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Original article

Title: Sprint Interval Training (SIT) and the school curriculum: Benefits upon cardiorespiratory fitness, physical activity profiles and cardiometabolic risk profiles of healthy adolescents

Running title: School-based Sprint Interval Training

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Abstract

Background: This study examined the impact of a 4-week school-based sprint interval training (SIT) programme on cardiorespiratory fitness (CRF), daily physical activity (PA) behaviour and cardiometabolic risk (CMR) outcomes in adolescents. **Methods:** Fifty-six adolescents (22 females) were allocated to either an intervention (INT) (n = 22, 17.0 (0.3) years) or control group (CON) (n = 30, 16.8 (0.5) years). INT performed 5-6, 30 s “all out” running sprints, interspersed with 30s rest intervals, 3 times per week, for 4 consecutive weeks while CON performed their normal physical education lessons. CRF was estimated from the 20m Multi Stage Fitness Test and PA behaviour was determined by accelerometry. Fasted blood samples were obtained to measure biochemical markers of CMR. **Results:** Significant group x time interactions were observed for CRF (5.03 (1.66 - 8.40); $P < 0.001$; $d = 0.95$), sedentary time (136.15 (91.91 - 180.39); $P = 0.004$; $d = 1.8$), Moderate PA (57.20 (32.17 - 82.23); $P < 0.001$; $d = 1.5$), vigorous PA (5.40 (4.22 - 6.57); $P < 0.001$; $d = 1.2$), fasting insulin (0.37 (-0.48 - 1.21); $P = 0.005$; $d = 1.0$), HOMA-IR (0.26 (0.15 - 0.42); $P < 0.001$; $d = 0.9$) and clustered CMR score (0.22 (-0.05 -0.68; $P < 0.001$; $d = 10.63$). **Conclusion:** Findings of this study indicate that 4 weeks of school-based SIT improves CRF and PA profiles and maintains CMR in adolescents during the school term.

1. Introduction

Participation in regular moderate to vigorous physical activity (MVPA) is known to improve cardiorespiratory fitness (CRF), body composition, cardiometabolic risk (CMR) profiles and reduce the risk of cardiometabolic disease (CMD) (41). However, recent epidemiological data show that physical activity (PA) levels decline by 10% each year during adolescence (23). Additionally, evidence from the Scottish Health Behaviour in School-aged Children (HBSC) study indicates that approximately only 1 in 5 children and adolescents (< 18%) participate in sufficient PA to elicit health benefits (21, 29). Moreover, it is well known that school-aged children and adolescents can accumulate a substantial amount of sedentary time during school hours (21, 29), with findings from Scotland estimating that 3.8 - 5.6 hours per day are spent being sedentary (43). Therefore, given this decline in PA levels among adolescents, it is important to target PA participation in the adolescent population.

Structured school-based PA in the UK is largely achieved through the medium of standard physical education (PE) classes, which aim to provide high quality PE that is motivational and encourage high levels of active learning (13). However, a recent systematic review and meta-analysis investigating time spent in MVPA during school PE lessons suggests that secondary school students only spend on average 40.5% of lesson time participating in MVPA (27). Time constraints have been proposed as a primary obstacle that inhibits adequate MVPA in school-based PE classes (7) hence, developing interventions that are time efficient and aim to improve PA and health profiles are required.

Adolescent CRF is strongly associated with CMR in adulthood (42), hence, identifying strategies to improve CRF levels in this population is vital to reduce the increasing burden of CMD later in life. Exercise interventions in adolescents typically focus upon increasing levels of MVPA with current guidelines suggesting that children and adolescents should engage in 60 min of MVPA daily (22). Yet, many children and adolescents fail to meet this minimal requirement leading some to suggest that adolescent populations may have difficulty, and perhaps little interest, in engaging in activity of this kind (9). As accumulating evidence suggests that vigorous, rather than moderate PA, may be more beneficial for a number of health outcomes in youth (37, 38), many investigations have begun to explore

the feasibility and effectiveness of embedding sprint interval training (SIT) interventions within the school environment (8, 10, 33, 34, 52).

Despite contrasting SIT and high intensity interval training (HIIT) study designs, a consistent finding between all investigations is an improvement in CRF levels (8, 10, 33, 34, 52). A recent review demonstrated that HIIT has the potential to improve CRF by 2.2 to 23% in healthy, overweight and obese children and adolescents (5). Supporting this, findings from a meta-analysis reported large improvements in CRF (unstandardized mean difference $2.6 \text{ ml.kg}^{-1} \cdot \text{min}^{-1}$; 95% confidence interval 1.8 to $3.3 \text{ ml.kg}^{-1} \cdot \text{min}^{-1}$; Cohen's d effect size 1.05) (19). Clearly this growing body of literature supports the efficacy of embedding HIIT and SIT interventions within the school curriculum for improving the CRF levels of adolescents.

Emerging evidence demonstrates the potential of HIIT to improve CMR outcomes in children and adolescents (5, 30, 33, 40, 48, 52). A recent review on the effect of HIIT on CMR outcomes (5) concluded that school-based HIIT induces similar or superior benefits compared to continuous aerobic exercise across a range of outcomes including body composition, insulin and glucose homeostasis, blood lipids and blood pressure in healthy, overweight and obese children and adolescents. Supporting this, a further review concluded that school-based HIIT was effective in improving CMR in overweight and obese adolescents (33). These findings highlight the potential for school HIIT to improve CMR outcomes in overweight and obese children. Nonetheless, there is a lack of evidence of the effects of SIT on CMR in healthy children and adolescents.

The effect of SIT and HIIT on objectively measured PA levels is less documented in children and adolescents. Nonetheless, HIIT in the school environment has been shown to improve levels of MVPA (20, 52), although further evidence is required to fully understand the effects of school-based SIT on objectivity measured PA.

Our previous work found that 7 weeks of school-based running SIT implemented in the first term of school following a summer vacation period maintained CRF, insulin and glucose homeostasis compared with age matched controls receiving standard PE classes in healthy adolescents (34). We also reported that the SIT cohort subjectively self-selected greater levels of PA during this study, compared

with control participants and that the control group experienced a small decrease in CRF during the school term. However, limitations of this study which limits the interpretations of the findings include: (1) that a 7 weeks intervention did not fit consecutively into a single school term and (2) no objectively measured PA levels were obtained. Considering these findings and limitations we sought to further examine whether these data could be replicated in a controlled study consisting of 4 weeks of SIT exercise using accelerometry as a more robust determinant of PA. Therefore, the primary aims of the current study were to: Examine the effects of a 4-week school-based SIT intervention on CRF and PA levels in adolescents. A secondary aim was to examine the effects of a 4-week school-based SIT intervention on CMR outcomes in adolescents.

2. Materials and Methods

2.1 Participants

Following ethical approval from the University of the West of Scotland Ethics Committee, a convenience sample of 56, apparently healthy and recreationally active adolescent participants were approached to participate in the study. Participants were recruited from one school within South Lanarkshire, Scotland, which was within the 1st Decile of the Scottish Index of Multiple Deprivation (SIMD). The first decile represents the most deprived areas of Scotland (47). All 56 participants (16.5 (0.5) years; 34 males) provided written informed consent to participate in the study. No other inclusion or exclusion criterion was applied. The study employed a quasi-experimental design with participants recruited from two higher PE classes. One class was randomly allocated to the intervention group (INT, $n = 24$; 14 males, 10 females) with the other class allocated to the control group (CON) ($n = 32$; 20 males, 12 females) using a coin toss (Table 1; Figure 1). The INT group completed the SIT protocol and CON continued their normal PE lessons which consisted of 3 x 1 hour PE classes per week for 4 consecutive weeks. Homogeneity between the INT and CON groups was confirmed prior to the commencement of the intervention (Table 1). Of the cohort sampled, 91.6% of the INT and 90.6% of the CON group were classed as normal weight with 8.4% and 9.4% classed as overweight according to international age and gender percentile curves (16, 17) (Table 1).

2.2 Sprint Interval Training (SIT) Programme

The SIT intervention was implemented in the first term (autumn) of school following a summer vacation (August to September) and consisted of 12 sessions undertaken 3 times per week over 4 consecutive weeks. HIIT ranging from 2-12 weeks has been shown to be effective for improving many health outcomes in children and adolescents (5, 30, 33, 40, 48, 52). Therefore, a 4 week intervention period was chosen based on our previous study which indicated that 7 weeks was too long to fit continuously within one single Scottish school term (34). Each SIT session began with a standardised 10 min warm-up consisting of 5 min of slow jogging followed by 5 min of stretching of major muscle groups and ended with a standardised cool down comprising of dynamic and static stretches. The 1st author, with assistance from the PE staff, delivered the SIT sessions. This is a sustainable way of delivering the SIT sessions as PE staff can continue delivering the intervention without the presence of the 1st author. The SIT sessions involved 5 to 6, 30 s of “all-out” effort running sprints between two cones set 20 m apart, interspersed with 30 s passive (walking) recovery. Five sets of 30 s sprints were performed during weeks one and two with progression achieved by increasing the SIT to six sets performed in weeks three and four. A SIT Pacer (either PE staff or researchers) was included in the SIT exercise to add a competitive element and help achieve the “all-out”/ “maximal” intensity of the SIT protocol since no specific intensity was given in term of %HRmax. Although Taylor et al. (46) has proposed a maximal peak HR of $\geq 90\%$ for HIIT in adolescents which could be used to reflect maximal exercise, we felt this would be difficult to monitor given the short time taken to complete each SIT session. Participants were required to complete a minimum of 10 SIT sessions ($>80\%$) to be included in the final data analysis. Each SIT intervention session (including warm-up, rest periods and cool down) equated to 25 min in weeks 1 and 2 and 26 min in weeks 3 and 4. The total 4 week SIT intervention time for all participants equated to 66 min excluding warm up and cool down and 306 min including warm up, the SIT intervention and cool down periods. The total SIT exercise time over the 4-week intervention (excluding warm up, rest intervals and cool down) equated to 33 min during the intervention.

[FIGURE 1 NEAR HERE]

2.3 Anthropometrics and sexual maturation

Data collection and SIT sessions were performed in the school games hall on separate days (Monday, Wednesday and Thursday). Measures were obtained 7 days prior (PRE) to the first session and again 7 days post-intervention (POST). Participant stature (cm) was measured using a Seca stadiometer (Seca Ltd. Birmingham UK). Body mass (kg) was recorded to the nearest 0.1 kg using a Seca 880 digital scale (Seca Ltd. Birmingham UK). Body Mass Index (BMI) was calculated as body mass/stature² (kg/m²). Waist and hip circumference were measured to the nearest 0.1 cm using a Seca measuring tape (Sec Ltd. Birmingham UK) following standard procedures (31). Waist to hip ratio (WHR) was calculated by waist circumference/ hip circumference. Sexual maturation was evaluated using a previously validated self-reported questionnaire for pubic hair development (45).

2.4 Cardiorespiratory fitness (CRF)

Participant CRF was estimated using the 20m multistage fitness test (MSFT) (32). Participants were encouraged to participate until complete exhaustion. The last shuttle number was recorded with relative peak oxygen uptake ($\dot{V}O_{2peak}$, mL/kg/min) determined using a previously validated equation (2). Heart Rate (HR) monitors were used during the 20m MSFT to establish maximal HR.

2.5 Physical activity (PA)

Participants wore uniaxial Actitrainer accelerometers (ActiGraph LLC, Pensacola, FL, USA) for 4 consecutive days, including 2 week days and 2 weekend days (50). The accelerometer was secured on the participants waist during waking hours to determine habitual activity and sedentary time behaviour both prior to (week 0) and during the last week (week 4) of the intervention. The accelerometers were only worn during one single SIT session on week 4 to capture PA levels during the SIT session. The accelerometer was set to capture data using a 10 s epoch in order to provide sufficient sensitivity to detect short bouts of activity (35). Time spent sedentary and in moderate and vigorous PA were determined using adolescent-specific threshold points defined by Treuth et al where sedentary time was defined as <100 counts-per-minute (CPM), light PA (LPA) as 101-2999 CPM, moderate physical activity (MPA) as 3000-5200 CPM and vigorous physical activity (VPA) as > 5200 CPM (49). Periods of >20 min of consecutive 0 accelerometer counts were classified as non-wear time

(49). Similarly, a minimum of 9 hours wear time during weekdays and 8 hours wear time during weekend days were required for inclusion (35). Finally, participants had to wear the accelerometer for 4 days (2 weekend days and 2-week days) to be included within the analysis. For analysis, data from the SIT intervention period (the counts recorded during the SIT session) were removed to establish PA levels outside of the SIT intervention. This was done by the lead researcher taking a note of the time that the SIT sessions started and finished and ensured these were identical to the time of the computer used to initialize the accelerometers. Thereafter, counts recorded during the SIT session were excluded from the analysis.

2.6 Heart rate (HR)

Participant HR (bpm) including the maximal value (HR_{max}) were assessed using continuous heart rate telemetry (Suunto, Vantaa, Finland). HR_{max} was assessed during the 20m MSFT. The highest heart rate (bpm) during the 20m MSFT was recorded as HR_{max} . SIT intensity was recorded once per week by recording HR to confirm maximal exertion and to establish relative SIT intensity as a percentage of participants' maximal HR ($\%HR_{max}$) determined from the 20m MSFT HR_{max} . Individual HR_{max} was calculated for each sprint and each week of the intervention to calculate an overall HR_{max} /SIT intensity. SIT intensity was recorded only during the sprints hence, rest intervals were not recorded.

2.7 Blood pressure

Systolic blood pressure (SBP) and diastolic blood pressure (DBP) were measured PRE and POST intervention in a seated position using an automated blood pressure monitor (Omron M10-IT Blood Pressure Monitor HEM-7080IT-E, Omron Healthcare UK Ltd, Milton Keynes, UK), with an average of two readings used for analysis.

2.8 Cardiometabolic blood measures

Venous blood was sampled between 09.00 and 11.00 am from an antecubital forearm vein using the standard venepuncture method. Fasting blood samples were analysed in duplicate for blood glucose, plasma insulin, total cholesterol (TC), triglycerides (TG), high density lipoprotein cholesterol (HDL-C) and low density lipoprotein cholesterol (LDL-C) using procedures described in detail elsewhere (26). Fasting plasma insulin was analysed by enzyme-linked immunosorbent assay (ALPCO, Salem, NH).

All other blood measures (glucose, TC, TG, HDL-C) were determined by spectrophotometry using commercially available reagents (Randox, Antrim, UK). LDL-C was determined using the Friedewald formula (25).

The intra and inter assay coefficient of variation (CV's) for plasma insulin were 3.3% and 3.0%, respectively; blood glucose were 5.1% and 4.5%, respectively; TC were 4.8% and 2.3%, respectively; TG were 3.6% and 0.7%, respectively; HDL-C were 1.6% and 1.3% and LDL-C were 3.1% and 2.7%.

The Homeostasis Model of Assessment (HOMA) was used to determine insulin resistance (IR) (HOMA-IR) using the formula: "HOMA-IR = (fasting insulin x fasting blood glucose) / 22.5" (44).

Using established risk factors of CMR as proposed by the International Diabetes Federation (54), clustered CMR scores were calculated using the sum of standardised z-scores for waist circumference, SBP, fasting glucose, inverted HDL-C and TG. Each variable was standardized as follows: standardized value = value-mean/SD.

2.9 Statistical analysis

Data were analysed using IMBSPSS (version 22.0, New York, USA). Q-Q plots were used to confirm normal distribution of data. Sample size and power were estimated using the procedures of Park and Schutz (39) for ANOVA designs that incorporate a repeated factor. For a medium effect size in the intervention group of $d = 0.50$, power of 0.80 (suggesting an 80% probability of achieving significance at the $P = .05$ level) this is achieved with a minimum group size of 17 participants. Assuming a drop-out rate of 30%, this would require an initial recruitment of 24 participants per group. Independent t-tests were used to confirm homogeneity between groups for age, $\dot{V}O_{2peak}$, PA behaviour and body mass at baseline. Pearson's Chi-square analysis was used to compare independence of maturation status between the intervention and control groups. Training effects were compared using a 2 x 2 (group x time) mixed design ANOVA with pair wise comparisons for simple main effects including a Bonferroni correction. A criterion alpha value of $P \leq 0.05$ was used to indicate statistical significance. Partial eta squared values (η^2) are reported as effect size estimates. The magnitude of the effect size for the partial eta squared is 0.01 (small), 0.06 (medium), and 0.14 (large) according to

Cohen's guidelines (15). Data are expressed as mean and standard deviation (SD), with uncertainty in the estimates expressed as mean difference and 95% lower and upper confidence intervals (CI) [lower 95%CI to upper 95%CI].

[TABLE 1 NEAR HERE]

3 Results

3.1 Participants Characteristics

The flow of participants throughout the study and reasons for exclusion are presented in Figure 1. Of the 56 participants that commenced the study, 52 were included in the final analysis for all physical and physiological measurements (INT n = 22, CON n = 30). Within the INT group, 2 participants failed to meet 80% of the SIT sessions due to being absent from school. In CON, 2 participants provided no PRE or POST data due to being absent from school on data collection days. With respect to metabolic measures, 43 participants were included in the final biochemical analysis (INT n = 21, CON n = 22) (Figure 1). One participant in the INT group and four in CON withdrew blood sampling consent on the day of sampling. A further 4 participants in CON informed the research team that they had not adhered to the fasted protocol prior and were not sampled. No adverse effects or injuries were reported throughout the SIT intervention. In addition, informal feedback from the participants indicated that students enjoyed the SIT exercise over their standard PE classes. Some students indicated that they favoured SIT to their PE classes as it was over quicker, liked the competitiveness and fun nature added, enjoyed working hard and felt themselves getting fitter as the intervention progressed. Nonetheless, while our participants reported enjoyment of SIT it is important to highlight that HIIT type training is known to decrease exercise pleasure (24). Therefore, HIIT type exercise may not be appropriate for everyone as a mode of exercise.

No significant differences over time or between groups at PRE or POST were observed for body mass, BMI, hip circumference, waist circumference, WHR, SBP or DBP ($P > 0.05$ for all, Table 2).

[TABLE 2 NEAR HERE]

3.2 Maximal Heart Rate

HR_{max} obtained from the 20 m MSFT at PRE in SIT and CON were 203 ± 8 bpm and 201 ± 8 bpm, respectively and 205 (6) bpm and 202 (7) bpm at POST. No significant difference was observed PRE to POST within groups or between time points. The average HR in the SIT group during the 4 week intervention was 186 (11) bpm and 92 (1%) of HR_{max}. Average weekly SIT HR_{max} is displayed in Table 2.)

3.3 Cardiorespiratory Fitness ($\dot{V}O_{2\text{peak}}$)

A group \times time interaction was observed in CRF ($\dot{V}O_{2\text{peak}}$) following the SIT intervention ($f_{(1,50)} = 202.20$, $P < 0.001$, partial $\eta^2 = 0.80$) (Table 3; Figure 2). No main effects of time ($f_{(1,50)} = 0.09$, $P = 0.765$, partial $\eta^2 = 0.002$) or group were observed ($f_{(1,50)} = 0.69$, $P = 0.411$, partial $\eta^2 = 0.01$).

3.4 Physical Activity and Sedentary time

A group \times time interaction was evident in sedentary time following the intervention ($f_{(1,38)} = 21.26$, $P < 0.001$, partial $\eta^2 = 0.36$) (Table 3). No main effects of time were observed ($f_{(1,38)} = 0.25$, $P = 0.622$, partial $\eta^2 = 0.01$), however a significant main effect of group was evident ($f_{(1,38)} = 19.77$, $P < 0.001$, partial $\eta^2 = 0.34$).

A group \times time interaction was observed in MPA following the intervention ($f_{(1,38)} = 48.07$, $P < 0.001$, partial $\eta^2 = 0.56$) (Table 3). No main effect of time was found ($f_{(1,38)} = 0.03$, $P = 0.857$ partial $\eta^2 = 0.001$) although a main effect of group was evident ($f_{(1,38)} = 48.07$, $p < 0.001$, partial $\eta^2 = 0.56$).

A group \times time interaction was observed in VPA following the intervention ($f_{(1,38)} = 75.24$, $P < 0.001$, partial $\eta^2 = 0.66$) (Table 3). A significant main effect of time ($f_{(1,38)} = 29.50$, $P < 0.001$, 0.44) and group ($f_{(1,38)} = 19.53$, $P < 0.001$, partial $\eta^2 = 0.34$) was also evident (Table 3).

3.5 Cardiometabolic outcomes

No group \times time interaction was evident following the intervention in fasting glucose ($f_{(1,44)} = 3.13$, $p = 0.084$, partial $\eta^2 = 0.07$) (Table 3; Figure 3A). No main effects of time ($f_{(1,44)} = 0.15$, $P = 0.703$, partial $\eta^2 = 0.003$) or group ($f_{(1,44)} = 1.27$, $P = 0.267$, partial $\eta^2 = 0.03$) were evident for fasting glucose.

A group \times time interaction was evident for insulin following the intervention ($f_{(1,41)} = 8.86$, $P = 0.005$, partial $\eta^2 = 0.18$) (Table 3; Figure 3B). No main effects of time were noted ($f_{(1,41)} = 1.29$, $P =$

0.262, partial $\eta^2 = 0.03$) but a main effect of group was evident ($f_{(1,41)} = 5.81$, $P = 0.020$, partial $\eta^2 = 0.12$).

A significant group \times time interaction was evident in HOMA-IR following the intervention ($f_{(1,44)} = 19.00$, $P < 0.001$, partial $\eta^2 = 0.30$) (Table 3; Figure 3C). No main effects of time were observed ($f_{(1,44)} = 1.03$, $P = 0.316$, partial $\eta^2 = 0.02$) although a main effect of group was evident ($f_{(1,44)} = 7.89$, $P = 0.007$, partial $\eta^2 = 0.15$).

A significant group \times time interaction was found in TG following the intervention ($f_{(1,41)} = 13.06$, $P = 0.001$, partial $\eta^2 = 0.24$) (Table 3). No main effect of time ($f_{(1,41)} = 0.45$, $P = 0.508$, partial $\eta^2 = 0.01$) or group were noted ($f_{(1,41)} = 3.75$, $P = 0.06$, partial $\eta^2 = 0.08$).

A significant group \times time interaction was evident in TC following the intervention ($f_{(1,41)} = 12.28$, $P = 0.001$, partial $\eta^2 = 0.23$) (Table 3). A significant main effect of time ($f_{(1,41)} = 5.27$, $P = 0.03$, partial $\eta^2 = 0.11$) and group ($f_{(1,41)} = 10.88$, $P = 0.002$, partial $\eta^2 = 0.21$) were also observed.

A significant group \times time interaction was observed in LDL-C following the intervention ($f_{(1,41)} = 7.91$, $P = 0.008$, partial $\eta^2 = 0.16$) (Table 3). A main effect of time ($f_{(1,41)} = 7.19$, $P = 0.011$, partial $\eta^2 = 0.15$) was evident but not for group ($f_{(1,41)} = 1.55$, $P = 0.220$, partial $\eta^2 = 0.03$) was also evident.

No significant group \times time interaction was evident in HDL-C following the intervention ($f_{(1,41)} = 0.50$, $P = 0.483$, partial $\eta^2 = 0.01$) (Table 3). No significant main effect of time ($f_{(1,41)} = 0.05$, $P = 0.827$, partial $\eta^2 = 0.001$) or group ($f_{(1,41)} = 0.10$, $P = 0.750$, partial $\eta^2 = 0.003$) were evident (Table 3). A significant group \times time interaction was observed in CMR score following the intervention ($f_{(1,41)} = 7.01$, $P = 0.011$, partial $\eta^2 = 0.15$). No significant main effect of time ($f_{(1,41)} = 1.36$, $P = 0.251$, partial $\eta^2 = 0.03$) or group ($f_{(1,41)} = 0.77$, $P = 0.386$, partial $\eta^2 = 0.02$) was observed.

[FIGURE 3ABC NEAR HERE]

4 Discussion

The main aims of this study were to examine the impact of a 4-week school-based SIT intervention on CRF and objectively measured PA in the first term of school following a summer vacation period. A further aim was to examine the impact of a 4-week school-based SIT intervention on CMR outcomes

in the first term of school following a summer vacation period. The main findings of the study suggests that 4 weeks of school-based SIT significantly improved CRF and self-selected habitual PA in the first term of school following a summer vacation period. A secondary finding indicates that 4 weeks of school-based SIT maintained several markers of CMR. Other important findings suggest that standard PE lessons may not be sufficient to prevent declines in CRF, self-selected habitual PA and indicators of CMR when school pupils return from their summer vacation.

4.1 *Cardiorespiratory Fitness*

The potential of HIIT interventions to improve CRF has been well documented in adults (1, 53). Our findings from the current study reported a significant improvement in CRF following 4 weeks of school-based SIT (Table 3; Figure 2). These findings are in contrast with previous work from our group that reported a maintenance of CRF following a 7-week school-based SIT in 15-17 year-old adolescents (34). The difference in findings between the 7-week SIT study and the current 4-week SIT study may be a consequence of the higher average intensity (%HR_{max}) of SIT observed in this current study compared with our previous work (92% of HR_{max} Vs 87% of HR_{max}, respectively). Furthermore, it is important to mention that the observed improvement in CRF may be a result of fitness levels returning to levels gained throughout the school year prior to the summer vacation period, where levels of CRF are known to decline (14). Nonetheless, the current data are supported by previous systematic reviews and meta-analysis which reported substantial increases in CRF in adolescents following 2-15 weeks of school-based HIIT (19, 33). A recent systematic review and meta-analysis by Costigan and colleagues (19) reported a large effect ($d = 1.05$) of HIIT on CRF in overweight and obese adolescents following HIIT interventions ranging from 4 – 15 weeks. Similarly, a review by Logan and colleagues (33) also reported improvements in CRF (3-10.9%) following 2-12 weeks of HIIT in overweight and obese adolescents. Supporting the above review and meta-analysis, a more recent review demonstrated that CRF improved by 2.2% to 23% following 2-15 weeks following HIIT interventions in healthy overweight and obese adolescents (5). Taken in context, these data support the tenet that school-based SIT is effective for improving CRF in healthy, overweight and obese adolescents.

In agreement with our previous work (34), we observed a significant decline in CRF of 7.3% ($d = 0.95$) in the CON group who received standard PE lessons over the 4-week intervention period (Figure 2). Whilst concerning, it is unclear whether this decline in CRF has continued from the summer vacation period (14) or is a result of insufficient PA within PE lessons in the autumn school term. These findings further support the importance and potential of school-based SIT for improving and preventing declines in CRF in the first term of school following a summer vacation period.

4.2 Physical Activity and Sedentary time

Many school-based PA interventions aim to increase MVPA but findings suggest they have little effect on overall PA levels (6). The potential of HIIT interventions to promote PA and decrease sedentary behaviours is emerging in children and adolescents (20, 34, 52). Previous research from our group reported increased levels of self-selected PA measured by the Physical Activity Questionnaire for Adolescents (PAQ-A) following 7 weeks of school-based SIT (34). In the current study we provide objective measures of PA which confirm our earlier observations that the intervention is effective and encourages participants to partake in significantly higher levels of MVPA. Our study observed an increase in MVPA of 39 mins which was independent of the SIT intervention. Additionally, time spent in sedentary time declined by 60 mins in INT group over the 4-week intervention. However, we acknowledge that these findings may be explained by the increase in time spent in MVPA and therefore, a respective reduction in sedentary time (51). Supporting our findings, Weston and colleagues observed improved MVPA levels of 16 mins in adolescents following school-based HIIT (52). Whilst these findings are promising, we are aware that the increase in activity levels are likely to be the result of the intervention delivery (4) and may be short-term. Therefore, future studies would benefit from including follow up measures of MVPA to establish if improved PA profiles are a result of enhanced opportunities or of participants self-selecting greater PA to establish the true effectiveness of school-based SIT on PA profiles.

4.3 Cardiometabolic risk outcomes

The potential of HIIT to improve CMR outcomes in adolescents is becoming more evident (52). Current evidence relating to the effects of HIIT on insulin and glucose homeostasis in healthy

adolescents is mixed with some studies reporting no changes (8, 11, 12, 34), and others reporting moderate but clinically relevant improvements ranging from 7.6% to 12.2% (18, 40, 48). In addition, a recent review article demonstrated that an average of 12 weeks of HIIT improved insulin homeostasis by 26-29% and glucose homeostasis by 4.2-5.8% in overweight and obese children and adolescents (5). Our previous work demonstrated no significant changes in insulin and glucose following 4 weeks of SIT in healthy adolescents (34). In contrast, the current study observed a positive effect of SIT on insulin homeostasis with a significant improvement of 18% being observed following 4 weeks of SIT. Although improvements in insulin homeostasis were evident from our findings, initial fasting insulin levels were healthy hence, any improvements observed were clinically insignificant. It is unclear whether the changes in insulin and glucose homeostasis were a contribution from the final SIT session (5). When considered in context with other findings involving overweight and obese adolescents where larger improvements in insulin and glucose homeostasis have been observed (18, 40, 48), larger effects may have been observed if our intervention involved participants who were overweight/obese and/or displayed poor glucose homeostasis at baseline.

Despite our previous research failing to report improvements in HOMA-IR in healthy adolescents (34), the present study found a small but significant improvement in HOMA-IR amongst INT participants with concomitant worsening in CON. Albeit clinically trivial, it has been proposed that HIIT induced improvements in HOMA-IR are likely to be greater in overweight and obese adolescents (33). Nonetheless, our study suggests that SIT induced improvements in HOMA-IR are possible in healthy adolescents over a short intervention duration which mirrors the findings in adults (1, 53).

Regarding, the effects of SIT upon CMR markers such as measures of fatness (BMI and waist circumference), TG, HDL-C and clustered CMR score, no improvements were evident. However, this may be explained by the participants presenting with clinically healthy CMR profiles at baseline. We did nonetheless, observe a significant decline in CON which highlights the potential of SIT to maintain healthy CMR profiles in the first term of school following a summer vacation period. Other research has demonstrated improvements in CMR outcomes following HIIT (30, 40, 52). A recent review of

HIIT in healthy, overweight and obese children and adolescents on CMR outcomes found that HDL-C and LDL-C can improve by 4 to 9.7% and 1.5 to 12% following an average of 12 weeks of HIIT (5). Similar studies involving overweight and obese adolescents have demonstrated significant effects on CMR outcomes including measures of fatness, TG, HDL-C, TC and overall CMR scores (30, 40, 52). These findings suggest that SIT may have a more significant impact on improving CMR outcomes in overweight and obese adolescents who present risk factors at baseline or over a longer intervention period.

4.4 SIT and the School Environment

An important additional finding from this study highlights the potential and feasibility of SIT to be incorporated into the school day through PE lessons. The school provides the ideal opportunity to implement interventions to increase PA levels and the health of children and adolescents (27). However, PA within school-based or curricular PE is often reported to be at an inadequate intensity to induce health benefits (36) with a lack of time and equipment being common barriers teachers face (7). SIT has the potential to overcome these barriers that are reported to impact upon adequate PA within school-based PE (7). Furthermore, SIT is regarded as a more enjoyable exercise mode when compared to aerobic/ endurance exercise due to feeling of reward, excitement and success (5, 33). Although perceived enjoyment within the SIT intervention was not measured, informal feedback from the participants indicated that SIT was more enjoyable than their normal PE class due to; the competitiveness and fun nature of SIT as well as seeing and feeling improvements in fitness. Therefore, SIT may be a feasible and convenient addition to traditional PE lessons.

4.5 Study strengths and limitations

The current study has several strengths. The novelty of the study is that the study is the first to examine the effects of school-based running SIT on validated objective measures of PA, field-based assessed CRF and CMR biomarkers in the first term of school following a summer vacation period in adolescents. Our study is also the first to report undesirable changes in measure of PA, CRF and CMR

biomarkers within the control group who were participating in standard PE classes during the first term of school following a summer vacation.

Despite these novel findings, the present study is not without limitations. Firstly, due to a small sample size and the use of a single school being used our results may not be generalisable and may lack external validity. Our study utilised only healthy adolescents so our results may only be generalisable to healthy adolescents described as aerobically fit with CRF levels > 80th percentile for age and gender. Furthermore, CRF was not measured prior to the summer vacation period so it is unclear whether the improvements in CRF are a result of CRF decline during the summer months. To establish the true effectiveness, it would be beneficial for future studies to measure CRF prior to the summer vacation. A further limitation to the current study is the lack of follow up measures of PA. It is unclear therefore if the improvements in PA are due to the opportunity for increased PA during the intervention or the effect of the intervention. Future studies would benefit from a follow up study to determine the long-term effectiveness and feasibility of school-based SIT. Also, a 4 week SIT intervention may not be long enough to demonstrate improvements in CMR profiles of healthy adolescents. A further limitation of the study concerns the running nature of the SIT protocol. Evidence has suggested that high-intensity interval exercise may be more enjoyable than moderate-intensity continuous exercise but it has also been reported to be unenjoyable on a daily basis (3, 28). SIT and HIIT studies would also benefit from measuring perceived enjoyment to fully understand the feasibility and acceptability of school-based SIT. It is clear that more research is required to establish the precise SIT exercise dose required to improve health related outcomes and establish the full feasibility of school-based SIT (4). Further work is also required across larger cohorts including multiple school sites involving a more diverse sample to make the findings more generalisable (4, 43).

5 Conclusion

The findings from this study indicate that 4 weeks of school-based SIT is a feasible and effective intervention that can induce improvements in CRF and encourages more desirable PA profiles in adolescents outside of the school environment. Other important findings suggest that SIT maintains and

prevents declines in CMR profiles in the first term of school following a summer vacation period. Furthermore, these findings endorse the use of short-term SIT as a time efficient mode of exercise which could be incorporated into the traditional PE curriculum or as an extracurricular activity to improve CRF and PA profiles whilst preventing CMR development in school-aged adolescents.

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Authors' Contributions

RM led the research study design and data collection, carried out analysis of blood biomarkers and statistical analysis and wrote the manuscript. DB, NS, CE and FG conceived and designed the study. All authors significantly contributed to the knowledge content and drafting of the manuscript

Competing interests

The authors declare that they have no competing interest.

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595 Table 1. Developmental characteristics of Sprint Interval Training (INT) and structured PE (CON)
 596 groups prior to (PRE) 4-week SIT training intervention (mean (SD) where appropriate)

	INT (n = 22)	CON (n = 30)
	PRE	PRE
Age	17 (0.3)	16.8 (0.5)
Sex (Male/Female)	13/9	19/11
Stature (cm)	172.1 (10.7)	169 (9.2)
Body Mass (kg)	67.1 (14.4)	66.2 (13.8)
BMI (kg/m ²)	22.5 (2.5)	21.8 (2.1)
Sexual maturation Tanner stage (n/%)		
Pubic hair growth: 3	1/4.2	2/6.3
4	9/37.5	14/37.5
5	11/58.3	16/56.2

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600 Table 2 Weekly maximum HR (bpm) and weekly relative HRmax (%) of SIT intervention. Mean and
 601 standard deviation presented (mean (SD))

Week	Maximum HR (bpm)	Maximum relative HR
	(mean (SD))	(%HR _{max}) (mean (SD))
Week 1	185 (12)	92 (1)
Week 2	186 (11)	92 (1)
Week 3	187 (9)	92 (2)
Week 4	190 (11)	92 (2)
Over all	187 (11)	92 (1)

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Table 2 PRE and POST physical/ physiological, activity time (excluding SIT PA time/mins), cardiometabolic blood measures in INT and CON. Mean and SD presented (Mean (SD))

	SIT (n = 22)		CON (n =23)		Mean Difference at Post (95% CI)	ES
	Baseline (mean (SD))	Post (mean SD))	Baseline (mean (SD))	Post (mean SD))		
Physical/ Physiological measures						
$\dot{V}O_{2peak}$ (ml·kg ⁻¹ ·min ⁻¹)	48.28 (6.84)	51.81 (6.37) ^a	50.46 (5.96)	46.77 (5.68) ^{a,b}	5.03 (1.66 - 8.40)	0.95
Waist circumference (cm)	73.1 (9.8)	72.5 (9.8)	70.1 (5.4)	71.3 (6.1)	1.2 (-0.08 – 1.64)	0.14
Hip circumference (cm)	92.9 (7.8)	92.0 (7.8)	90.6 (7.2)	90.4 (7.4)	0.73 (-1.01 – 2.45)	0.11
WHR	0.78 (0.06)	0.77 (0.06)	0.79 (0.06)	0.81 (0.07)	0.007 (0.000 – 0.014)	0.18
SBP (mm Hg)	121 (5)	118 (8)	127 (15)	125 (13)	7 (-2.96 – 1.80)	0.05
DBP (mm Hg)	73 (12)	72 (12)	70 (10)	72 (8)	0 (-5.96 – 4.11)	0.09
Activity Time (min ^{-day})						
Sedentary	561.15 (64.39)	500.93 (49.05) ^a	588.59 (73.49)	637.08 (84.54) ^{a,b,c}	136.15 (91.91 - 180.39)	1.8
Moderate	111.10 (43.48)	136.65 (46.52) ^a	103.70 (29.01)	79.45 (29.89) ^{a,b,c}	57.20 (32.17 - 82.23)	1.5
Vigorous	3.20 (1.93)	7.55 (1.90) ^a	3.15 (2.92)	2.15 (1.76) ^{a,b,c}	5.40 (4.22 - 6.57)	1.2
Cardiometabolic Blood measures						
Glucose (mmol/L)	4.27 (0.77)	4.15 (0.79)	4.33 (0.79)	4.53 (0.56) ^{a,b}	0.38 (-0.02 - 0.78)	0.46
Insulin (μIU/mL)	2.77 (1.16)	2.14 (1.25) ^a	4.32 (1.82)	3.50 (1.48) ^{a,b,c}	0.37 (-0.48 - 1.21)	1.0
HOMA-IR	0.58 (0.25)	0.46 (0.21) ^a	0.67 (0.23)	0.74 (0.25) ^{a,b,c}	0.26 (0.15 - 0.42)	0.9
TG (mmol/L)	0.73 (0.21)	0.56 (0.17)	0.69 (0.23)	0.81 (0.28) ^b	0.26 (0.11 - 0.39)	0.43
TC (mmol/L)	4.74 (0.29)	4.49 (0.29)	4.79 (0.21)	4.85 (0.22) ^{a,b,c}	0.37 (0.21 - 0.52)	0.98
LDL-c (mmol/L)	3.13 (0.24)	2.89 (0.30)	3.09 (0.26)	3.09 (0.24)	0.21 (0.04 - 0.37)	0.87
HDL-c (mmol/L)	1.31 (0.06)	1.32 (0.84)	1.33 (0.10)	1.31 (0.11) ^b	0.003 (-0.06 - 0.06)	0.06
CMR score	0.81 (0.62)	0.77 (0.63)	0.81 (0.52)	0.99 (0.48) ^{a,b,c}	0.22 (-0.05 -0.68)	0.63

Note- ^a= significant change PRE to POST. ^b= significant difference between group . ^c= significant group x time interaction

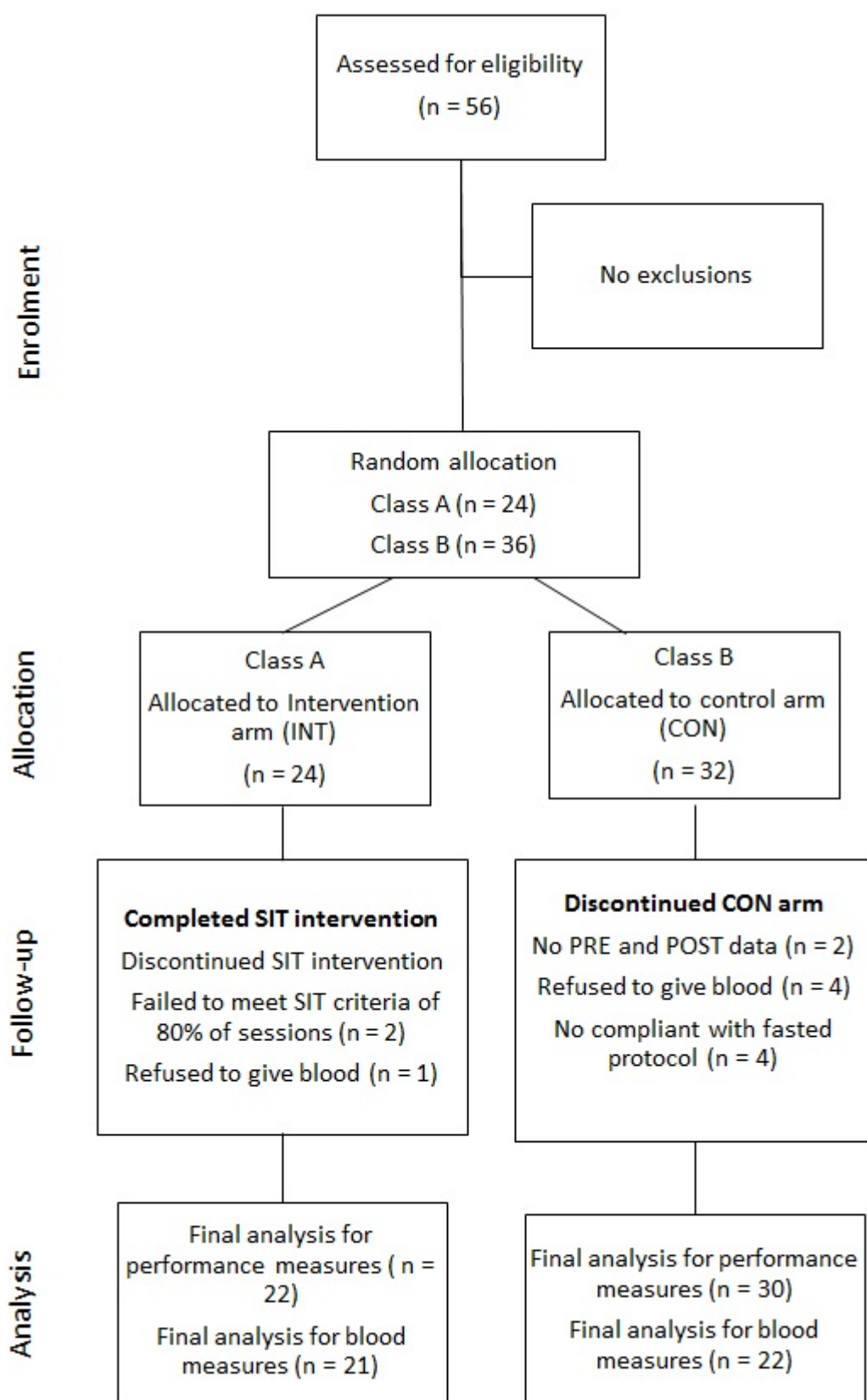


FIG 1. Flow diagram depicting participant enrolment, allocation and progress through the study.

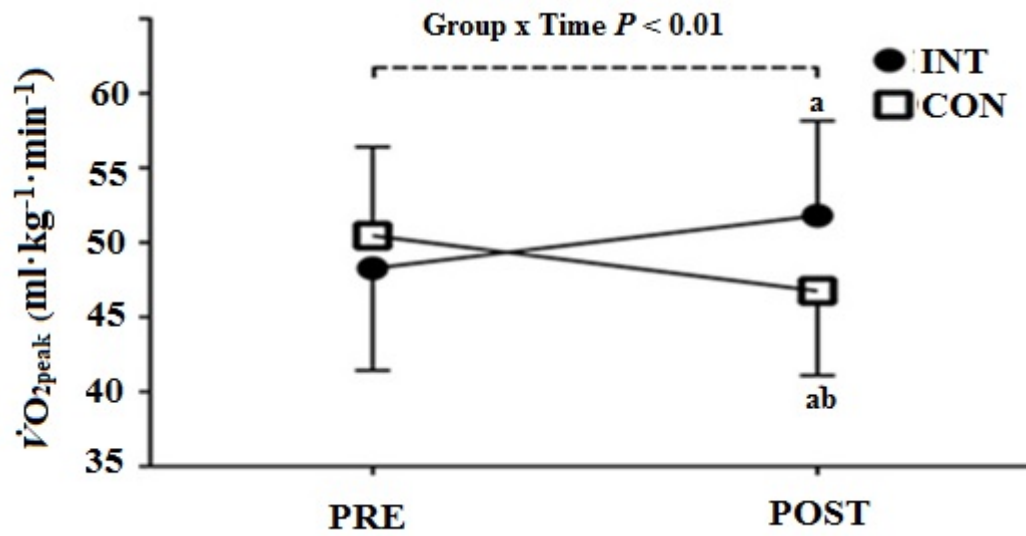


FIG 2. Predicted cardiorespiratory fitness ($\dot{V}O_{2max}$) prior to (PRE) and after (POST) in INT and CON.

Note: a= significant difference from PRE to POST in within groups ($P < 0.05$). b= significant differences between groups at POST ($P < 0.05$).

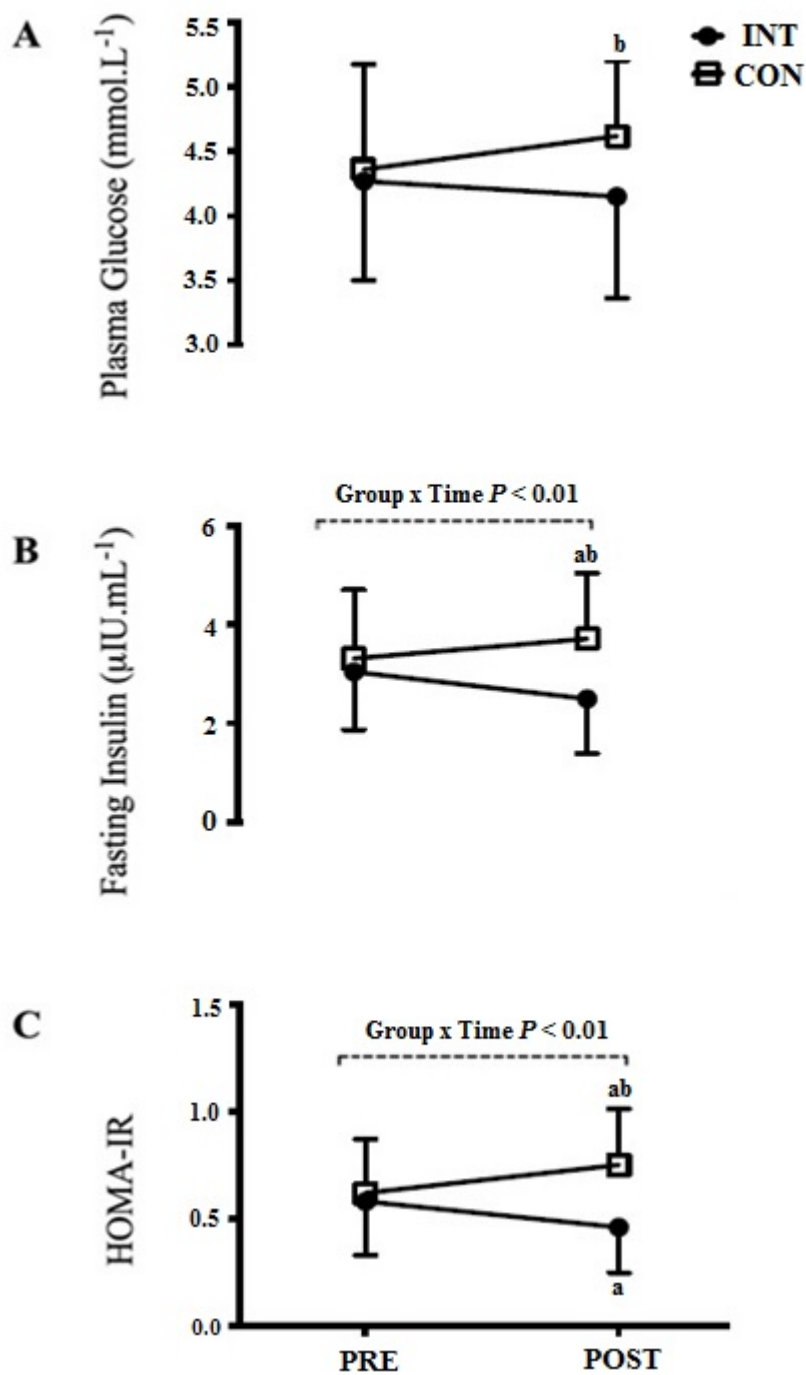


FIG 3. **A-** Fasting blood glucose levels PRE to POST intervention. **B-** Fasting insulin levels PRE to POST intervention. **C-** HOMA-IR PRE to POST intervention. Note: a= significant difference from PRE to POST in within groups ($P < 0.05$) b= significant differences between groups at POST ($P < 0.05$)