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Original research

High intensity interval exercise is an effective alternative to moderate intensity exercise for improving glucose tolerance and insulin sensitivity in adolescent boys

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ABSTRACT

Objectives: High-intensity interval exercise (HIIE) may offer a time efficient means to improve health outcomes compared to moderate-intensity exercise (MIE). This study examined the acute effect of HIIE compared to a work-matched bout of MIE on glucose tolerance, insulin sensitivity (IS), resting fat oxidation and exercise enjoyment in adolescent boys.
Design: Within-measures design with counterbalanced experimental conditions.
Methods: Nine boys (14.2 ± 0.4 years) completed three conditions on separate days in a counterbalanced order: (1) HIIE; (2) work matched MIE, both on a cycle ergometer; and (3) rest (CON). An oral glucose tolerance test (OGTT) was performed after exercise or rest and the area under curve (AUC) responses for plasma [glucose] and [insulin] were calculated, and IS estimated (Cederholm index). Energy expenditure and fat oxidation were measured following the OGTT using indirect calorimetry. Exercise enjoyment was assessed using the Physical Activity Enjoyment Scale.
Results: The incremental AUC (iAUC) for plasma [glucose] was reduced following both MIE (−23.9%, $P = 0.013$, effect size [ES] = −0.64) and HIIE (−28.9%, $P = 0.008$, ES = −0.84) compared to CON. The iAUC for plasma [insulin] was lower for HIIE (−24.2%, $P = 0.021$, ES = −0.71) and MIE (−29.1%, $P = 0.012$, ES = −0.79) compared to CON. IS increased by 11.2% after HIIE ($P = 0.03$, ES = 0.76) and 8.4% after MIE ($P = 0.10$, ES = 0.58). There was a trend for an increase in fat oxidation following HIIE ($P = 0.097$, ES = 0.70). Both HIIE and MIE were rated as equally enjoyable ($P > 0.05$, ES < 0.01).
Conclusion: A single bout of time efficient HIIE is an effective alternative to MIE for improving glucose tolerance and IS in adolescent boys immediately after exercise.
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1. Introduction

Insulin resistance (IR) and glucose tolerance are important components of the metabolic syndrome and implicated in the aetiology of type two diabetes (T2D) and cardiovascular disease (CVD).[1] As the origin of such diseases may lie in childhood,[2] the prevention of IR and glucose intolerance in this age group is an important strategy for public health. Physical activity (PA) can play a major role and a recent meta-analysis found a small to moderate effect for exercise training performed over several weeks to improve fasting insulin and IR in youth.[3] However, the optimal form, duration and intensity of exercise to improve glucose tolerance and IR in youth are currently unknown. Furthermore, research is largely based on overweight/obese children and adolescents despite metabolic abnormalities being present in normal weight individuals.[4]

Recent work in adults has shown time efficient, low volume, high-intensity interval exercise (HIIE) to improve health outcomes, including insulin sensitivity (IS).[5] Furthermore, a study on prediabetic adults found a single bout of high-intensity exercise to afford either comparable or superior improvements in IS and glucose tolerance compared to moderate-intensity exercise (MIE).[6] Evidence suggests IS remains elevated up to 17 h after 45 min of aerobic exercise in adolescents with low levels of PA and aerobic fitness,[7] but the impact of a single bout of HIIE on IS and glucose tolerance in youth is currently unknown. This is important to establish as less than a third of boys and girls aged 2–15 years currently meet the recommended daily level of PA within the UK[8] and interventions designed to raise the PA levels in youth only have a small effect.[9]

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The health benefits that can be gained through alternative forms of exercise, such as HIIE, should be considered.

The primary aim of the study is to test the hypothesis that a single bout of HIIE would result in superior improvements in IS and glucose tolerance in normal weight adolescents when compared to a work-matched bout of MIE. The secondary aim is to examine the effect of HIIE and MIE on resting metabolic rate (RMR), fat oxidation and exercise enjoyment.

2. Methods

Nine pubertal boys (age: 14.2 ± 0.40 years, weight: 55.9 ± 12.4 kg, stature: 1.67 ± 0.13 m; body fat: 17.1 ± 4.2%), were recruited from a local school. This sample size was based on the ability to detect a ~30% change in plasma glucose following exercise (alpha = 0.05, power = 0.80) using previous published data.[7] Following an explanation of the study procedures, parental consent and participant assent were obtained. Participants completed an initial health questionnaire and were free from any metabolic or medical conditions. Ethics approval was granted by the institutional ethics committee.

This cross-over study consisted of four laboratory visits, separated by approximately 1 week. Visits included an initial familiarisation session and three experimental conditions in a temperature controlled laboratory. All procedures were identical during the experimental conditions apart from the exercise or rest period undertaken. All exercise was performed on a cycle ergometer (Lode Excalibur Sport, Gronigen, Netherlands).

During visit 1 stature and body mass were measured to the nearest 0.1 cm and 0.1 kg. Body fat percentage was estimated using skinfold measurements from the triceps and subscapular sites.[10] Pubertal status was determined by self-assessment of the five Tanner stages of pubic hair development.[11] Participants were familiarised with the cycle ergometer and completed a combined ramp-incremental and supramaximal test to exhaustion to determine maximal O_2 uptake ($\dot{V}O_{2,max}$) and the gas exchange threshold (GET).[12] Pulmonary gas exchange and heart rate were measured (Cortex Metalyzer III B, Germany) and $\dot{V}O_{2,max}$ was accepted as the highest 10 s average $\dot{V}O_2$ during the ramp or supra-maximal test. The GET was estimated at the point where the first disproportionate increases in CO_2 production compared to $\dot{V}O_2$ and verified using the ventilatory equivalents for $\dot{V}O_2$ and $\dot{V}CO_2$.

For visits 2–4 participants arrived at the laboratory at ~08:00 following a 12 h overnight fast. After 10 min of seated rest, participants provided a capillary blood sample for plasma [glucose] and [insulin]. Baseline resting metabolic rate (RMR) and fat oxidation were determined *via* indirect calorimetry (Cortex Metalyzer II, Leipzig, Germany) over a 10 min period.

At ~08:30 participants undertook one of the following conditions in a counterbalanced order: (1) HIIE: 3 min warm up at 20 W followed by eight repeated bouts of 1 min cycling at 90% of the peak power, interspersed with 1.25 min recovery at 20 W, followed by a 3 min cool down at 20 W; (2) MIE: continuous cycling at 90% GET, the duration of which was determined to match the mechanical work-done during HIIE; and (3) rest (CON). Throughout the exercise conditions gas exchange and heart rate were monitored. Participants provided a rating of perceived exertion (RPE) every 5 min during MIE and immediately following each 1 min interval during HIIE.[13] Immediately after each exercise condition participants completed the 16-point Physical Activity Enjoyment Scale (PACES).[14]

Ten minutes after completion of each experimental condition, an oral glucose tolerance test (OGTT) took place. Participants consumed 75 g glucose in 300 mL of water with capillary blood samples taken at 0, 10, 20, 30, 60, 90 and 120 min for assessment of plasma [glucose] and [insulin]. RMR was assessed at 60, 120 and 180 min post OGTT. During the 3 h postprandial measurement period, no other food was consumed although water was available *ad libitum*. This was recorded for the first experimental condition and replicated for the remaining conditions. Participants remained in the laboratory throughout the visit, completing sedentary activities. Participants left the laboratory at ~13:00.

PA was measured during the 48 h period prior to each condition using a wrist worn accelerometer (GENEActiv, GENEA, UK). Data were converted into 1 min epochs and used to estimate the time spent during sedentary, light, moderate and vigorous PA using validated cut points.[15] Participants were asked to avoid any organised sport during this period.

With supervision from their parents/guardians, a food diary was completed by each participant during the 48 h period preceding each experimental condition. Food diaries were assessed for total energy and macronutrient content using commercially available software (CompEat Pro, Nutrition systems, UK). Participants were asked to replicate their diet during the 48 h preceding each experimental condition, and to document any discrepancies.

Fingertip capillary blood samples (~600 μL) were taken from a pre-warmed hand into a heparin fluoride coated and lithium heparin coated microvette (CB 300 tubes, Sarstedt Ltd., Leicester, UK) for plasma [glucose] and [insulin] determination respectively. Microvettes were centrifuged at 6000 revolutions per min for 10 min. Plasma was separated for immediate analysis of [glucose] (YSI 2300 Stat Plus Glucose analyser, Yellow Springs, OH, USA) or stored at −80 °C for later analysis of plasma [insulin] using an ELISA enzyme immunoassay kit (DRG Diagnostics, Germany). The within batch coefficient of variation for the plasma [insulin] and [glucose] analyses was <5%.

Changes in plasma [glucose] and [insulin] during the OGTT were quantified using total and incremental area under the curve (tAUC, iAUC) analyses employing the trapezium rule (GraphPad Prism, San Diego, CA). In line with previous HIIE studies,[9,5] the Cederholm index was used to estimate IS, which represents peripheral IS.[16] RMR and the absolute fat and carbohydrate oxidation were estimated using the mean $\dot{V}O_2$ and respiratory exchange ratio for each 10 min measurement.[17] AUC was used to document changes in RMR and fat oxidation following the OGTT.

Descriptive statistics were calculated using SPSS (version 19.0, Chicago, USA) and presented as mean ± SD. Mean differences in the physiological and perceptual responses during HIIE and MIE were analysed using paired samples *t* tests. Analyses of fasting measures, IS and the AUC analyses across conditions were performed using repeated measures ANOVA. Pairwise comparisons between means were interpreted using *P*-values along with standardised effect sizes (*ES*) to detail the magnitude of the effect using the following thresholds: trivial (<0.2), small (>0.2), moderate (>0.5), large (>0.8), and very large (>1.0).[18] Results are presented as (*P* value, ES), unless stated otherwise.

3. Results

Participants' Tanner stage ranged between 2 and 5 (stage 5: $n = 1$, stage 4: $n = 7$, stage 2: $n = 1$). The combined ramp-incremental and supramaximal test elicited a peak power of 225 ± 42 W, $\dot{V}O_{2,max}$ of 46.5 ± 9.6 mL kg^{-1} min^{-1}, and a GET of 1.42 ± 0.36 L min^{-1} (55.4 ± 7.0% $\dot{V}O_{2,max}$).

Time spent in light, moderate and vigorous PA in the 48 h preceding each condition was similar across conditions ($P > 0.05$, data not reported). Likewise, carbohydrate, fat and protein intake were similar in the 48 h prior to each visit ($P > 0.05$, data not reported).

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