) and required to  
327 recall (using specific keys) whether the shape currently displayed (trial 'n') matches the  
328 shape immediately prior (1-back, 'n-1'), or two shapes prior (2-back, 'n-2'). For each trial  
329 (within each n-back condition) participants are required to indicate whether the shape is a  
330 match (i.e., target) or not a match (i.e., non-target). Shapes are presented for a duration of 250  
331 ms following a fixed inter-stimulus interval of 2500 ms. Following task instructions,  
332 participants will complete a practice block consisting of 20 trials to ensure understanding. If  
333 overall accuracy is below 70%, participants will complete another practice block, and the test  
334 administrator will confirm their understanding of the test. Each task condition (i.e., 1-back, 2-  
335 back) consists of two blocks of randomised target (n=24) and non-target (n=48) trials, and are  
336 presented in a counterbalanced order. Response time and accuracy will be recorded for both  
337 target shapes (i.e., correctly identifying a match) and non-target shapes (i.e., correctly  
338 identifying a non-match). Additionally, the relative proportion of 'hits' (correct target trials)  
339 to 'false alarms' (incorrect selection on target trial), otherwise known as the d-prime score,



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3 340 will be calculated for both task conditions.<sup>63</sup> A higher d-prime score reflects a greater  
4  
5 341 capacity to differentiate target from non-target shapes when performing the n-back tasks,  
6  
7 342 thereby indicating greater working memory.  
8  
9 343

10 344 *Stress.* Objectively measured stress will be determined by examining the build-up of cortisol  
11 345 within the hair shaft using a sample taken from the vertex at the rear of the head. As human  
12 346 hair grows at a rate of approximately 1 cm per month, each cm is considered to reflect life  
13 347 stressors experienced by the individual over the last month.<sup>64</sup> Cortisol concentrations will be  
14 348 determined from the 3-cm hair segment (maximum) most proximal to the scalp. This will  
15 349 represent the cumulative stress level in the past two to three months. Inter-individual  
16 350 variation in hair growth rate can be factored into analyses by measuring hair growth at the  
17 351 initial sampling site one month later. The intra-individual stability ( $r = .68-.79$ )<sup>65</sup> and validity  
18 352 of hair cortisol as a retrospective index of stress are supported in the literature in adults<sup>66 67</sup>  
19 353 and adolescents.<sup>68</sup> Perceived stress will be self-reported using the Perceived Stress Scale,  
20 354 which is designed to assess the degree to which situations in one's life are stressful.<sup>69</sup>  
21 355 Participants will be required to respond to the 10-item questionnaire in relation to the  
22 356 previous month (e.g., "*In the last month, how often have you felt you were on top of*  
23 357 *things?*"). Responses are scored on a 5-point scale ranging from 0 "*Never*" to 4 "*Very often*"  
24 358 and then summing across all scale items. Higher scores indicate a greater degree of subjective  
25 359 stress experienced by participants.  
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40 361 *Psychological difficulties.* The Strengths and Difficulties Questionnaire will be used to assess  
41 362 psychological distress.<sup>70</sup> The questionnaire consists of 25 items, covering 2 subscales (i.e.,  
42 363 strengths and difficulties). The strengths subscale consists of one domain (prosocial  
43 364 behaviour [e.g., "*I try to be nice to other people. I care about their feelings.*"), and the  
44 365 difficulties subscale consists of four domains: emotional symptoms (e.g., "*I worry a lot.*"),  
45 366 conduct problems (e.g., "*I get very angry and often lose my temper.*"), hyperactivity (e.g., "*I*  
46 367 *am restless, I cannot stay still for long.*"), and peer problems (e.g., "*I would rather be alone*  
47 368 *than with people of my own age.*"). For each item, participants respond using a three-point  
48 369 scale (i.e., "*Not true*" = 0, "*Somewhat true*" = 1, and "*Certainly true*" = 2). For each of the  
49 370 five domains the score can range from 0 to 10. A difficulties composite score will be obtained  
50 371 by adding the scores of all four difficulty domains, with a possible range from 0 to 40. Lower  
51 372 scores indicate fewer psychological difficulties.  
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3 374 *Autonomous motivation.* Motivation for physical activity will be assessed using the  
4  
5 375 ‘Behavioural Regulations in Exercise Questionnaire’.<sup>71</sup> The identified (e.g., “*I value the*  
6  
7 376 *benefits of exercise*”), and intrinsic (e.g., “*I exercise because it’s fun*”) regulation subscales  
8  
9 377 will be used. Responses are scored on a 5-point scale ranging from 0 “*Not true for me*” to 4  
10 378 “*Very true for me*”.

379

13 380 *Basic psychological needs satisfaction.* Friends’ and teachers’ support for exercise will be  
14 381 assessed via the ‘Adolescent Psychological Need Support in Exercise Questionnaire’.<sup>72</sup> Items  
15 382 assess needs satisfaction during exercise across the three psychological needs identified  
16 383 within self-determination theory, namely autonomy support (e.g., “*I feel that they understand*  
17 384 *why I choose to exercise*”), relatedness support (e.g., “*I feel they care about me*”), and  
18 385 competence support (e.g., “*They display confidence in my exercise ability*”). Participants  
19 386 respond using a 7-point Likert scale ranging from 1 “*Strongly disagree*” to 7 “*Strongly*  
20 387 *agree*”.

388

29 389 *Psychological well-being.* Well-being is assessed using the validated Warwick-Edinburgh  
30 390 Mental Wellbeing Scale.<sup>73</sup> The 14-item questionnaire requires participants to reflect on their  
31 391 experiences over the last two weeks. Items are scored on a 5-point scale ranging from 1  
32 392 “*None of the time*” to 5 “*All of the time*”, and summed across all to produce a well-being  
33 393 composite (possible range = 14 to 70).

394

39 395 *Perceived fitness.* Perceived physical fitness will be self-reported using the International  
40 396 Fitness Scale.<sup>74</sup> Participants are required to report perceptions of their ‘general fitness’ and  
41 397 four specific sub-components of health-related fitness. The 5-item instrument is scored on a  
42 398 scale ranging from 1 “*Very poor*” to 5 “*Very good*”. The validity and test-retest reliability of  
43 399 the IFIS has been found to be acceptable among a sample of 9-12 year old youth.<sup>74</sup>

400

50 401 *HIIT self-efficacy.* Self-efficacy for HIIT will be assessed using a 6-item scale developed for  
51 402 the current study. The scale uses the common stem “*If you really wanted to, how confident*  
52 403 *are you that you can...*” and participants respond as follows: 1 “*Not at all confident*” to 10  
53 404 “*Completely confident*”. Sample item- “*maintain a high level of effort right through to the*  
54 405 *end of a HIIT session*”. The mean of the 6-items will be calculated.

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3 407 *Brain structure and function.* To further elucidate exercise-induced neural changes, a target  
4 408 sub-sample of approximately 60 students (i.e., 15 students per school from 4 schools; 2 x  
5 409 intervention group, 2 x control group) identified as being in the bottom 50% of students from  
6 410 their school for CRF (using their baseline PACER test result) will undergo multi-modal  
7 411 magnetic resonance imaging. We have undertaken a systematic review of neuroimaging  
8 412 studies that have examined associations between physical activity, CRF or muscular fitness,  
9 413 and brain structure/function. Preliminary findings from this review informed our multi-modal  
10 414 magnetic resonance imaging protocol to explore changes in the following areas: (i) structural  
11 415 magnetic resonance imaging (T1 and T2-weighted imaging) to identify volumetric changes in  
12 416 white and grey matter of the hippocampus,<sup>75-77</sup> frontal regions/prefrontal cortex,<sup>75</sup> anterior  
13 417 cingulate cortex,<sup>78</sup> and basal ganglia;<sup>79</sup> (ii) diffusion tensor imaging will be used to identify  
14 418 changes in white matter structural connectivity of the superior longitudinal fasciculus and  
15 419 corpus callosum. (iii) resting state functional magnetic resonance imaging will be used to  
16 420 assess changes in activation of the default mode network, cognitive control network, saliency  
17 421 network,<sup>80</sup> hippocampus, and prefrontal cortex;<sup>81 82</sup> (iv) magnetic resonance spectroscopy will  
18 422 be used to identify changes in brain metabolite concentrations (i.e., gamma-aminobutyric  
19 423 acid, N-acetyl Aspartate, adenosine tri-phosphate, and glutamate/glutamine) in the  
20 424 hippocampus and frontal regions/prefrontal cortex.  
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### 36 426 **On-task behaviour**

37 427 Cohort 2 schools will be invited to participate in a sub-study to determine the acute effect of  
38 428 the B2L intervention on students' behaviour in the classroom. Classroom observations will be  
39 429 conducted by trained research assistants at baseline and mid-intervention (week 5 to 8) using  
40 430 established methods.<sup>83 84</sup> During each 30 minute observation period (starting 5-mins after  
41 431 students enter the classroom), research assistants will assess the on- and off-task behaviour of  
42 432 six randomly selected students (5 min per student). For each lesson, two observers will  
43 433 randomly select 12 students (i.e., six boys and six girls) and the order in which they are  
44 434 observed (teachers and students will not know who is being observed). Observers will listen  
45 435 to an MP3 audio file via headphones, which will inform them when to observe and record (in  
46 436 15-sec intervals). After each 10-sec interval, the observers will record the student's behaviour  
47 437 by circling an appropriate code (i.e., actively engaged, passively engaged, off-task motor, off-  
48 438 task verbal or off-task passive) using an observation sheet. After 15 seconds, the observer  
49 439 will then focus on the next student and repeat this process five times until the six students  
50 440 have been observed 20 times. On-task behaviour includes times when the child is actively

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3 441 engaged in an academic activity (e.g., reading, writing, or performing the designated task) or  
4 442 passively engaged (i.e., sitting quietly and listening to the teacher). Off-task behaviour  
5 443 includes times when the student is not engaged in the designated task and can be classified as  
6 444 off-task motor (i.e., walking around the class), off-task verbal (i.e., talking) or off-task  
7 445 passive (i.e., passively not attending to the assigned academic activity). Time spent on- and  
8 446 off-task during the lesson will be expressed as a percentage of total lesson time. Two trained  
9 447 research assistants will be responsible for conducting all observations and inter-rater  
10 448 reliability scores will be established in the training phase.  
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### 19 450 **Process evaluation**

20 451 A detailed process evaluation will be conducted to determine intervention fidelity. Process  
21 452 measures will include: (i) students' mean heart rate from the HIIT sessions (measured using  
22 453 Bluetooth heart rate monitoring technology), (ii) teacher attendance and satisfaction with the  
23 454 professional learning workshop and curriculum materials (workshop evaluation  
24 455 questionnaires), (iii) students' satisfaction with all intervention components (student  
25 456 evaluation questionnaire), (iv) number of practical sessions delivered (school champion logs  
26 457 and session observations), (v) teachers' implementation questionnaire (adapted from an  
27 458 existing questionnaire),<sup>85</sup> (vi) student engagement (objective usage data) with the app, and  
28 459 (vii) practical session fidelity (3 observations per teacher) using the SAAFE observation  
29 460 checklist.<sup>49</sup>  
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### 40 462 **Statistical analyses**

41 463 Analyses of the primary and secondary outcomes will be conducted using linear mixed  
42 464 models in IBM SPSS Statistics for Windows, Version 20.0 (2010 SPSS Inc., IBM Company  
43 465 Armonk, NY), with alpha levels set at  $p < 0.05$ . The models will be used to assess the impact  
44 466 of treatment (B2L or control), time (treated as categorical with levels baseline, 6- and 12-  
45 467 months) and the group-by-time interaction, using random effects to account for the clustered  
46 468 nature of the data. Although randomisation will occur at the school level, statistical analyses  
47 469 will be adjusted for the clustering of effects at the class level, as students from each school  
48 470 are nested in classes. Previous school-based studies have demonstrated that clustering at the  
49 471 school-level is negligible after adjusting for clustering at the class-level.<sup>86 87</sup> However, we  
50 472 will test this assumption and additionally adjust our analyses for school-level clustering if  
51 473 required.<sup>88</sup> Several potential moderators of intervention effects will be explored using  
52 474 interaction tests.<sup>89</sup> Subgroup analyses will be conducted for the following variables if the

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3 475 significance of the group-by-moderator interaction is  $\leq .10$ : Socio-economic status (Low,  
4 476 Medium, High), sex (male, female), baseline weight status (not overweight,  
5 477 overweight/obese), baseline psychological distress (using established cut-offs from the  
6 478 Strengths and Difficulties Questionnaire), and baseline CRF (using FITNESSGRAM fitness  
7 479 standards).

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11 480 Compared to complete case analyses, mixed models include available data for all  
12 481 participants in the analysis and are thus both more efficient and robust to bias. Mixed model  
13 482 analyses are consistent with the intention-to-treat principle, assuming the data are missing at  
14 483 random.<sup>90</sup> The validity of this assumption will be explored by assessing relationships between  
15 484 missingness and observed values of covariates and previous outcomes. A range of sensitivity  
16 485 analyses will be conducted (e.g., multiple imputation and complete-case analysis). In addition  
17 486 to our primary analysis (i.e., intention-to-treat) and sensitivity analyses, we will also conduct  
18 487 two per-protocol analyses (i.e., at the class and student levels, respectively). After  
19 488 consideration of typical school disruptions (i.e., sporting events, school excursions, exams  
20 489 etc.), we estimate that a minimum of 28 exercise sessions offered over the duration of Phases  
21 490 1 and 2 is achievable for schools, and sufficient to observe effects for our primary outcome at  
22 491 the primary end point (i.e., 6-months). Therefore, our class-level per-protocol analysis will  
23 492 include only students from classes in which at least 28 school-based sessions were offered.  
24 493 For our student-level per-protocol analysis, we will include only those students who achieved  
25 494 an average heart-rate of 80% of their age-predicted maximum (220-age) across the  
26 495 intervention period (up until our primary endpoint), using heart-rate data drawn from the B2L  
27 496 smartphone app.

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### 42 498 **Patient and public involvement**

43 499 The need for a time efficient physical activity intervention for older adolescents was  
44 500 identified through consultation with the NSW Department of Education School Sport Unit,  
45 501 who provided initial funding to evaluate the feasibility of the B2L intervention. The pilot  
46 502 study was conducted in two secondary schools in Newcastle (N = 68 students) and  
47 503 participants (i.e., students and teachers) were invited to provide feedback on the intervention  
48 504 and suggestions for further improvement. This feedback was then used to refine the B2L  
49 505 intervention components (e.g., B2L smartphone app) and implementation strategies (e.g.,  
50 506 professional learning for teachers).

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58 507 The findings of the RCT will be published in peer-reviewed journals and the NSW  
59 508 Department of Education and all participating schools will receive a report outlining the

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3 509 study findings at the conclusion of the trial. Burden of the intervention was not assessed prior  
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5 510 to commencing the trial; teacher and student experiences in the intervention will be  
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7 511 determined using a detailed process evaluation questionnaire at post-test.  
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## 10 513 **DISCUSSION**

11 514 Despite the importance of physical activity and fitness for adolescents' physical and mental  
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13 515 health, increasing time demands and academic pressures in the final years of schooling often  
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15 516 drive older adolescents to sacrifice time usually spent being active. Although schools are well  
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17 517 equipped to promote physical activity to adolescents, secondary schools in NSW do not  
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19 518 schedule mandatory physical activity opportunities (e.g., physical education, co-curricular  
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21 519 school sport) for senior school students (i.e., Grades 11 and 12). Lack of physical activity  
22  
23 520 may contribute to the high levels of stress, anxiety, and depression observed in older  
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25 521 adolescents.<sup>91-93</sup> The B2L intervention will be promoted to schools, teachers, students and  
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27 522 parents as a strategy to improve older adolescents' cognitive control and academic  
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29 523 performance (rather than focusing on the metabolic health benefits).

30 524 Phases 1 and 2 of the B2L intervention aim to provide Grade 11 students with  
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32 525 additional physical activity opportunities embedded within the school day in order to increase  
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34 526 fitness and physical activity levels. Phase 3 will provide an opportunity to explore fitness and  
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36 527 behaviour change once the scheduled sessions are no longer facilitated by teachers. We  
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38 528 hypothesize that intervention group participants' fitness levels will decrease during this  
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40 529 period, but remain higher than control group participants. Providing older adolescents with  
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42 530 the knowledge, skills, and opportunities to engage in HIIT may compliment their  
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44 531 participation in other types of leisure-time physical activity. It is therefore important to ensure  
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46 532 that students are equipped with the necessary tools in order to engage in self-directed physical  
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48 533 activity, outside of the school setting. Self-efficacy (i.e., a belief in one's capability or  
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50 534 competence within a specific context) is consistently identified as a central determinant of  
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52 535 human motivation, and exercise adherence.<sup>94</sup> B2L has also been guided by self-determination  
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54 536 theory and designed to satisfy students' basic psychological needs for autonomy (e.g.,  
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56 537 providing choice/allowing students to feel in control), competence (e.g., incorporating  
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58 538 technique cards to develop correct exercise form), and relatedness (e.g., encouraging social  
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60 539 connection and encouragement from others), ultimately impacting on students' autonomous  
60 540 motivation.

61 541 Poor implementation may explain why so many school-based physical activity  
62 542 interventions fail to reach their potential. Lack of time has been noted as the greatest barrier

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3 543 to implementation by teachers<sup>95</sup> and providing robust evidence for the positive effects of  
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5 544 vigorous physical activity on cognitive and mental health outcomes may provide the impetus  
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7 545 for schools to make mandatory physical activity for older adolescents. While several studies  
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9 546 have established that HIIT can be successfully delivered in schools,<sup>96</sup> previous studies have  
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11 547 used research staff members or external providers to deliver HIIT sessions, which is neither  
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13 548 'scalable' nor 'sustainable'. Although we do not have funding to conduct an economic  
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15 549 evaluation, incorporating short breaks into the school day appears to be a cost-effective way  
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17 550 to increase young people's activity levels.<sup>97</sup>

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## 18 552 **ETHICS AND DISSEMINATION**

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20 553 Ethics approval for the RCT was obtained from the Human Research Ethics Committee of the  
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22 554 University of Newcastle, Australia (H-2016-0424) and the NSW Department of Education and  
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24 555 Communities (SERAP: 2017116). School Principals, teachers, parents and students all  
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26 556 provided informed written consent prior to enrolment. It is not expected that participants will  
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28 557 be at any greater risk of adverse events than they would be when participating in other types of  
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30 558 school-based physical activity. However, the teacher handbook includes a section for teachers  
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32 559 to report any injuries or adverse events that may occur. Any amendments to the study protocols  
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34 560 will be publicly available via the Australian and New Zealand Clinical Trials Registry (Trial  
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36 561 number: ACTRN12615000360516). Data management procedures will be conducted by DRL  
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38 562 and SK. All entered data will be de-identified using participant codes and will be stored  
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40 563 electronically in a password protected drive at the University of Newcastle. Quality checks of  
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42 564 entered data will be completed by AL (i.e., range checks). Access to the final trial dataset will  
43  
44 565 comply with the conditions of the ethics committee approval and will be at the discretion of  
45  
46 566 the lead investigator, DRL.

44 567

46 568 **Contributions:** DRL, CH, PJM, RCP, MN, CL, NE and JJS secured funding for the project.  
47  
48 569 DRL, CH, PJM, MN, NE, JJS, SAC, NH and SGK designed the intervention. CH, MN, SV  
49  
50 570 and DRL designed the multimodal magnetic resonance imaging sub-study. CH, TTS and AL  
51  
52 571 designed and contributed to the administration of the cognitive assessments. RW and PG  
53  
54 572 designed the cortisol measurement protocol. EH conducted the power calculation and guided  
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56 573 the statistical analysis. SY and SGK are responsible for project management, school  
57  
58 574 recruitment and data collection. All authors contributed intellectually to the study design and  
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60 575 research methodology, or will. AL and DRL were responsible for drafting the manuscript. All  
576 576 authors provided critical review and endorsed the final version of the manuscript.

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879 **Table 1:** Intervention components and implementation evaluation

Level	Intervention component	Dose	Description	Implementation evaluation
TEACHER	1) Professional learning workshop	1 x 5 hour workshop	Professional development workshop for teachers responsible for facilitating the delivery of the Burn 2 Learn (B2L) program in their school (hereafter referred to as school champions). The workshop will be delivered by members of the research team (i.e., 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 high-intensity interval training (HIIT), and they will also be shown how to use the 'Burn 2 Learn' resources (i.e., HIIT task cards, smartphone application). A condensed online version of the workshop will be provided for school champions that could not attend the face-to-face workshop.	<ul style="list-style-type: none"> <li>• Workshop evaluation questionnaire (following workshop completion by school champions)</li> <li>• Post-program implementation questionnaire (school champions) developed for the current study based on an existing questionnaire.<sup>98</sup></li> </ul>
	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.	<ul style="list-style-type: none"> <li>• Research team will sign-off once completed by school champions in the penultimate session of the workshop.</li> </ul>
	3) Session observations	3 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.	<ul style="list-style-type: none"> <li>• SAAFE observations<sup>49</sup> conducted by research team in Terms 2 and 3.</li> <li>• SAAFE observation conducted by peer teacher in Term 2.</li> </ul>

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	4) Support from research team	On-going	The research team will create a B2L WhatsApp group and invite school champions to join. School champions will be encouraged to use the on-line messaging platform to share challenges and successful strategies.	<ul style="list-style-type: none"> <li>• Post-program implementation questionnaire (school champions)</li> <li>• Analysis of WhatsApp engagement</li> </ul>
SCHOOL	5) Presentation to school staff	1 x 15 minutes	School champions will design a tailored presentation, using pre-designed program resources (i.e., 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 program, and to promote a supportive school climate.	<ul style="list-style-type: none"> <li>• Research team will confirm staff presentation during meeting with school principal.</li> </ul>
	6) Equipment	Once	Schools will be provided with a small equipment pack to assist in the delivery of the B2L program (~AUD\$2500) including: 1 x heart rate monitor/student, 1 x Bluetooth speaker for playing music during sessions, 1 x WASP device (connect Ant+ to WiFi) and a selection of sports equipment (e.g., balls, cones).	<ul style="list-style-type: none"> <li>• Post-program implementation questionnaire (school champions)</li> </ul>
	7) Technique and HIIT session cards	1 x set/school champion	B2L technique cards (i.e., describing key components to perform each exercise) and HIIT session cards (i.e., describing the various HIIT workouts).	<ul style="list-style-type: none"> <li>• Post-program implementation questionnaire (school champions)</li> </ul>
STUDENT	8) Interactive seminar	1 x 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 program 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	<ul style="list-style-type: none"> <li>• Post-program evaluation questionnaire (students)- satisfaction</li> </ul>

			<p>introductory session, students will participate in a practical HIIT session using the B2L smartphone application.</p>	
	<p>9) HIIT sessions</p>	<p>3/week</p>	<p>Sessions will be run at school during curricular time, supported by program resources and the B2L app. In Phases 1 and 2, teachers will be asked to facilitate the delivery of at least two exercise sessions/week across 2 school terms (i.e., 16 weeks) during regularly scheduled lessons. Participants will be able to select from a variety of pre-designed 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 minutes 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 3, 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 utilise the natural environment. Students will be able to select from pre-designed HIIT workouts, which may be delivered for between 8-16 intervals (30 seconds work, 30 seconds rest; 1:1 work to rest ratio). A shorter option (i.e., 8 intervals; 20 seconds work, 10 seconds rest; 2:1 work to rest ratio; 4 minutes) 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</p>	<ul style="list-style-type: none"> <li>• Students' attendance at the activity sessions will be tracked using the B2L app and via teacher recording.</li> <li>• Average heart rate during sessions</li> <li>• Post-program evaluation questionnaire- session preference, barriers to participation (students)</li> </ul>

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			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.	
	10) Smartphone app	On-going	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 6 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 (i.e., 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.	<ul style="list-style-type: none"> <li>• Post-program evaluation questionnaire- satisfaction (students)</li> <li>• B2L app usage and engagement- number of sessions completed, average heart rate</li> </ul>
PARENT	11) e-newsletters for parents	2 x 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.	<ul style="list-style-type: none"> <li>• Post-program evaluation questionnaire (student)</li> </ul>

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3 880 *Note.* B2L = Burn 2 Learn, SAAFE = Supportive, Active, Autonomous, Fair, Enjoyable teaching principles  
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For peer review only

881 **Table 2:** Strategies used to facilitate implementation in the Burn 2 Learn intervention

<b>Domains</b>	<b>Constructs</b>	<b>Strategies</b>
<b>Intervention characteristics</b>	Evidence strength and quality	B2L intervention resources and evidence from 2 pilot studies
	Adaptability	Flexible intervention delivery model (i.e., during class-time, breaks, before or after school) requiring minimal access to facilities (i.e., can be done in the classroom) and equipment (i.e., body weight exercises).
	Complexity	Time efficient, student-directed intervention requiring only two or three 10 minute sessions per week.
	Design quality and packaging	Intervention resources developed by professional graphic designer.
<b>Outer setting (Educational authorities)</b>	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.
<b>Inner setting (Schools)</b>	School culture	Interactive seminar (20 minutes), B2L promotional posters for schools, short video for parents.
	Leadership engagement	Meeting with School Principal to ensure commitment to the program.
	Resources and facilities	Schools provided with B2L session cards, heart rate monitors, WASP device (connect Ant+ to WiFi) and Bluetooth speaker (~\$2,500AUS). 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.
	Organizational incentives	Teacher professional learning workshop accredited with New South Wales Education Standards Authority.
<b>Characteristics of individuals (Teachers)</b>	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.
<b>Implementation process</b>	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 (e.g., What's App).
	Evaluation and feedback	B2L session observations and feedback provided by research team.

882 *Note.* B2L = Burn 2 Learn



884 **Table 3: SAAFE principles and example strategies**

Principle	Definition	Example strategies
Supportive	Sessions are designed to facilitate a supportive environment	<ul style="list-style-type: none"> <li>• Provide constructive feedback</li> <li>• Praise effort and improvement</li> <li>• Encourage supportive behaviour among students</li> </ul>
Active	Sessions involve a high level of movement	<ul style="list-style-type: none"> <li>• Commence sessions quickly</li> <li>• Minimise talk and instruction time</li> <li>• Encourage students to exercise at high-intensity</li> </ul>
Autonomous	Sessions involve elements of choice	<ul style="list-style-type: none"> <li>• Provide students with opportunities of choice (e.g., music, partner, activity)</li> <li>• Minimise controlling language (e.g., ordering students around)</li> <li>• Remind students about the benefits of high intensity activity</li> </ul>
Fair	Sessions provided all students with an opportunity to experience success	<ul style="list-style-type: none"> <li>• Encourage self-comparison rather than peer-comparison</li> <li>• Encourage students to modify exercises to personal fitness and ability level</li> <li>• Treat all students equally and fairly (i.e., high expectations for all)</li> </ul>
Enjoyable	Sessions are designed to be enjoyable and engaging for all students	<ul style="list-style-type: none"> <li>• Play motivational music during exercise sessions</li> <li>• Provide students with a variety of HIIT workout options</li> <li>• Encourage students to reflect on their post exercise affect (i.e., how they are feeling)</li> </ul>

885 **Note.** SAAFE = Supportive, Active, Autonomous, Fair, Enjoyable teaching principles.