Journal of Strength and Conditioning Research Publish Ahead of Print
DOI: 10.1519/JSC.0000000000001590

ACUTE RESPONSES TO RESISTANCE AND HIGH INTENSITY INTERVAL TRAINING IN ADOLESCENTS

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ABSTRACT

The purpose of this study was to compare the acute physiological responses within and between resistance training (RT) and high intensity interval training (HIIT) matched for time and with comparable effort, in a school setting. Seventeen early adolescents (12.9 ± 0.3 y) performed both RT (2-5 repetitions perceived short of failure at the end of each set) and HIIT (90% of age predicted maximum heart rate), equated for total work set and recovery period durations comprising of 12 'sets' of 30 s work followed by 30 s recovery (total session time 12 min). Variables of interest included oxygen consumption, set and session heart rate (HR) and rate of perceived exertion (RPE), and change in salivary cortisol (SC), salivary alpha amylase (SαA), and blood lactate (BL) from pre- to post-session. Analyses were conducted to determine responses within and between the two different protocols. For both RT and HIIT there were very large increases pre- to post-trial for SC and BL, and only BL increased greater in HIIT (9.1 ± 2.6 mmol·L^{-1}) than RT (6.8 ± 3.3 mmol·L^{-1}). Mean set HR for both RT (170 ± 9.1 bpm) and HIIT (179 ± 5.6 bpm) was at least 85% of HR maximum. VO_2 over all 12 sets was greater for HIIT (33.8 ± 5.21 mL·kg^{-1}·min^{-1}) than RT (24.9 ± 3.23 mL·kg^{-1}·min^{-1}). Brief, repetitive, intermittent forays into high, but not supra-maximal intensity exercise utilising either RT or HIIT appeared to be a potent physiological stimulus in adolescents.

KEYWORDS: Energy Expenditure, Physiological, Metabolic, Pubescent, Youth

INTRODUCTION

High intensity interval (intermittent) training (HIIT) is now acknowledged as a potent exercise modality, if not yet universally accepted as a viable public health strategy (4). Most research on HIIT has focussed on training induced adaptation resultant from interventions, often comparing relative efficacy with lower or moderate intensity steady state exercise, and often utilising young male adults as the subject cohort, in laboratory settings. Recent reviews (15,26) detailed studies investigating the general health outcomes of HIIT interventions in adolescents and concluded that the evidence, although limited, supports its efficacy and feasibility with the youth cohort. Less evidence is available for the acute physiological responses to HIIT in adolescent populations. Some research has detailed the physiological and endocrine responses in youth during short sprint bursts, such as a Wingate style 30 s maximal cycle sprint (2,10,18), supra-maximal 4 min intermittent efforts (13), and repeated sets of 1 min work interspersed with 1 min recovery (37). Some age (6) and body composition status (13) specific responses to exercise in general are apparent, although it is often dependent on the variables measured (40). There is however a paucity of research specifically investigating the acute physiological responses to HIIT in youth particularly in real world settings, such as schools.

Resistance training (RT) is a recommended component of general activity guidelines for youth (19), and general muscular fitness is associated with health related benefits in this cohort (35). A large and expanding body of evidence underpins the recommendations across a wide variety of populations including children and adolescents, but similarly to HIIT research, limited information on the acute physiological responses to resistance training in adolescents exists, although a recent review thoroughly details endocrine responses (20). To our knowledge, no research has specifically compared the acute responses to HIIT with equi-

time and comparable effort RT in adolescents. Such an approach would serve to better detail some fundamental mechanisms underpinning potential training induced adaptations. It would also determine if RT could potentially provide meaningful improvements that enhance not only the known neuromuscular adaptations resultant from recommended training parameters, but also positive cardiorespiratory adaptations associated with typical cardiovascular training modalities. Additionally, intensity prescription for HIIT typically uses a target output such as percentage of maximum heart rate or previously established maximum workload. Intensity or 'effort' in RT typically prescribes loads based on prior assessment of actual or estimated one repetition maximum (1RM) or on perception of effort, and is traditionally structured with the intention of eliciting predominantly neuromuscular adaptations.

Hence the primary purpose of this study was to describe and compare the acute responses for oxygen consumption, salivary cortisol (SC) and alpha amylase (SαA), blood lactate (BL), heart rate (HR), and both set and session rate of perceived exertion (RPE) within and between equi-time and comparable effort sessions of RT and HIIT in early adolescents, in a school setting where HIIT was structured to elicit a target HR and RT a target load effort.

METHODS

Experimental approach to the problem

All subjects acted as their own control in a repeated-measures, randomized crossover design in which subjects performed both RT and HIIT, separated by at least three days. Subject groups were divided so nine individuals performed RT first, and eight performed HIIT first. Trials were exactly equated for total work set and recovery period durations comprising of 12 'sets' of 30 s 'work' followed by 30 s recovery. Testing was conducted in-school within an

unoccupied classroom at various times over a normal school day (between 9 AM and 3 PM), but each subject performed both trials at the same time of day to account for diurnal variation in key physiological measures. Subjects were asked to perform each trial with identical 16 h pre-trial preparation such as nutrition, activity, exercise, and sleep (as practicably as possible). Variables of interest included oxygen consumption via gas analysis, total energy expenditure (TEE) via indirect calorimetry, SC and SαA, BL, HR, and both set and session RPE. Analyses were conducted to determine within and between trial differences in these variables.

Subjects

After approval from the institutional ethics committee, students from three class groups in year eight (N=77, typical age for year group 12-13 y) within one school were invited to participate in this study. Individuals were eligible to participate if they were able to be regularly involved in the physical aspects of the compulsory physical education curriculum, and did not have any medical or orthopaedic issues that would either limit their ability to participate in strenuous exercise or confound the key physiological measurements. The number of subjects was limited to 18 given practical resourcing requirements. Hence, one week after an information session was delivered and information sheets provided, all those who had provided signed informed assent and guardian informed consent were at that stage eligible for randomised selection to be part of the study (N=25). One subject later withdrew owing to a serious injury unrelated to this study, henceforth all subsequent data represents N=17 (M=8, F=9). Subject baseline characteristics are presented in Table 1. The age offset from peak height velocity (PHV), termed ‘maturity offset’ was estimated from age and anthropometric measurements (body mass, standing height, and sitting height) (29). Generally, the cohort represented a cross-section of activity levels with some subjects

actively involved in intra- and extra-curricular sports, some in recreational sport, and others not engaged in any structured physical activity outside the compulsory physical education curriculum.

****Table 1 about here****

Procedure

Standardized, progressive familiarization period. For a total of four weeks prior to performance of the acute physiological response sessions, all subjects actively participated in thrice weekly progressive familiarization sessions. The intention of these sessions was to ensure all subjects gained sufficient movement competency required to perform the resistance training exercises, and to progressively become familiarized with the requisite intensity, modalities, session structure, and equipment used (including all testing procedures). Twice weekly, and typically separated by two to three days, RT sessions were delivered by at least two supervising New Zealand Registered Exercise Professionals (NZ REP). These sessions initially focussed on unloaded general movement competency and technique, then some gradual and progressive increase in loading. For the final three sessions the resistance training sessions were performed with individually prescribed loads. The exercises used during the sessions focussed on squats, push-ups, and a modified pull-up (supine pull), but derivatives of all three exercises were also included to add variety to the sessions (36). Loading was body mass only utilizing body position for load alteration, except some subjects utilized a sand bag as external resistance for the squat. Once weekly HIIT sessions were delivered by a NZ REP, to introduce use of the cycle ergometers (Monark 824™, Vansbro, Sweden) and non-contact boxing technique using a hanging boxing bag and a 40cm handheld round pad. Subjects wore boxing gloves and were coached in fundamental techniques, including basic combinations. In a similar manner to the RT sessions, the initial focus was on

technique, safety, and familiarization with session structure, HR monitoring and RPE usage, before incrementally progressing intensity. Target HR's were communicated and all subjects were encouraged to reach their target by both peers and supervising NZ REP.

Physical profiling. During the familiarization phase prior to the acute physiological response trials, all subjects were assessed for general fitness using protocols based ostensibly on the 'FITNESSGRAM®' assessment battery (1). Briefly, the tests were: aerobic capacity with a multistage 20m shuttle run; a 90° push-up to failure; a supine pull; and grip strength. The assessment results provided a physical characteristic profile of subjects and allowed an estimation of effort relative to maximums during the acute physiological response trials.

RT acute physiological response trial. After collection of the baseline saliva sample and BL, the subjects were fitted with the face-mask connected to the online gas analysis system (Metalyzer 3B system™; CORTEX Biophysik GmbH, Leipzig, Germany) and HR monitor (Polar™, Finland). An 8-10 min seated passive period ensued in which baseline VO_2 and HR data were averaged over the final 5 min once real-time data indicated a steady state resting plateau. The passive period was conducted seated in a classroom in which there was only occasional incidental activity, otherwise it was quiet within the context of an operating school environment at various times of the school day. A standardized warm-up period consisting of 3 min of stationary cycling at approximately 70 W was then performed. Following that, subjects performed two sets of each of the three exercises used. The first set was performed for eight repetitions at a slow pace using effectively very light loads by adjusting body position. The next set was performed using 10 repetitions at a perceived medium load by adjusting body position or, for the squat, holding a sand bag. Dynamic stretching consisting of a variety of leg and arm swing movements was then performed for a total of approximately

1 min. The total duration of these warm-up activities including transitions was approximately 6 min. Once completed, an approximately 1 min period ensued in which the researcher reiterated session instructions and the subjects assumed the starting position for the first exercise. For the main trials, during which physiological data was monitored, three exercises (wide stance squat, push-up, and the supine pull) were performed in sequence for exactly 30 s each, followed by a 30 s passive rest period, and repeated four times consecutively in that order for a total of 12 work sets as detailed in Table 2. Load was prescribed based on completion of approximately 10-15 repetitions at a perceived effort level of approximately 2-5 repetitions short of failure at the end of each set, determined by specifically asking 'how many more do you think you could have done?', with load adjustments made accordingly after each set if needed. Additionally, a set RPE of ≥7 was targeted. The structure was designed to meet stated guidelines for youth resistance training (19), but in a time efficient manner by structuring the order of the exercises to allow the appropriate rest between repeated efforts on the same muscle group, and also conceivably result in work intensity equivalent of at least a so-called 'vigorous' category (21) level.

****Table 1 about here****

HIIT acute physiological response trial. After baseline measures were completed as per the RT trial, a standardized warm-up period consisting of 4 min of stationary cycling at incrementally increasing load (from 50 W to 100 W) was first performed. Within the last 1 min of the warm-up period, two 'bursts' of 10 s each at approximately the target workload were performed. Subjects then dismounted the cycle to perform 1 min of non-contact boxing with general instructions on basic combinations to be used. One burst of 15 s hard boxing was included. General dynamic stretching including arm 'swinging' was then performed. The

subject then returned to the cycle ready to commence the trial whilst key instructions were reiterated.

The structure of the trial after warm-up was: 3 sets of 30 s work on the cycle, then 3 sets of 30 s boxing, then another 3 sets on the cycle and finally 3 more sets of boxing to total 12 work sets as per the RT trial. Boxing sets were conducted using the 40 cm round target pad used in familiarization. All work sets were interspersed with 30 s passive recovery, during which subjects either remained seated on the cycle or simply stood between boxing sets. The prescribed work set intensity was target HR 90% of age predicted maximum (HR_{max}) and ≥7 RPE. Work set load was prescribed in reference to individual HR responses from the previous familiarization sessions with minor adjustments made during trial sessions as needed to meet the target HR. External encouragement to reach target HR was used consistently throughout HIIT.

SC and SαA. Saliva was collected at passive baseline immediately prior to starting each trial, and then again at 10 min post completion of the final work set. Subjects were asked to abstain from brushing their teeth or eating for 60 min prior to testing. Subjects were instructed to first thoroughly rinse their mouth with warm water and spit the rinse, then after approximately 1 min an un-stimulated (passive drool) whole saliva sample was collected into a sterile bijou tube (7 ml-capacity with screw top, Labserve™, Auckland, NZ) with subjects seated, leaning forward, and their heads tilted down. Care was taken to allow saliva to dribble into the collection vial with minimal orofacial movement. Following collection, saliva volume was estimated by weighing to the nearest mg assuming saliva density to be $1.0 g \cdot ml^{-1}$ (14). Saliva flow rate ($ml \cdot min^{-1}$) was calculated by dividing the volume of saliva by collection time. Of the 17 subjects there were 5 (all female) who were unable to produce the

minimum required saliva volume, hence saliva collection for these subjects was abandoned and no subsequent SC or SαA analyses performed. Samples were immediately refrigerated at 4°C for up to 4 h, centrifuged at 1400 rpm for 4 minutes, transferred into 1.5ml Eppendorf™ containers, then stored at -20°C until subsequent analysis. This procedure resulted in a clear supernatant of low viscosity. The SC concentrations were measured in $nmol \cdot L^{-1}$ using specific assays on a Roche Diagnostics™ Modular Analytics E170 instrument at the Auckland University of Technology-Roche Diagnostics Laboratory. SαA activity was measured using a commercially available kit (Infinity™ α-Amylase Liquid S Reagent, Thermo Scientific, UK), with proportional reduction of volumes so that the assay could be carried out in a 96-well microplate. Briefly, sample analysis was performed in duplicate using 20 µl of saliva, diluted 1:100 with 1.0 mM $CaCl_2$, which was then mixed with 180 µl of Infinity reagent. The plate was incubated at room temperature for 1 min and the increase in absorbance at 405 nm was recorded for minutes 1 and 3 on an automated plate reader (Multiskan GO Microplate Spectrophotometer, Thermo Scientific™, UK). The difference in absorbance per minute was multiplied by 2515, which is a reagent and temperature specific factor provided by the manufacturer of the amylase reagent. The secretion rate of SαA ($U \cdot min^{-1}$) was calculated by multiplying saliva flow rate ($mL \cdot min^{-1}$) by the concentration of SαA ($U \cdot ml^{-1}$). All samples from one subject were analyzed on the same microplate. The intra-assay coefficient of variation was 1.3%.

BL. Whole blood was taken via fingertip puncture at resting baseline prior to each trial and measured at 5 min post completion of the final work set using a spring loadable lancet (Safe-T-Pro Plus™, Germany). A lactate analysis unit (Lactate Pro™, Arkray, Japan) was used to determine BL ($mmol \cdot L^{-1}$).

*HR***.** HR was recorded immediately post each work and recovery set, and every 1 min for 10 min post completion of the final work set using a heart rate strap and watch. HR_{max} was based on the formula 208 - (0.7 x age) given greater validity for an adolescent population (27).

RPE. At the end of each work set subjects were asked to manually signal without verbalising their RPE on a visually presented 'Omni' scale from 1-10 (33). At the completion of the 10 min post trial phase and saliva collection, subjects were also asked their overall 'session RPE' from 1-10 (28) by responding to the question "how hard was your workout?" and a visually presented Omni scale.

Oxygen consumption. Gas exchange was measured using breath-by-breath gas analysis. The metabolic cart was calibrated with known gas concentrations, and volume using a 3 L syringe. Calibration was performed at the start of each assessment occasion, and where there were consecutive subjects within occasion, prior to every second subject. The face-mask was fitted to the subjects prior to the baseline passive measurement period and remained on and recording data until the 10 min post-trial passive recovery data collection period was complete.

Calculation of energy expenditure. For the work sets, aerobic energy expenditure (EE) in kilocalories per kg body mass ($kcal \cdot kg^{-1}$) was estimated by multiplying breath-by-breath absolute VO_2 ($L \cdot min^{-1}$) by 5.05 $kcal \cdot L^{-1}$ given that all respiratory exchange ratios (RER) were ≥1.0. Anaerobic EE was estimated based on equations used by Scott et al. (34): that is, difference between peak BL and baseline BL x bodymass (kg) x 3 mL O_2, converted to L O_2 and multiplied by 5.024 kcal. Aerobic and anaerobic EE were then summed to give EE for work sets. For the inter-set recovery periods and the 10 min post trial passive recovery

period, VO_2 was multiplied by 4.7 kcal·L^{-1} (34). TEE from the start of the first work set after the warm-up to the end of the 12th work set was then calculated as the sum of work set aerobic and anaerobic EE + recovery set EE, expressed as an absolute value (kcal) and relative to body mass (kcal·kg^{-1}). The 10 min passive recovery period EE was also recorded. Metabolic equivalent (METS) were also used to describe EE.

Statistical Analyses

Descriptive data are presented as mean ± SD. Pre- and post-trial data are presented as means with 95% confidence intervals. Linear modelling on SPSS software (version 22, SPSS Inc, Chicago, IL) was used to determine differences within and between RT and HIIT trials using interaction terms for: 1) sex (boys versus girls), and 2) baseline value (α=0.05). Cohen's d was used to provide a measure of effect size (ES) for the mean difference (post-test minus baseline) between RT and HIIT divided by the standard deviation, expressed as <0.2 = trivial, 0.2-0.5 = small, 0.5-1.1 = moderate, 1.2-1.9 = large, 2.0 or more = very large, and 4.0 or more = extremely large (24).

RESULTS

All subjects completed both RT and HIIT with the exception of two reporting discomfort with the face mask after 10 work sets during HIIT at which point it was removed and no further gas analysis data collected.

Figures 1 and 2 present group means for VO_2 and HR respectively for both RT and HIIT for each of the 12 work and recovery sets, and 10 min post trial. The x-y axis intercept represents immediate pre-trial baseline values.

****Figures 1 and 2 about here****

Table 3 details SC, SαA, BL, VO_2, and HR, values immediately pre-trial baseline within and between the RT and HIIT trials with Cohen's d and p values. Set and session RPE are also presented. Mean VO_2 over all 12 work sets was higher (ES 2.77; 95% CI 0.80, 3.81) for HIIT than RT. Mean HR over all 12 work sets (169.9 ± 9.2 bpm for RT and 179.0 ± 5.6 bpm for HIIT) represented 85% and 90% of HR_{max} for RT and HIIT respectively and was greater in HIIT than RT (ES 1.87; 95% CI -0.79, 6.23). TEE was greater ($p \leq 0.001$) for HIIT (136 ± 28.1 kcal, 2.6 ± 0.4 kcal·kg^{-1}) than RT (104 ± 30.7 kcal, 2.0 ± 0.4 kcal·kg^{-1}). In HIIT, VO_2 was greater ($p \leq 0.000$) for the six cycle than the six boxing sets, but HR was not. In RT, HR was greater for the squat exercise (178 ± 8.5 bpm) than both push-ups (167 ± 12.1 bpm) and supine pulls (165 ± 10.3 bpm) but VO_2 was not. Both VO_2 and HR remained elevated ($p \leq 0.000$) for the 10 min post exercise recovery period compared to baseline. Mean METS was 7.0 ± 0.32 for RT and 9.5 ± 0.41 for HIIT.

****Table 3 about here****

Figure 3 presents individual pre- and post-trial values for SC, SαA concentration, and BL within and between RT and HIIT for all subjects, and group means. There were very large increases pre- to post-trial in SC for both RT and HIIT but only a small difference between trials. SαA concentration increased moderately for RT and HIIT, and the difference between trials was trivial. SαA secretion rates increased trivially for both trials (ES 0.14, p=>0.05). Peak BL 5 min post-trial was extremely large compared to baseline, and that increase was greater (ES 0.72 p=0.046) in HIIT than RT.

****Figure 3 about here****

DISCUSSION

We found that a 12 min session of RT comprising 12, 30 s sets of multi-joint exercises performed at an effort level perceived as close to volitional failure, interspersed with 30 s passive recovery elicited physiological responses that would result in both positive general neuromuscular and cardiovascular adaptations if performed with the requisite weekly frequency, as it is known to in deconditioned adults (30). When compared to HIIT utilising matched durations for both work and recovery sets, for total duration, and structured specifically to elicit 90% HR_{max}, HR was lower in RT than HIIT, possibly owing to the horizontal body positions of two exercises, but still within the so-called 'vigorous' intensity zone (21). Our results are consistent with Pullinen et al.'s (31) findings, who noted a peak HR of 179 ± 7 bpm in adolescent boys (14 ± 0 y) in response to a resistance training protocol of 5 sets of 10 repetitions (set duration ~20 s) of a knee extension exercise at 40% of one repetition maximum interspersed with a 40 s recovery period, then two further sets to failure (18-23 repetitions). The VO_2 for RT in the present study was comparable to the multitude of studies investigating VO_2 during RT in adults. For example, Ratamess et al. (32) measured the VO_2 during several different RT exercises over multiple sets and reported mean VO_2 of 19.6 $mL \cdot kg^{-1} \cdot min^{-1}$ for the squat during sets of ~37 s duration although the mean HR was only 135 bpm, but the push-up elicited only 11.9 $mL \cdot kg^{-1} \cdot min^{-1}$ and 117 bpm. Our findings provide reference values for VO_2 response during RT of common, accessible exercises for adolescents in a school setting. The structure of RT allowed for four sets of 30 s hard efforts per exercise but in a format allowing 2 min 30 s between sets per muscle group, whilst other exercises were performed. The included passive rest phases are arguably requisite to allow

repeated localised strenuous muscular contractions and general effort over the duration of the session (5) in order elicit the associated suite of positive neuromuscular adaptations (19,35).

The HIIT responses we observed are similar to those reported in the few other studies detailing acute responses to some form of HIIT in young adolescents (7,13,18,37). Engel et al., (18) utilized four repeated 30 s Wingate anaerobic tests interspersed with a two min active recovery phase in boys (11.5 ± 0.8 y) from a soccer academy. Peak heart rate during the session was 174 ± 11 bpm, but VO_2 peak (42.3 ± 5.6 $mL \cdot kg^{-1} \cdot min^{-1}$) was greater than the work set mean VO_2 we observed for HIIT; although, the mean VO_2 for our six cycle sets was 37.6 ± 6.6 $mL \cdot kg^{-1} \cdot min^{-1}$, thus the session difference is attributable to lower relative VO_2 observed in the six boxing sets (29.8 ± 6.04 $mL \cdot kg^{-1} \cdot min^{-1}$). Bond et al., (7) reported that eight repeats of 1 min cycling at 90% of previously established peak power interspersed with 1 min light active recovery periods in adolescent males (14.1 ± 0.3 y) resulted in lower mean HR (150 ± 14 bpm) and VO_2 (~26 $mL \cdot kg^{-1} \cdot min^{-1}$ [extrapolated]) than both our findings and those of Engel et al. (18), although a similar protocol (37) produced 194 ± 8 bpm in the final of 10 sets of 1 min work at maximal aerobic speed in boys (11.8 ± 0.4 y). Patently, physiological responses are resultant from the combination of set duration, workload prescription, and total session duration, with sessions normally based on achieving prescribed outputs. Subject characteristics may also influence results. For example, Chuensiri et al., (13) reported the responses of lean and obese boys (age ~10 y) to workloads of 100%, 130%, and 170% VO_2 peak for eight repeats of 20 sec cycling bursts interspersed with 10 sec passive rest. The obese boys group VO_2 ranged from 31 to 36 $mL \cdot kg^{-1} \cdot min^{-1}$ (from 100% to 170% VO_2 peak intensities respectively), and for the lean boys 39 to 49 $mL \cdot kg^{-1} \cdot min^{-1}$, a significant difference, not surprising given the 11 $mL \cdot kg^{-1} \cdot min^{-1}$ lower baseline VO_2 peak of

the obese boys. HR response was not different within or between groups, ranging from 188 to 196 bpm across the intensity range in the obese boys and 186 to 192 bpm in the lean.

A limitation of the present study is that we did not directly assess maximal aerobic capacity in order to prescribe workload, hence we are unable to define percentage of maximum for the work sets. Given that the intention was to utilize a real-world setting, and two different exercise modalities, such maximal testing was deemed unnecessary, given that we closely monitored workload with HR and RPE. We acknowledge this is a departure from laboratory trial convention but such an approach arguably provides greater translatability. Additionally, some SC and SαA data were unavailable given five participants did not produce the requisite saliva volume and in two participants the final two work sets of HIIT were not performed owing to discomfort with the face mask.

We calculated TEE as the sum of aerobic and anaerobic energy expenditure (34), given RER values of ≥1.0 throughout both RT and HIIT, and high BL in both RT and HIIT. Such an approach is not always applied; standard multiplication factors of between 4.7 and 5.05 $L \cdot min^{-1}$ are typically utilised for indirect calorimetry. Hence, the TEE we observed were comparatively higher than typically reported, and supports the contention that both RT and HIIT would provide meaningful contributions to total weekly energy expenditure recommendations within the vigorous category (21). We noted that HR and VO_2 (and hence EE) remained significantly elevated after a 10 min post exercise passive recovery phase furthering such a contention. Even very brief excursions into higher intensity exercise will increase EE. For example, 4 s maximal cycling bursts interpolated every 2 min within a 30 min low intensity steady state session resulted in significantly greater TEE than 30 min non-stop at low intensity (16) in both overweight and normal weight boys (~10.4 y).

Salivary cortisol is a non-invasive and valid biomarker of 'psycho-physiological stress response' (18) to exercise despite some apparent age and fitness specific differences (3). Elevated cortisol is sometimes associated with negative physiological status such as catabolic condition, and some imply that acute elevations are a potentially negative response (17). Such elevations are also considered a marker for the milieu of other acute physiological and metabolic responses cascading post intense exercise. For example, acute increase in SC is acknowledged as a surrogate for transient exercise induced growth hormone (GH) increase (11) known to be responsive in particular to exercise intensity (39), and representative of anabolic and lipolytic processes (23). Such transient increases are considered a stimulus for positive adaptations if total chronic dose is appropriate and in context to general physiological status and overall training load. We observed substantive increases in SC resultant from both RT and HIIT in our cohort, comparable to previous findings (8,9,12,18). For example, Capranica et al., (12) noted peak SC of 17.9 ± 3.5 nmol·L^{-1} at 30 min post taekwondo match, although Budde (8) reported cortisol immediately after 12 min of running at 70-85% of HR_{max} of only 8.4 mmol·L^{-1} (sic: we assume the units should have been reported as nmol·L^{-1}) in school students (15 y), most probably attributable to the lower relative intensity, and Engel et al., reported (15.1 ± 9.7 nmol·L^{-1}) and blood lactate (12.6 ± 3.5 mmol·L^{-1}) were both significantly elevated at 30 min. The increases we observed in SC were concurrent with the anticipated elevations in BL for both RT and HIIT, also associated with potentially positive effect such as beta-endorphin release (22). Zafeiridis et al. (40) reported similar BL levels in boys (11.4 ± 0.5 y) and adolescents (14.7 ± 0.4 y) in response to 4 sets of 18 repetitions (30 s sets) knee extension (~6 and ~8.5 mmol·L^{-1} for boys and adolescents respectively), as did Pullinen et al., (31) (8.0 mmol·L^{-1}) resultant from the RT

protocol detailed prior, and four repeated 30 s Wingate cycle set HIIT (18) elicited 12.6 ± 3.5 mmol·L^{-1} 30 min post session.

Salivary alpha amylase is known to up-regulate with exercise in adults, particularly intense exercise (25), and is considered a valid surrogate for markers of sympathetic nervous system activity such as plasma epinephrine (38). Fewer data are reported on acute exercise induced SαA in youth. The immediate post Taekwondo match SαA reported by Capranica et al., (12) (169.6 ± 47.0 U·mL^{-1}) was much lower than the approximately 900 U·mL^{-1} we observed after both RT and HIIT. We found considerable individual variation in both resting and post trial SαA for both RT and HIIT, and in some individuals there was a slight decrease post exercise. A limitation of the present study was that subjects were scheduled across a range of times within a normal school day, although both trials were conducted at the same time of day within each subject. It is conceivable that the scheduling of our trials influenced both baseline and responses for SC and SαA given known diurnal variation. Nonetheless, the generally observed increases in SC and SαA during both trials add to the general quantification of the physiological demands of both the RT and HIIT we utilised. Additionally, although we attempted to standardise pre-trial preparation it is acknowledged that variations within and between subjects, and between trials was likely given the cohort and the setting. Such variations are most likely to influence measures such as SC and SαA, thus the results for these variables must be taken in that context.

PRACTICAL APPLICATIONS

Brief, repetitive, intermittent forays into high, but not supra-maximal intensity exercise appeared a potent physiological stimulus in adolescents. A 12 min RT and HIIT session of equal work to rest durations and comparable effort resulted in very similar physiological

outputs. Although HIIT prescribed to elicit 90% HR_{max} per set resulted in greater VO_2, HR, and BL than RT, both were categorical as 'vigorous' and thus would contribute to the accumulation of recommended weekly dose of vigorous physical activity. Given the additional known neuromuscular responses and adaptations to RT in this cohort, young adolescents performing RT structured in such a manner and using perceived repetitions to failure prescriptively would conceivably gain both neuromuscular and cardiovascular adaptations if performed with the requisite weekly frequency.

Acknowledgements

The authors would like to express gratitude to the staff and students of Year 8 at Orewa College for their support and participation. Particular appreciation is extended to Cushla Shepherd for enthusiasm and willingness in arranging for this research to be conducted in school, in class time.

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Figure Legends:

Figure 1. VO_2 response across 12 work and recovery sets, and 10 min post-trial for both RT and HIIT. The x-y intercept represents baseline value

Figure 2. HR response across 12 work and recovery sets, and 10 min post-trial for both RT and HIIT. The x-y intercept represents baseline value

Figure 3. Individual pre- and post-trial values for SC, SαA, and BL within and between RT and HIIT trials

Closed circles=M; Open circles=F; Diamond=representative group mean

Table 1. Subject characteristics

	Male n=8			Female n=9			Group n=17		
	Mean	±	SD	Mean	±	SD	Mean	±	SD
Age (y)	13.0	±	0.32	12.9	±	0.33	12.9	±	0.32
Height (cm)	162.4	±	9.88	160.2	±	5.78	161.2	±	7.79
Body mass (kg)	52	±	10.5	53	±	12.6	53	±	11.5
BMI ($kg \cdot m^2$)	20	±	2.2	21	±	3.9	20	±	3.1
Maturity offset (y)	-0.8	±	0.59	0.9	±	0.45	0.1	±	1.04
Multistage shuttle run laps completed	81	±	20.1	64	±	21.9	72	±	22.1
Press-up repetitions to failure	17	±	7.9	13	±	6.2	14	±	6.9
Modified pull-up repetitions to failure	22	±	5.2	20	±	9.0	21	±	7.4
Grip strength (kg)	30	±	6.6	27	±	5.5	29	±	6.0

Table 2. Structure of acute response sessions

Resistance training (RT) session										
Exercise	Number of sets	Set duration	Rest duration	Repetitions completed per set			Repetitions short of failure per set			
				Mean	±	SD	Mean	±	SD	
Squat	4	30 s	30 s	11.1	±	2.6	3.2	±	1.5	
Press-up	4	30 s	30 s	13.9	±	3.8	3.8	±	1.9	
Supine pull	4	30 s	30 s	13.7	±	3.0	3.1	±	1.6	
Session	12	6 min	6 min							

High intensity intermittent training (HIIT) session										
Exercise	Number of sets	Set duration	Rest duration	Load (W)			Load ($W \cdot kg^{-1}$)			
				Mean	±	SD	Mean	±	SD	
Cycle	6	30 s	30 s	236	±	6.1	4.4	±	0.5	
Box	6	30 s	30 s							
Session	12	6 min	6 min							

Table 3. Baseline values, and within and between trial differences for both RT and HIIT.
Values are Mean (95% CI)

	RT	HIIT	Between group difference Cohen's d	p value
Cortisol (nmol·L^{-1})			0.58	0.191
Baseline	5.7 (4.0, 7.5)	6.1 (4.4, 7.8)		
10 min post trial	12.4 (9.8, 15.0)	14.7 (11.0, 18.5)		
Cohen's d within trial change	2.41	3.26		
p value within trial change	0.000	0.000		
Alpha Amylase (U·mL^{-1})			0.13	0.771
Baseline	593 (303, 884)	590 (353, 826)		
10 min post trial	881 (455, 1307)	928 (525, 1330)		
Cohen's d within trial change	0.63	0.91		
p value within trial change	0.023	0.028		
Lactate (mmol·L^{-1})			0.73	0.046
Baseline	1.3 (1.0, 1.7)	1.5 (1.0, 1.9)		
5 min post trial	7.0 (5.1, 8.9)	8.8 (7.3, 10.4)		
Cohen's d within trial change	9.62	12.47		
p value within trial change	0.000	0.000		
VO2 (mL·kg·min^{-1})			2.77	0.000
Baseline	5.3 (4.7, 5.8)	5.6 (4.9, 6.3)		
Work set mean	25.8 (23.8, 27.7)	35.0 (31.8, 38.2)		
HR (bpm)			1.87	0.001
Baseline	76.6 (70.5, 82.6)	71.8 (66.6, 77.0)		
Work set mean	169.9 (165.1, 174.6)	179.0 (176.2, 181.0)		
RPE (set)	6.7 (6.3, 7.1)	6.8 (6.3, 6.9)	0.16	0.668
RPE (session)	8.0 (7.5, 8.6)	8.3 (7.9, 8.7)	0.29	0.155