Title: Exploring the impact of high intensity interval training on adolescents' objectively measured physical activity: Findings from a randomized controlled trial

Running title: HIIT and adolescents' objectively measured physical activity

Sarah A. Costigan (MPH)
Sarah.Costigan@newcastle.edu.au
Priority Research Centre in Physical Activity and Nutrition, University of Newcastle, Newcastle, NSW, Australia
Deakin University, Geelong, School of Exercise and Nutrition Sciences, Australia

Nicola D. Ridgers (PhD)
nicky.ridgers@deakin.edu.au
Deakin University, Geelong, Institute for Physical Activity and Nutrition (IPAN), School of Exercise and Nutrition Sciences, Australia

Narelle Eather (PhD)
Narelle.Eather@newcastle.edu.au
Priority Research Centre in Physical Activity and Nutrition, University of Newcastle, Newcastle, NSW, Australia

Ronald C. Plotnikoff (PhD)
Ron.Plotnikoff@newcastle.edu.au
Priority Research Centre in Physical Activity and Nutrition, University of Newcastle, Newcastle, NSW, Australia

Nigel Harris (PhD)
Nigel.Harris@aut.ac.nz
Auckland University of Technology, Human Potential Centre, Auckland, New Zealand

David R. Lubans* (PhD)
David.Lubans@newcastle.edu.au
Priority Research Centre in Physical Activity and Nutrition, University of Newcastle, Newcastle, NSW, Australia

*Corresponding author: Professor David Lubans
Phone: 02 4985 4255
Email addresses: David.Lubans@newcastle.edu.au
Postal address: Priority Research Centre for Physical Activity and Nutrition ATC303, University Drive, Callaghan NSW 2308

Introduction: High Intensity Interval Training (HIIT) may be effective for accumulating VPA. However, the contribution of HIIT to overall physical activity is unknown. Our primary aim was to explore the impact of school-based HIIT on physical activity. The secondary aim was to explore within-individual changes in physical activity after participating in HIIT (i.e., compensation).

Methods: Participants [n=65; 15.8(0.6)years] were randomized to a HIIT or control group. Intervention groups participated in three HIIT sessions/week. GENEActiv accelerometers assessed objective physical activity at baseline and week one, to detect changes in MPA and VPA. Intervention effects were examined using linear mixed models and evidence of a change in physical activity (i.e., compensation) were examined using multilevel linear regression models.

Results: The group-by-time interaction effects for MPA and VPA were small and moderate respectively. The adjusted difference between groups for VPA was 1.70 min/day, 95%CI -1.96 to 5.36; *p*=0.354; *d*=0.55).

*Conclusions***:** Embedding HIIT within the school-day had a moderate effect on VPA in comparison to controls. In addition, compensation analyses (i.e., individual level) suggested that adolescents were more active on days when they participated in HIIT. Further studies are needed to test the effects of HIIT on adolescents' physical activity over extended time periods.

Key words: High Intensity Interval Training, HIIT, adolescents, vigorous physical activity, moderate physical activity

Introduction

The benefits of participating in regular physical activity are well established (Reiner, Niermann, Jekauc, & Woll, 2013; Warburton, Nicol, & Bredin, 2007). Current physical activity guidelines recommend adolescents (13–17 years) participate in 60 minutes of moderate-to-vigorous physical activity daily, and also recommend participation in vigorous physical activity (VPA) on three days per week (Department of Health, 2014). Dose-response evidence suggests participating in VPA (>6 METs; (Ainsworth et al., 2000)) has the strongest health benefits (Ortega, Ruiz, Castillo, & Sjöström, 2008; Owens, Galloway, & Gutin, 2015; Swain & Franklin, 2006), and short bouts of vigorous exercise have been shown to result in fitness improvements comparable to longer sessions of lower intensity exercise (Costigan, Eather, Plotnikoff, Taaffe, & Lubans, 2015; Owens et al., 2015).

Regular participation in High Intensity Interval Training (HIIT) has the potential to provide young people with a dose of VPA that can improve their health. HIIT has been previously defined as: (a) short or long intervals (from ≤45s to 2-4 minutes) of high intensity exercise (e.g., ≥85% maximum heart rate) interspersed by short rest periods, or (b) reoccurring short or long (<10-30s) bouts of maximal sprints, interspersed by a rest period between exercises (Buchheit & Laursen, 2013). The inclusion of HIIT within the school-day may be an effective approach for accumulating sufficient VPA.

We recently examined the impact of an 8-week school-based HIIT intervention on adolescents' fitness, mental health and cognitive outcomes (Costigan, Eather, Plotnikoff, Hillman, & Lubans, 2016; Costigan, Eather, Plotnikoff, Taaffe, Pollock, et al., 2015); moderate intervention effects for waist circumference, BMI-z, BMI and executive function, and small but meaningful effects for cardiorespiratory fitness, psychological well-being and perceived appearance were observed for HIIT participants compared to controls (Costigan et al., 2016; Costigan, Eather, Plotnikoff, Taaffe, Pollock, et al., 2015). However, it is unknown if participation in brief HIIT sessions can increase overall physical activity levels.

There is clearly a need to develop and implement strategies to engage adolescents in physical activity of sufficient volume and intensity to accrue health benefits. Although schools are ideal settings for promotion of physical activity, the impact of school-based interventions have been inconsistent and appear to have resulted in limited change to overall physical activity (Borde, Smith, Sutherland, Nathan, & Lubans, 2017). For instance, a meta-analysis examining the efficacy of objectively measured physical activity interventions for youth (n=30 studies) reported school-based physical activity interventions achieved small-to-negligible increases in total activity volume, and small improvements in duration of MVPA (Metcalf, Henley, & Wilkin, 2012).

Although highly debated (Reilly, 2011), some researchers have suggested that the limited improvement in total physical activity observed in school-based interventions may be attributed to an innate physical activity set-point (or ‘activitystat’)(Gomersall, Rowlands, English, Maher, & Olds, 2013). The activitystat hypothesis posits that an individual maintains a steady level of physical activity (or energy expenditure); and therefore if physical activity increases/decreases in one domain (e.g., school day, leisure time, organized activity, etc.) or time of day, compensatory changes will occur to sustain a ‘set point’ (Rowland, 1998). Which could be problematic if benefits from additional activity accrued via school-based programs are negated by decreases in physical activity at other times. While increasing school-based physical activity is a common strategy for improving young people’s health, it is important to determine if physical activity increases within school hours can increase overall physical activity (Long et al., 2013), or if physical activity is reduced at other times (Ridgers, Timperio, Cerin, & Salmon, 2014).

The primary aim of the current study is to explore the impact of a school-based HIIT intervention on participants' objectively-measured physical activity. A secondary aim is explore an important yet under-investigated hypothesis (activitystat) - which is crucial to understand when designing and implementing physical activity interventions. This will be achieved by examining within-individual changes in physical activity in response to HIIT (i.e., evidence of physical activity compensation).

Methods

The study design, participant characteristics and methods have been previously described (Costigan, Eather, Plotnikoff, Taaffe, Pollock, et al., 2015). Ethical approval to conduct the study was granted from the University of Newcastle Human Research Ethics Committee(H-2014-0083) and the study protocol was registered with the Australian and New Zealand Clinical Trials Registry(ACTRN12614000729628). Written informed consent was gained from the school principal, parents and study participants prior to participating in the study. The design, conduct and reporting for this study complied with the Consolidated Standards of Reporting Trials (CONSORT) guidelines (Moher et al., 2010).

Participants

The number of participants involved at each phase of the study is reported in Figure 1. The study sample included 65 adolescents from three Physical Education (PE) classes (45 males, 20 females, mean age: 15.8(0.6) years) in grades 9 and 10 from one secondary school (typical cohort age range 14-16 years).

****INSERT FIGURE 1****

Intervention

After baseline data collection, participants were randomized using a random number-producing algorithm. A stratified random sampling procedure was used to ensure equal numbers of girls and boys were distributed between the three groups. Participants randomized to intervention conditions (Aerobic Exercise Program (AEP) and Resistance and Aerobic Program (RAP)) participated in 24 HIIT sessions (three sessions/week, over eight weeks). Each week, two HIIT sessions were delivered at the beginning of PE lessons and one session delivered at lunchtime. The duration and targeted intensity of HIIT sessions were the same for the AEP and RAP, however the session focus differed. For instance, the AEP sessions involved gross-motor cardiorespiratory exercises (e.g., shuttle runs, jumping jacks, skipping, etc.), participants completed one exercise per work interval. The RAP sessions involved a combination of cardiorespiratory and body-weight resistance training exercises, completed in a sequence during each work interval (e.g., 4 walking lunges, a 10m sprint, 3 push-ups repeated as many times as possible in 30 seconds). Control group participated in usual PE lessons/lunchtime activities.

The AEP and RAP groups engaged in HIIT sessions (short warm-up activity, dynamic stretching, 8-10 minutes HIIT (weeks 1-3: 8 minutes; weeks 4-6: 9 minutes; weeks 7-8: 10 minutes), brief cool down), while the control group completed their typical PE warm-up, stretching and one activity. Once the HIIT session was completed, the intervention and control groups were combined to complete the planned PE lesson. Participants wore Polar H7 heartrate monitors which were connected to a central iPad application (Polar Team). Heart rates were projected on a screen during sessions to encourage adherence to appropriate exercise intensities (e.g.,≥85% of maximum heart rate).

Outcome measures

Assessments were conducted by researchers blinded to group allocation. A training session and assessments protocol manual was provided to research staff.

Objective physical activity was assessed using GENEActiv wrist-worn accelerometers (Model GAT04, Activinsights Ltd, Cambridgeshire, England) (Finn & Specker, 2000). Study participants wore devices during waking/sleeping/aquatic activities for 2-weeks (baseline and intervention week one). GENEActiv wrist-worn accelerometers have demonstrated acceptable intra- and inter-instrumental reliability and provide a valid and reliable estimate of physical activity in youth (Esliger et al., 2011; Phillips, Parfitt, & Rowlands, 2013). Data were converted into five second epochs and used to estimate time spent in MPA and VPA validated using cut-points (Esliger et al., 2011; Phillips et al., 2013).

To determine group changes (HIIT and control groups) in physical activity (aim 1), mean MPA and VPA were used; whereas individual daily MPA and VPA were used to determine evidence of a difference between baseline and intervention days (aim 2).

Process evaluation

GENEActiv compliance

Data were included in the analyses if a participant wore the device for a minimum of 8 hours on three weekdays at baseline and/or week one (intervention), consistent with other studies examining adolescent's physical activity (Ruiz et al., 2011; Smith et al., 2014). Weekdays were of specific interest to identify changes in usual physical activity that may occur when participating in school-based HIIT.

Participant perceptions

At the completion of the intervention HIIT participants were invited to complete a post-intervention evaluation questionnaire which considered perceived enjoyment, motivation, health benefits, future HIIT participation, and fatigue related to HIIT. Participant perceptions of the program related to perceived activity levels were assessed on a 5-point scale with response options ranging from "strongly agree" [5] to "strongly disagree" [1], (dichotomised as 'agree'[4-5] vs. 'disagree'[1-3]). Since compensation could be indicated by changes in physical activity after the session, questions aligning with this hypothesis were asked:

i. After the HIIT session I was tired and did not want to participate in PE
ii. Participating in the HIIT sessions made me less active at school during break times
iii. Participating in the HIIT sessions made me less active after school

Statistical analysis

Physical Activity (Aim 1)

This study was designed to examine the impact of school-based HIIT on adolescents' objectively measured physical activity and test the 'activitystat' hypothesis. More specifically, we sought to determine the dose of physical activity received by participants under optimal conditions.

Comparing baseline with week 1 was considered more appropriate than using another week later in the study period because not all sessions were compulsory and we anticipated that attendance might taper in the final weeks of the intervention. In addition, school weeks 1 and 2 were considered to be more similar than the final weeks of term, which are often disrupted with poor student attendance. For the purposes of this study, GENEActiv data from participants randomized to the AEP and RAP groups were combined for the following reasons. First, both conditions involved the same duration and intensity of activity, despite the sessions involving one (AEP) or two (RAP) training exercises per interval. Second, both conditions were delivered by the same trained research assistants at the start of PE lessons and at lunchtime. Finally, the primary objective of the study was to examine the impact of school-based HIIT on objectively measured physical activity and combining the two HIIT conditions reduced the number of statistical tests and chance of type 2 error.

Statistical analyses of the physical activity outcomes (aim 1) were conducted using linear mixed models with IBM SPSS Statistics for Windows, Version 22.0 (2010 SPSS Inc., IBM Company Armonk, NY). Cohen's *d* was used to provide a measure of effect size (adjusted difference between HIIT and control groups over time divided by the pooled standard deviation of change). The clinical inference of the true value of change scores was derived using a custom made spreadsheet (Hopkins, 2007). A clinical inference was based on the probabilities of harm and benefit for each outcome, and are presented as the chance that the true value of the change scores was beneficial, trivial or harmful (Hopkins, 2007). Our study used the default probabilities (%) and associated descriptors of 0 "most unlikely", 0.5 "very unlikely", 5 "unlikely", 25 "possibly" 75 "likely", 95 "very likely", and 99.5 "most likely" (Hopkins, 2007).

Examining Physical Activity Compensation (Aim 2)

This study also investigated evidence of a change (compensation) in physical activity of participants randomized to the intervention group (aim 2). Data were analysed using STATA version 14 (STATA, 2015). Multilevel linear regression models were conducted to examine associations between each day of data collection for each of the outcomes of interest (MPA, VPA). These models were conducted to account for the nested nature of the data (i.e. multiple days of physical activity data collected within the same participant). They are the most appropriate technique for analysing nested data and as they can estimate effects using incomplete data sets (Twisk, 2006), all valid data points collected were used in the analyses. A two-level model structure was used (Level 1: Day; Level 2: Participant) and the random structure considered random intercepts for participants. All models were adjusted for wear time on a given day. Bonferroni-adjusted post-hoc tests were conducted to identify whether activity levels on a HIIT day differed compared to a usual PE day, usual sport day or a usual non-PE day. It was anticipated that if there was evidence of a difference between a usual PE day and a HIIT day, then compensatory changes in the outcome had occurred. If there was no evidence of a difference between a usual PE day and a HIIT day, then no compensatory changes in the outcome had occurred. The same analytical approach was undertaken using activity levels on an intervention sport day as the outcome variable. The comparison of HIIT days and the sport intervention day to a usual non-PE day identified whether physical activity levels were higher on those days compared to normal (i.e., PE/sport increased daily physical activity levels indicative of an intervention effect).

Results

Physical Activity (Aim 1)

Moderate Physical Activity

Analyses of efficacy (adjusted difference between group and Cohen's *d* effect sizes) identified trivial intervention effects of HIIT for MPA (0.53min, 95% CI -5.18 to 6.24; p=0.853; d=0.04), classified as "very likely trivial" using the Hopkins calculations (Hopkins, 2007).

Vigorous Physical Activity

A moderate intervention effect for VPA was found for HIIT in comparison to the control group (adjusted difference in change 1.70 min, 95% CI-1.96 to 5.36; p=0.354; d=0.55), classified as "possibly positive".

****INSERT TABLE 1****

Examining Physical Activity Compensation (Aim 2)

Moderate physical activity

Post-hoc analyses, adjusting for multiple comparisons using the conservative Bonferroni correction (Table 2), showed there is evidence of a difference between Day 4 (HIIT) and Day 3 (usual school day), with an increase in MPA of 11.61 min (95%CI 1.91 to 21.3); and between Day 4 (HIIT) and Day 1 (baseline PE day), with an increase in MPA of 10.78 min (95%CI 1.33 to 20.24). This indicates daily MPA was higher on the HIIT day compared to a baseline regular school/PE day.

Vigorous physical activity

Differences were observed between Day 4 (HIIT) and Day 3 (usual school day), with an increase in VPA of 8.38 min (95%CI 1.80 to 14.95); and Day 4 (HIIT) and Day 1 (baseline PE day), with an increase in VPA of 7.4 min (95%CI 1.08 to 13.72). This findings suggest that daily VPA was higher on HIIT days compared to usual school days.

****INSERT TABLE 2****

Process evaluation

GENEActiv compliance

GENEActiv wear time (≥8 hours/day, 3 days minimum) was met by 62% and 78% of participants at baseline and during the intervention period (week 1), respectively. Mean wear time was 19.3 hours/day and 19.1 hours/day at baseline and during the intervention period, respectively.

Participants' perceptions

Of the 43 participants randomized to HIIT, 31 (72.1%) completed process evaluation questionnaires (post-intervention). The results revealed 87.1% of participants *disagreed* that after the HIIT session they were tired and did not want to participate in PE, 87.0% *disagreed* that participating in the HIIT sessions made them less active at school breaks, and 80.6% *disagreed* that participating in the HIIT sessions made them less active after-school.

Discussion

The primary aim of this study was to examine the impact of school-based HIIT on objectively measured physical activity. Our findings suggest that the inclusion of HIIT within the school day had a moderate effect on adolescents' VPA. The second aim was to explore within-individual changes in physical activity in response to participating in HIIT. Evidence of a difference in physical activity was observed; MPA and VPA were higher on the first HIIT intervention day, in comparison to a usual school day or PE day at baseline.

Physical Activity (Aim 1)

Participation in physical activity is beneficial for young people, however VPA is particularly potent and even a low dose (e.g., <10 mins) can result in significant physical, mental and cognitive health benefits (Costigan, Eather, Plotnikoff, Taaffe, Pollock, et al., 2015; Rehn, Winett, Wisløff, & Rognmo, 2013). Encouragingly, our school-based HIIT intervention was found to have a moderate effect on adolescents' VPA. Similarly, a meta-analysis examining the effectiveness of interventions for increasing MVPA within PE reported that incorporating short high-intensity activity into usual PE resulted in significantly more MVPA compared to control conditions (absolute difference=16.2%, 95% CI 5.3% to 27.1%, standardized mean difference=1.4, 95%CI 0.3–2.5) (Lonsdale et al., 2013). Despite significant increases in MVPA, time in VPA was not differentiated and the four studies included in the meta-analyses did not include follow-up assessments; therefore the sustained effect is unknown (Lonsdale et al., 2013). In contrast, a 3-week school-based high-intensity dance intervention for girls (11.79±0.3 years), utilizing accelerometers, reported a non-significant 3.0 minute difference in daily MVPA between baseline and re-test (Boddy, Stratton, Hackett, & George, 2010). The small sample size (n=16), short intervention duration and low dose (4 sessions of 6x30second work intervals) may explain the small intervention effect on MVPA observed (Boddy et al., 2010). There appears to be a lack of research specifically reporting how HIIT contributes to overall physical activity, and physical activity of differing intensities. Longitudinal studies examining larger sample sizes that include follow-up assessments are needed.

Examining Physical Activity Compensation (Aim 2)

Our study also investigated whether evidence of physical activity compensation exists for HIIT participants. Our findings suggest a significant increase in daily MPA and VPA on the first day of the intervention, in comparison to a baseline usual school day/PE day. It is possible that students were more motivated at the beginning of the week or needed to experience the first HIIT session before adjusting their overall activity (Sylvester et al., 2014). Further investigation is needed to verify these findings. Our small sample size may limit interpretation of results, and multiple comparisons between various baseline and intervention days may reduce the ability to detect significant changes and inflate type 2 error.

Interestingly, there was no evidence of a difference in MPA or VPA between a sport day at baseline and HIIT days; suggesting that adolescents can achieve equivalent amounts of MPA and VPA in ~10 minutes of HIIT as a ~60 minutes sport session. Regardless of participation in HIIT, school sport contributed to a greater proportion of higher intensity activity compared to PE lessons. While school sport appears effective for accruing VPA, students are typically involved in one session per week, and regular VPA is needed for health gains. Additional school sport may increase VPA, however this is not a practical (Hills, Dengel, & Lubans, 2015), and more scalable approaches which are easy to implement (e.g. HIIT), are needed.

To date, physical activity interventions have had limited effects on adolescents' overall physical activity (Borde et al., 2017). For health gains, effective strategies are needed to maximize opportunities for higher intensity physical activity within the school day. Beets and colleagues (Beets et al., 2016) suggest school based interventions could benefit from utilizing the Theory of Expanded, Extended and Enhanced Opportunities (TEO). This theory suggests that replacing sedentary tasks with active options (expanding), increasing time available for physical activity (extending), and adapting opportunities for activity by increasing the proportion of activity accrued within a timeframe (enhancing), can enhance physical activity (Beets et al., 2016).

There appears to be an absence of research testing the activitystat hypothesis within adolescent populations, and more specifically within HIIT literature. In general, evidence in support of the activitystat hypothesis is limited (Eisenmann & Wickel, 2009; Gomersall et al., 2013; Rowlands, 2009). A recent review conducted by Gomersall and colleagues (Gomersall et al., 2013) reported 63% of studies examining children showed evidence of physical activity compensation, however only eight studies examining children (no adolescent studies were available) were included. Importantly, much of the evidence for physical activity compensation come from cross-sectional observational studies. Design limitations of previous studies, such as measurement issues associated with examining between group changes rather than individual level changes, could have hindered interpretation of results (Ridgers, Timperio, Crawford, & Salmon, 2013); and may explain why intervention effects were evident when comparing group changes in MPA/VPA (baseline vs. intervention) but not in our compensation analyses (i.e., individual level changes). In addition, differences in physical activity (i.e. time of day, school hours, weekday/weekend, etc.) have often been reported, but poorly examined. It may be difficult to gain an accurate account of 'usual' physical activity for adolescents, as physical activity is often highly reflective of timetabling and scheduled activities.

Process evaluation

Some researchers have suggested HIIT is not a feasible strategy for population level health promotion, due to increased risk of injury, reduced exercise adherence, and reduced motivation (Biddle & Batterham, 2015; Hardcastle, Ray, Beale, & Hagger, 2014). However, consistent with other HIIT studies in adolescents (Buchan et al., 2011; Logan et al., 2016), no injuries or adverse events were recorded in the current study. In addition, motivation for and adherence to HIIT may be explained by the short time commitment needed to perform a standard session, and the potential for activity variety included in sessions (Bartlett et al., 2011; Costigan, Eather, Plotnikoff, Taaffe, Pollock, et al., 2015; Sylvester et al., 2014). Encouragingly our process evaluation results indicate HIIT participants weren't more fatigued and less active during PE, school breaks or after-school.

Study strengths and limitations

The strengths of this study include the randomized design, assessor blinding, and use of validated objective physical activity measures. However, some limitations should also be acknowledged and include: a small sample from one secondary school; a relatively short intervention period (potentially limiting generalizability of our findings); and although the study was powered to detect changes in the cardiorespiratory fitness (primary outcome), it may be underpowered to detect changes in physical activity.

Future directions

There is a lack of high quality studies reporting the impact of HIIT on overall physical activity. Further research is needed to confirm if including HIIT within the school setting can increase daily physical activity, or if adolescents reduce physical activity at other times in response to extra in-school activity. Longitudinal studies examining larger sample sizes, which include follow-up assessments, are needed to explore the impact of HIIT on daily physical activity. In addition, longer assessments of objective physical activity are needed to accurately represent adolescents' usual physical activity, whilst also maintaining compliance.

Conclusions

Previous research has reported HIIT to be effective for improving a range of fitness and cognitive outcomes for adolescence; yet there is a lack of research investigating the impact of brief HIIT sessions on adolescents' overall physical activity. The findings of our study suggest that the inclusion of HIIT within the school day had a moderate effect on adolescents' VPA levels. These results are promising, as small increases in VPA can result in meaningful improvements in cardiorespiratory fitness and body composition (Costigan, Eather, Plotnikoff, Taaffe, Pollock, et al., 2015). Moreover, compensation analyses (i.e., individual level) suggested that adolescents accumulated more VPA and MPA on days when they participated in HIIT. Taken together, our study findings do not support the activitystat hypothesis.

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