CARDIORESPIRATORY FITNESS AND VASCULAR STRUCTURE AND FUNCTION IN FIRST-YEAR POST-PRIMARY SCHOOL STUDENTS

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Declaration

I hereby certify that this material, which I now submit for assessment on the programme of study leading to the award of Doctor of Philosophy is entirely my own work, and that I have exercised reasonable care to ensure that the work is original and have conformed to the regulations on the use and declaration of Generative AI, and does not to the best of my knowledge breach any law of copyright, and has not been taken from the work of others save and to the extent that such work has been cited and acknowledged within the text of my work. I hereby certify that no Generative Artificial Intelligence (Gen AI) tools have been used in the creation of the thesis.

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Abbreviations

20mSRT	20-m shuttle run test
ANOVA	Analysis of variance
AR	Adrenergic receptors
ASCVD	Atherosclerotic cardiovascular disease
AUC	Area under the receiver operating characteristic curve
baPWV	Brachial-ankle pulse wave velocity
BCTs	Behaviour change techniques
BF%	Body fat percentage
BIA	Bioelectrical impedance analysis
BM	Body mass
BMI	Body mass index
BP	Blood pressure
CCA	Common carotid artery
cfPWV	Carotid–femoral pulse wave velocity
CI	Confidence interval
cIMT	Carotid intima-media thickness
CMR	Cardiometabolic risk
CRF	Cardiorespiratory fitness
CRP	C-reactive protein
CV	Cardiovascular
CVD	Cardiovascular disease
DBP	Diastolic blood pressure
DEIS	Delivering Equality of Opportunity in Schools
est$\dot{V}O_2$max	Estimated maximal oxygen uptake
est$\dot{V}O_2$peak	Estimated peak oxygen uptake
FFM	Fat-free mass
FITT	Frequency, intensity, time and type
FN	False negatives
FP	False positives
GBDT	Gradient Boosting Decision Tree

HDL-C	High-density lipoprotein cholesterol
HIIT	High intensity interval training
HIT	High-intensity training
HR	Heart rate
HR@L1	Heart rate at level 1
HR@L2	Heart rate at level 2
HRmax	Maximal heart rate
HRPF	Health-related physical fitness
HRR	Heart rate reserve
hs-CRP	High-sensitivity C-reactive protein
ICCs	Intraclass coefficients
IQR	Interquartile range
LDL-C	Low-density lipoprotein cholesterol
LIFE	Lifestyle Intervention for Everyone
MANCOVA	Mixed multivariate analysis of covariance
MANOVA	Multivariate analysis of variance
MET	Metabolic equivalent
METs	Metabolic equivalents
MetS	Metabolic syndrome
MI	Myocardial infarction
ML	Machine learning
MVPA	Moderate-to-vigorous physical activity
ORs	Odds ratios
PA	Physical activity
PA4E1	Physical Activity 4 Everyone
PCA	Principal component analysis
PE	Physical education
PHRM	Predicted heart rate maximum
PHV	Peak height velocity
PKA	Protein kinase A
PNS	Parasympathetic nervous system

PWV	Pulse wave velocity
Q–Q	Quantile–quantile
RHR	Resting heart rate
RPE	Rate of perceived exertion
SA	Sinoatrial
SBP	Systolic blood pressure
SCT	Social Cognitive Theory
SD	Standard deviation
SDT	Self-Determination Theory
SEE	Standard error of the estimate
SEM	Sport Education Model
SES	Socioeconomic status
SFC	Schools' Fitness Challenge
SHAP	SHapley Additive exPlanations
SMCs	Smooth muscle cells
SMOTE	Synthetic minority oversampling technique
SNS	Sympathetic nervous system
T1DM	Type 1 diabetes mellitus
T2DM	Type 2 diabetes mellitus
TC	Total cholesterol
TG	Triglyceride
TGfU	Teaching Games for Understanding
TN	True negatives
TP	True positives
VIF	Variance inflation factor
$\dot{V}O_2max$	Maximal oxygen uptake
$\dot{V}O_2peak$	Peak oxygen uptake
WC	Waist circumference
WHO	World Health Organization
WHR	Waist-to-hip ratio
WHtR	Waist-to-height ratio

THE IMPACT OF CARDIORESPIRATORY FITNESS LEVELS ON VASCULAR HEALTH AMONG FIRST-YEAR POST-PRIMARY SCHOOL STUDENTS

Kevin O'Brien

Abstract

Study 1 established baseline normative values for cardiorespiratory fitness (CRF) using the 20 m shuttle run test (20mSRT) and examined disparities associated with school-level socioeconomic status (SES) among Irish first-year post-primary students. Retrospective analysis of national data collected between 2013 and 2018 demonstrated significantly lower CRF among students attending Delivering Equality of Opportunity in Schools (DEIS) schools, with the largest disparities observed in females, despite modest temporal improvements in female fitness levels.

Study 2 evaluated the effectiveness of a six-week nationwide school-based physical activity programme in improving CRF and explored factors influencing programme participation. Analysis of pre- and post-intervention 20mSRT data revealed significant improvements in CRF, with the greatest gains observed among the least-fit students (approximately 24%). In addition, a machine learning model was developed to predict class-level non-completion of post-intervention testing with high accuracy, providing a novel approach to identifying participation barriers.

Study 3 investigated the association between CRF, SES, and markers of subclinical cardiovascular disease (CVD) in a cohort of 540 adolescents. Lower CRF and lower SES were significantly associated with increased arterial stiffness, as measured by pulse wave velocity (PWV), but not carotid intima-media thickness (cIMT). Students attending DEIS schools exhibited poorer vascular health compared with their non-DEIS peers. Regression analyses indicated that CRF, body composition, and blood pressure (BP) were significant predictors of arterial stiffness

Study 4 examined the effects of a four-week targeted, school-based exercise intervention on CRF, vascular health, body composition, and BP in students attending a DEIS school. The prevalence of metabolic syndrome (MetS) within the cohort was 5.5%. No statistically significant improvements were observed across physiological or vascular outcomes following the intervention, highlighting the limitations of short-duration programmes and the need for sufficient exercise dose to elicit meaningful adaptations.

Study 5 evaluated the attainment of predicted maximal heart rate (PHRM) during the 20mSRT, examined physiological strain across CRF quartiles, and assessed the predictive value of submaximal HR responses. PHRM values closely approximated measured HRmax across commonly used equations. Females exhibited higher submaximal HR responses than males, and heart rate responses during the early stages of the test were inversely associated with overall performance, indicating their potential utility as practical predictors of CRF in school-based settings.

In conclusion, this thesis demonstrates clear socioeconomic disparities in CRF and early cardiovascular risk among Irish adolescents. While school-based interventions can improve CRF, particularly among lower-fit students, their effectiveness is dependent on sufficient duration, intensity, and implementation fidelity. These findings support the need for targeted, evidence-based strategies within school settings to reduce health inequalities and improve long-term cardiovascular outcomes in youth populations.

CHAPTER I

INTRODUCTION

Cardiovascular disease (CVD) encompasses a range of disorders affecting the heart and circulatory system, including coronary artery disease, cerebrovascular disease, peripheral vascular disease, rheumatic heart disease, congenital heart disease, aortic aneurysm, deep venous thrombosis and pulmonary embolism. Globally, CVD accounts for over 18.6 million deaths annually and approximately 45% of all non-communicable disease deaths.[1] In Europe, an estimated 113 million people were living with CVD in 2019 contributing to approximately 85 million disability-adjusted life years, underscoring a substantial population burden.[2] Autopsy studies demonstrate that atherosclerotic changes begin early in life. Moreover, exposure to modifiable risk factors during youth is associated with more advanced atherosclerotic lesions.[3,4]

Coronary atherosclerosis - the primary pathological process underlying CVD involves structural remodelling in the subendothelial layer of medium-to large-sized coronary arteries, leading to fibro-fatty plaque formation.[5] It major clinical manifestation include stable and unstable angina, myocardial infarction, and sudden cardiac death. While these typically present in middle and older age,[6] the disease process is imitated much earlier and is accelerated by genetic predisposition along with modifiable risk factors such as a sedentary lifestyle, elevated low-density lipoprotein cholesterol, obesity, diabetes and hypertension.[7] Evidence from autopsy studies further indicates that the severity of asymptomatic atherosclerotic CVD (ASCVD) is positively associated with the number of ante-mortem risk factors.[3]

Non-invasive assessment of sub-clinical ASCVD commonly employs surrogate markers such as carotid intima-media thickness (cIMT) and arterial stiffness. cIMT measured via ultrasound, quantifies structural changes in the intima-media layers of the superficial carotid arteries[8] and is associated with an increased risk for cardiovascular events.[9] Arterial stiffness is frequently assessed using pulse wave velocity (PWV) which measures at which the pressure wave travels along the arterial tree. An arterial stiffness increases with disease progression, PWV rises and serves as a strong predictor of adverse cardiovascular outcomes.[10]

Adolescence represents a critical window for the establishment of health behaviours that influence modifiable ASCVD risk factors including obesity, physical inactivity, sedentary lifestyle, unhealthy dietary habits and tobacco use.[3,4,11] Early interventions targeting these behaviours is essential to mitigate long-term cardiovascular risk.[12,13]

Cardiorespiratory fitness (CRF) is inversely associated with CVD and is a strong independent predictor of both all-cause and cardiovascular mortality.[14–17] Low CRF in youth is associated with a higher burden of CVD risk factors and the presence of sub-clinical disease.[18,19] Maximal oxygen uptake ($\dot{V}O_2max$) is the gold-standard measure of CRF, typically expressed as $mL \cdot kg^{-1} \cdot min^{-1}$ or metabolic equivalents (METs; 1 MET = 3.5 $mL \cdot kg^{-1} \cdot min^{-1}$). Threshold values of 41.8 $mL \cdot kg^{-1} \cdot min^{-1}$ for males and 34.6 $mL \cdot kg^{-1} \cdot min^{-1}$ for females have been associated with more favourable cardiovascular profile in adolescents.[20] Given that CRF tracks from childhood into adolescence, low during youth, is linked to an elevated risk of CVD later in life.[21] Despite the prognostic importance, there is a lack of contemporary Irish school-based data describing CRF distributions and their associations with cardiometabolic and subclinical vascular markers during early adolescence, limiting context-specific surveillance and intervention planning.

Direct laboratory-based measurement of $\dot{V}O_2$max is resource-intensive requiring expensive equipment, trained personnel and considerable time. Consequently field-based tests such as the 20-m shuttle run test (20mSRT) are widely used to estimate CRF in youth. The 20mSRT is an incremental exercise test that involves continuous running between 2 lines 20 m apart in synchrony with an audio signal and the most widely used field test to estimate CRF in youth.[22] The popularity of the 20mSRT is due in part to the fact that it is reliable,[23] simple to administer, low-cost, and can be used to measure large groups simultaneously, without the need for specialised human resources or equipment. A major limitation of the 20mSRT is that it relies on the participant's motivation to exert a maximal effort. Heart rate (HR)–based indices, relative HR and stage-by-stage HR responses, provide objective indicators of exercise intensity and support the assessment of effort. Nevertheless, few field-based studies have incorporated these physiological markers to verify maximal effort/exertion during the 20mSRT.[24]

Socioeconomic status is a key determinant of health inequalities and predicts disparities in both youth and adult health outcomes.[25] Children from socioeconomically disadvantaged backgrounds are more likely to be exposed to CVD risk factors including physical inactivity, sedentary behaviour, and poor nutrition.[26] In Ireland the 'delivering equality of opportunity in schools' (DEIS) programme introduced in 2015 provides additional support to schools in disadvantaged areas.[27] In 2025, 232 of all 722 post-primary schools in Ireland were designated as DEIS schools.[28] Students attending DEIS schools demonstrate higher absenteeism, lower parental support, reduced progression to third-level education and a higher rates of substance use.[29] They also exhibit lower levels of daily physical activity[30] and CRF[31] compared with their peers in non-DEIS schools.

The purpose of this PhD is to examine health related fitness levels among first-year post-primary school students and to investigate their associations with vascular health markers across differing socioeconomic school contexts with a particular focus on sex-based differences.

Covid Adaptations

- COVID-19 restrictions from March 2020 to September 2021 made access to schools impossible for prolonged periods and limited exercise testing, creating substantial uncertainty and disruption to data collection for this PhD
- Study 3 and 5 were due to be completed in 2020. COVID-19 restrictions at the time made it impossible to collect data until late 2021 into early 2022
- Although Study 3 was originally designed to include all post-primary year groups (ages 12-18), the loss of approximately two years of testing time during the COVID-19 pandemic necessitated restricting recruitment to first-year students which aligned with Studies 1 and 2
- When it became obvious that undertaking human testing was going to be limited, the direction of my research was shifted to a focus on data analytics and machine learning
- I learned three programming languages aligned with the project needs: MySQL to manage the Schools' Fitness Challenge database (Studies 1 and 2), R to implement GAMLSS for percentile modelling, and Python to support machine-learning and broader data-processing tasks
- In April 2020, I completed a 4-week Coursera course – 'The Data Scientists Toolbox', a 5-week Coursera course – 'MySQL – Managing Big Data' (Appendices B, C) focusing on MySQL, a programme based around the storing of data, creating databases
- In April 2021, I completed a 12-week course – 'Foundations: Data, Data, Everywhere' endorsed by Google (Appendix D) focusing on the R programming language
- In June 2021 I enrolled in a 4-month evening course 'Specialist Certificate in Data Analytics' offered through the UCD Professional Academy. I completed this in October

2021 with a distinction (Appendix E) and a certificate from Datacamp, an online platform for learning programming languages.

Research Studies

Study 1: A retrospective analysis of 20m shuttle run test performance among first year post-primary school students

Study 2: A retrospective analysis of a 6-week exercise intervention on cardiorespiratory fitness levels among first year post-primary school students

Study 3: Individual and combined effects of health-related fitness components and school socioeconomic status on subclinical CVD among first-year post-primary school students

Study 4: Effect of a school-based exercise intervention on cardiorespiratory fitness and vascular health in first year students attending a DEIS post-primary school

Study 5: Comparison of measured and predicted maximal heart rate and submaximal heart rate responses among Irish first-year post-primary students during the 20m shuttle run test

CHAPTER II

LITERATURE REVIEW

Health-related physical fitness

Health-related physical fitness (HRPF) refers to a multidimensional state that reflects an individual's capacity to perform specific exercises or functions, and the maintenance or enhancement of physiological function across biological systems contributing to disease prevention and rehabilitation.[32] HRPF is strongly associated with both current and future health outcomes in children and adolescents'.[33] Its primary components include cardiorespiratory fitness (CRF), muscular strength and endurance, body composition, and flexibility.[34]

Sex differences in HRPF become increasingly evident during early adolescence as biological maturation accelerates. Puberty is characterised by rapid, sexually dimorphic changes in body size and composition, driven by sex steroids and growth hormone. Boys typically accrue greater fat-free mass and skeletal muscle, whereas girls experience relatively larger increases in gains in fat mass.[35,36] These maturation-changes, alongside neuromuscular development, provide a physiological basis for higher muscular strength (e.g., handgrip strength) observed in males compared with females.[31] Furthermore, developmental trajectories in CRF are influenced by maturity status and morphological factors, such that sex differences in peak aerobic fitness generally widening across puberty.[37]

CRF reflects the integrated function of cardiovascular, respiratory, and muscular systems to deliver and utilise oxygen during sustained physical activity (PA).[38] The gold standard measure of CRF is maximal oxygen uptake ($\dot{V}O_2max$) defined as the highest rate of oxygen consumption achieved during exercise to volitional exhaustion.[39] The terms $\dot{V}O_2max$

and peak oxygen uptake ($\dot{V}O_2$peak) are often used interchangeably; however they are distinct. VO_2max requires the demonstration of plateau in oxygen uptake despite an increased workload, whereas VO_2peak refers the highest observed oxygen uptake when a plateau is not achieved.[40] Absolute $\dot{V}O_2$max ($L \cdot min^{-1}$) typically increases in males until approximately 18 years of age, while remaining relatively stable in females between the ages of 14 and 18 years.[41] When expressed relative to body mass, sex differences in $\dot{V}O_2$max become more pronounced following puberty.[42]

20 Metre Shuttle Run Test

The 20mSRT, also known as the "beep test" or the Progressive Aerobic Cardiovascular Endurance Run, is a widely used multistage field-based fitness test for estimating $\dot{V}O_2$max in children and adolescents.[23] During the test, participants run between two lines 20m apart, synchronised with an audio signal that dictates pace. The number of completed shuttles is used to predict $\dot{V}O_2$max.[43] The test begins at a velocity of 8.5 $km \cdot h^{-1}$ with increments of 0.5 $km \cdot h^{-1}$ each min. Details of the 20mSRT structure (i.e., level/stage, velocity, and time per stage) are provided in Table 2.1. The 20mSRT can be performed indoors and outdoors, accommodates large numbers of participants and requires minimal equipment or specialised training to administer.[38] Its simplicity, cost-effectiveness, and ease of interpretation contribute to its widespread use in school and research settings.

Table 2.1: 20mSRT Level-Shuttle Reference Table: Speed, Time, and Distance

Level	Shuttles	Total Shuttles	Speed (km/h)	Time per shuttle (s)	Total level time (s)	Cumulative Time (min:s)	Distance per level (m)	Total Distance (m)
1	7	7	8.5	9	63	01:03	140	140
2	8	15	9	8	64	02:07	160	300
3	8	23	9.5	7.58	60.6	03:08	160	460
4	9	32	10	7.2	64.8	04:12	180	640
5	9	41	10.5	6.86	61.7	05:14	180	820
6	10	51	11	6.55	65.5	06:20	200	1020
7	10	61	11.5	6.26	62.6	07:22	200	1220
8	11	72	12	6	66	08:28	220	1440
9	11	83	12.5	5.76	63.4	09:32	220	1660
10	11	94	13	5.54	60.9	10:32	220	1880
11	12	106	13.5	5.33	64	11:36	240	2120
12	12	118	14	5.14	61.7	12:38	240	2360
13	13	131	14.5	4.97	64.6	13:43	260	2620
14	13	144	15	4.8	62.4	14:45	260	2880
15	13	157	15.5	4.65	60.4	15:46	260	3140
16	14	171	16	4.5	63	16:49	280	3420
17	14	185	16.5	4.36	61.1	17:50	280	3700
18	15	200	17	4.24	63.5	18:53	300	4000
19	15	215	17.5	4.11	61.7	19:55	300	4300
20	16	231	18	4	64	20:59	320	4620
21	16	247	18.5	3.89	62.3	22:01	320	4940

20mSRT Validity/Reliability/Feasibility

Validity refers to the extent to which the 20mSRT accurately reflects VO_2max, reliability denotes the consistency of test outcomes under similar conditions, and feasibility relates to the practicality of administering the test in school settings (e.g., time, space, equipment, staff demands, safety, and acceptability).

A meta-analysis of 57 studies, reported that the criterion validity of the 20mSRT in children is moderate to high (r=0.66-0.84).[44] This supports earlier findings by Matsuzaka et al. (2004)[45] who concluded that criterion-validity was higher in adults (r=0.92) than in children (r=0.75) and adolescents (r=0.76) when used under similar conditions. The comparatively

lower validity in youth may reflect substantial inter-individual variability in biological maturation status among children and adolescents.[23]

Addressing this limitation, Nevill et al. (2019)[46] reanalysed data from a female adolescent cohort (mean age 13.4 years) and reported strong correlations between 20mSRT performance and $\dot{V}O_2$peak (r=0.91). Furthermore, Mayorga-Vega et al. (2015)[44] demonstrated that criterion validity improves when covariates such as age, body mass, and body fat percentage (BF%) are included in the prediction model (r=0.78-0.95). While multivariable equations may enhance estimation accuracy, the inclusion of adiposity related variables introduces shared variance, meaning that estimated CRF may partially reflect body composition rather than physiological capacity. [47,48]

Concerns have also been raised regarding the use of ratio-scaled $\dot{V}O_2$max ($mL \cdot kg^{-1} \cdot min^{-1}$) derived from 20mSRT equations.[48] Welsman and Armstrong (2019)[48] reported wide prediction error and no meaningful association with laboratory-measured $\dot{V}O_2$max after adjusting for body size and maturation, suggesting that such estimates may reflect adiposity as much as true CRF. Accordingly, although the 20mSRT demonstrates strong utility, caution is warranted when interpreting predicted $\dot{V}O_2$ values. Reporting raw performance (e.g., final speed, stage or total shuttles) and/or alternative scaling approaches is recommended. In terms of a reliability, a systematic review of 32 studies involving children aged 8-18 years reported intraclass coefficients (ICCs) ranging from 0.78 to 0.98, indicating high test-retest reliability.[49] Comparable reliability has also been observed in adults (ICC=0.90).[50]

The 20mSRT is believed to be highly feasible for use in school settings. It can be administered effectively to large groups with minimal equipment, space, and personnel requirements and does not require specialized laboratory facilities.[51] Additionally, the

externally paced audio signals help standardise effort and reduce pacing variability among participants.[43]

20mSRT Normative Data

Age- and sex-specific normative data for estimated $\dot{V}O_2$peak (est$\dot{V}O_2$peak) in youth have been derived from large international datasets (Table 2.2).[52] Across all age groups, males have higher est$\dot{V}O_2$peak (mL·kg^{-1}·min^{-1}) values than females, with sex differences becoming more pronounced with increasing age.[52]

Among adolescents aged 12-13 years est$\dot{V}O_2$peak values range from 34.6 to 55.4 mL·kg^{-1}·min^{-1} in males and from 32.6 to 49.3 mL·kg^{-1}·min^{-1} in females.[52] Longitudinal trends indicate a decline in median (50th percentile) values with age. In males, median (50th percentile) values decrease from 48.1 mL·kg^{-1}·min^{-1} at age 6 years to 42.6 mL·kg^{-1}·min^{-1} at age 17 years.[52] In females, corresponding values decline from 46.7 mL·kg^{-1}·min^{-1} to 34.1 mL·kg^{-1}·min^{-1} at age 17 years.[60] Similar age-related declines have been reported by Buchan et al. (2019)[53] with reductions from 48.1 mL·kg^{-1}·min^{-1} to 45.0 in males and from 45.6 mL·kg^{-1}·min^{-1} to 34.7 mL·kg^{-1}·min^{-1} in females between ages 10 and 17 years.

These normative data provide important reference points for interpreting CRF in youth populations; however, they should be applied with consideration of methodological limitations associated with prediction equations and population-specific differences.

Table 2.2: Sex-specific normative data for est$\dot{V}O_2$peak ($mL \cdot kg^{-1} \cdot min^{-1}$)[52]

	Male		Female	
Centile	**12 years**	**13 years**	**12 years**	**13 years**
5	36.0	34.6	34.6	32.6
10	38.0	36.9	36.2	34.3
20	40.5	39.7	38.2	36.4
30	42.3	41.7	39.6	37.9
40	43.8	43.4	40.8	39.2
50	45.2	45.0	42.0	40.4
60	46.7	46.6	43.1	41.6
70	48.2	48.3	44.3	42.9
80	50.0	50.3	45.7	44.4
90	52.4	53.1	47.7	46.5
95	54.5	55.4	49.3	48.2

Effectiveness of School-Based Interventions to Improve CRF

Schools provide an ideal setting for implementation and delivery of health-promoting interventions for children and adolescents. A systematic review of 20 studies involving 6,621 youth reported that school-based PA interventions, with at least 8 weeks duration, produced modest improvements in CRF of 0.47 $mL \cdot kg^{-1} \cdot min^{-1}$ (95% confidence intervals (CI) 0.33 – 0.61). The greatest improvements were observed among students with the lowest baseline CRF while males demonstrated twice the improvement observed in females.[54]

Among Tunisian students age 13 to 15 years, a 12-week school-based high intensity interval training (HIIT) programme delivered three times per week resulted in a greater improvement in 20mSRT performance, body composition and metabolic markers compared with a control group following the standard PE curriculum.[55] However, participants were obese adolescent females, and findings may not generalize to mixed-sex or non-obese school populations.

In contrast, an improvement of 1 metabolic equivalent (MET) in CRF was reported in a mixed-sex cohort of healthy adolescents in a Scottish school following their participation in a 4-week sprint interval programme.[56] Similarly, a systematic review of short-duration (4 - 6

weeks) school-based HIIT interventions reported significant improvement in CRF as measured by the 20mSRT.[57] Collectively, these findings suggest that well-designed, time-efficient school-based programme -particularly higher-intensity formats - can enhance adolescent CRF, supporting the rationale for evaluating such interventions in real-world school settings.

Maximal heart rate

Valid assessment of $\dot{V}O_2$max depends on participants exercising to maximal effort.[24] However, 20mSRT performance may not always reflect the true maximal capacity in younger participants, as motivational and pacing can influence test outcomes.[38] Maximal heart rate (HRmax) refers to the number of beats per minute (bpm) achieve under maximum stress. The percentage of HRmax attained during laboratory or field-based incremental exercise testing (relative HR) can provide supportive evidence regarding the level of effort exerted and the likelihood that maximal or near-maximal intensity was achieved. Several valid regression equations have been developed to estimate predicted HRmax (PHRM) for specific populations, with selected examples presented in Table 2.3 with further detail in Table 2.4.[34] The development of population-specific equations has been driven by the need to reduce prediction error and improve the accuracy of exercise intensity interpretation.[58]

Table 2.3: Adolescent HRmax prediction equations

Author	Equation
Tanaka	208 - 0.7 x age
Nikolaidis	223 - 1.44 x age
Gelbart (1)	186 + 0.25 x RHR - 0.13 x BM
Gelbart (2)	164 + 0.27 x RHR - 0.155 x BM + 1.1 x METs + 0.258 x BF
Mahon	158 + 0.44 x RHR + 0.68 x age

HRmax, heart rate maximum; RHR, resting heart rate; BM, body mass (kg); METs, metabolic equivalents; BF, body fat %

Although the Fox equation (HRmax = 220 – age) is the most commonly used method for estimating HRmax it has well recognised limitations.[59] Specifically, it demonstrates substantial prediction error, with a typical standard deviation (SD) of approx. 10 - 12 b·min^{-1}, in younger individuals and older adults.[60,61] Consequently, individual estimates may deviate by ≥10 b·min^{-1}, and in some cases by as much as 20 b·min^{-1} or more.[62]

These limitations may be particularly relevant during adolescence when chronological age is a poor surrogate for biological maturation. Paediatric evidence suggests that HRmax may be relatively age-independent across children and adolescence, with some studies indicating the age-related declines may only emerge following puberty.[63] As a result, adolescents of the same chronological age but differing pubertal stage may display different HR responses despite sharing the same age-predicted HRmax.

Despite these well-documented inaccuracies,[59,62,64–66] the Fox equation remains widely used in clinical and fitness centres and continues to be endorsed by several professional organizations. It may however, be inappropriate for use in adolescent populations.[67] A systematic review concluded that HRmax may be largely age-independent in children and adolescents,[63] whereas other authors suggest that age dependency may emerge only after puberty.[68] Among youth cohorts, the Tanaka equation (208 - 0.7 x age) has demonstrated greater predictive accuracy than the Fox equation and may provide a more appropriate alternative when estimating HRmax in adolescent populations.[64,69,70]

Table 2.4: Studies examining the accuracy of PHRM equations and sample characteristics.

Study	Sample characteristics Sample age (mean±SD; years)	n (% female)	Study design Test protocol	PHRM	Over-, under-estimate, or valid?
Mahon et al. (2010)[71]	Children and adolescents (12.0±3.1)	52 (40.4)	Incremental/ treadmill	Fox Tanaka	Overestimate Valid
Machado and Denadai (2011)[69]	Adolescents (12.6±1.5)	69 (0.0)	Incremental/ treadmill	Fox Tanaka	Overestimate Valid
Caputo et al. (2012)[72]	Adolescents (13.2±0.8)	23 (56.5)	Shuttle run	Fox Tanaka	Overestimate Overestimate
Colantonio and Kiss (2013)[73]	Untrained and trained adolescents (7–17 years; mean not mentioned)	145 (51.0)	Bruce/treadmill	Fox	Overestimate
Nikolaidis et al. (2014)[74]	Athletes (13.4±2.0)	147 (100.0)	Shuttle run	Fox Tanaka	Overestimate Valid
Nikolaidis (2015)[64]	Athletes (15.8±1.5)	162 (0.0)	Modified Conconi	Fox Tanaka	Overestimate Underestimate
Gelbart et al. (2017)[75]	Athletes (13.7±2.1)	433 (29.6)	Incremental/ treadmill	15 equations	Underestimate higher HR_{max} Overestimate lower HR_{max}
Cicone et al. (2018)[70]	Athletes (14.6±0.6)	30 (0.0)	Incremental/ treadmill	Fox Tanaka Nikolaidis	Valid Underestimate Valid
Heinzmann-Filho et al. (2018)[76]	Obese (16.8±1.2)	59 (56.0)	Adapted ramp/ treadmill	Fox Tanaka	Overestimate Overestimate
Papadopoulou et al. (2019)[77]	Active adolescents (13.3±0.7)	71(100.0)	Shuttle run	Fox Tanaka	Overestimate Underestimate
Ghouili et al. (2023)[78]	Athletes (11 to 18 years)	801 (0)	Shuttle run	Fox Tanaka	Underestimate Overestimate

Physiological differences between children, adolescents, and adults influence cardiovascular responses to exercise. Younger individuals typically exhibit lower stroke volume and a higher HRmax than adults.[71] These developmental differences, together with evidence that overweight adolescents exhibit a lower HRmax that their normal-weight peers despite similar $\dot{V}O_2$max values during cycle ergometer testing,[79] suggest that age alone does not fully explain variability in HRmax or the accuracy of HRmax prediction equations.[80,81]

An analysis of maximal exercise tests involving 627 adolescents (70.4% male) found a small but statistically significant difference in HRmax between males and females.[75] Multivariate linear regression further demonstrated that resting HR (RHR), $\dot{V}O_2$max, body mass, and BF% were independent predictors of HRmax.[75] These findings highlight the complexity of predicting HRmax in adolescents, body composition, aerobic fitness, sex, and maturation status influence physiological responses during maximal exercise.

Attaining HR_{max} during the 20mSRT

HR criteria have been used in a small number of field studies to determine whether children and adolescents achieve near-maximal effort during the 20mSRT. Among a small cohort of thirty three 13–14-year-old schoolchildren, 94% achieved a HRmax during the 20mSRT within 5% of their laboratory-derived, age-predicted value calculated using the equation 220 – age.[82]

Among 206 participants aged 11–16 years, mean HRmax during the 20mSRT was 196 beats·min^{-1}, with most exceeding a literature-based non-age-specific criterion of >185 beats·min^{-1}.[24] In a more recent study of children aged 8-10-years, 35% reached PHRM (≥200 b·min^{-1}), while mean HRmax was 195 b·min^{-1}.[83] In elite adolescent badminton players (mean age 14 years), mean HRmax during the 20mSRT was 185±9 b·min^{-1}, suggesting potentially

lower peak responses $_{HRmax}$ in trained youth.[84] Overall, most young people appear capable of reaching very high peak HR's during the 20mSRT, often exceeding non-age-based thresholds, supporting its utility use as a maximal field test in many settings. However, peak HR responses appear influenced by age, training status and maturation, indicating that fixed HR cut-offs may not be equally appropriate across all youth populations.

Resting heart rate

The sympathetic (SNS) and parasympathetic (PNS) branches of the autonomic nervous system interact to regulate the rate of depolarisation of sinoatrial (SA) nodal cells at rest and during exercise[85] with PNS influences predominating at rest.[85,86] Bradycardia defined as a RHR <60 b·min^{-1} is a frequent adaptation response to endurance exercise training.[87] This reduction in HR is primarily mediated by increased cardiac vagal activity acting on M_2 muscarinic cholinergic receptors within the SA node, thereby slowing pacemaker activity.[88]

In contrast, autonomic dysfunction reflects impaired or imbalanced SNS-PNS regulation of cardiac control, which may contribute to elevated RHR and abnormal cardiovascular responses during exercise.[89] In adolescent populations, a higher RHR is associated with an adverse cardiometabolic profile, including higher blood pressure (BP),[90] increased adiposity,[91] higher blood glucose,[91] lower participation in structured exercise,[90] and reduced CRF.[92] Autonomic dysfunction has also been associated with increased prevalence of metabolic syndrome (MetS) in younger populations.[93]

Collectively, these findings suggest that RHR may serve as a practical marker of autonomic and cardiometabolic strain during early adolescence - a developmental period characterised by rapid biological change and widening health inequalities. In school-based cohorts, examining the clustering of elevated RHR with low CRF and early vascular or

metabolic burden may help identify adolescents on a higher-risk health trajectory before overt disparities emerge.

HR responses during exercise

HR increases linearly during an incremental exercise test with the chronotropic response primarily governed by the frequency of depolarisation of SA nodal cells.[94] At the onset of exercise the initial rise in HR is driven predominantly by rapid withdrawal of parasympathetic tone, which is swiftly followed by increased sympathetic nervous system activation.[95] Postganglionic sympathetic fibres release norepinephrine which binds to β adrenergic receptors on the SA node.[85] Concurrently, preganglionic sympathetic nerves innervating chromaffin cells in the adrenal medulla release acetylcholine, which acts on nicotinic cholinergic receptors to stimulate epinephrine secretion into the systemic circulation.[96]

Catecholamine binding to β adrenergic receptors activates G_s-protein-coupled receptors, leading to the stimulation of adenylyl cyclase, increased cyclic adenosine monophosphate, and subsequent activation of protein kinase A (PKA).[97] PKA-mediated phosphorylation of sarcolemmal sodium channels, as well as T-type and L-type calcium channels, steepens the pacemaker potential slope by enhancing sodium and calcium permeability,[98] thereby accelerating spontaneous depolarisation and elevating HR. In addition to its positive chronotropic effect, SNS activation also exerts positive dromotropic (conduction velocity) and inotropic (contractility) effects on the myocardium.

Following a period of endurance exercise training, submaximal HR at a given absolute workload is reduced.[99] This training-induced bradycardia is associated with enhanced endurance exercise performance[100–102] and is considered a key marker of improved

cardiovascular efficiency. The attenuation in submaximal HR largely reflects reduced sympathetic activation at a same workload, representing a central physiological adaptation to endurance training.[87]

HR at both submaximal and maximal exercise intensities is typically higher in children and adolescents compared with adults. This age-related elevation HR declines progressively during adolescence, consistent with ongoing cardiovascular maturation.[103] Sex differences are also evident, with males generally exhibiting lower HR than females at equivalent relative or absolute workloads. These sex- and maturation-related differences can further vary according to exercise modality (e.g., treadmill running versus cycle ergometry).[103] Consequently, when interpreting HR data from the 20mSRT) in 13–14-year-olds, it is essential to account for sex- and maturation-associated differences in HR response at a given stage, as well as the specific demands of the intermittent shuttle protocol, particularly when employing HR thresholds to estimate effort or when comparing cardiovascular strain between males and females.[103]

Cardiovascular Disease

Cardiovascular diseases (CVDs) comprise a heterogeneous group of disorders affecting the heart and blood vessels, include coronary heart disease, heart failure, cerebrovascular disease (stroke), peripheral arterial disease, rheumatic heart disease, congenital heart disease, deep venous thrombosis, and pulmonary embolism.[104] In 2021, CVD accounted for 33% (20.5 million) of all deaths globally, with approximately 70% attributable to myocardial infarction (MI) or stroke.[105] Furthermore, one-third of CVD-related deaths in 2017 occurred in individuals younger than 70 years of age.[1] The burden of CVD is also disproportionately high among females in the European Union (EU), with prevalence

estimates of approximately 60 million women compared with 53 million men affected.[2] In Ireland approximately 10,000 death annually are attributed to CVD, accounting for 27% of all deaths.[106] The economic burden of CVD is substantial, with the European Heart Network estimating an annual cost of approximately €210 billion to the EU economy.[2]

Atherosclerotic cardiovascular disease

Atherosclerotic cardiovascular disease (ASCVD) refers to the pathological development of fibro-fatty plaques within the walls of medium-and large-sized muscular arteries, particularly those supplying the heart, brain, and lower extremities. It represents the leading cause of CVD globally, and is clinically manifested through conditions such as MI, cerebrovascular infarction, and intermittent claudication.

Endothelial dysfunction, induced by chronic exposure to established cardiovascular risk factors, plays a central role in the initiation and progression of atherosclerosis. The vascular endothelium, consisting of a single monolayer of endothelial cells, is critically involved in maintaining vascular homeostasis. In addition to endothelial cells, low-density lipoprotein cholesterol (LDL-C), platelets, monocytes, T lymphocytes, and vascular smooth muscle cells (SMCs) are key contributors to atherogenesis.[5]

The subendothelial accumulation and retention of LDL-C constitutes a pivotal early event in atherosclerosis development.[5] Prolonged retention within the subendothelial matrix increases the susceptibility of LDL-C particles to oxidative modification, particularly in the context of endothelial injury.[107] Oxidised LDL-C subsequently stimulates endothelial cells to express leukocyte adhesion molecules, chemotactic cytokines, and growth factors, thereby promoting the recruitment of circulating monocytes into the arterial wall.[108] Following migration into the intima, monocytes differentiate into macrophages, which internalise

oxidised LDL-C through scavenger receptors. Together with SMCs, these macrophages transform into lipid-laden foam cells, forming the earliest visible atherosclerotic lesions, commonly referred to as fatty streaks.[108] These lesions may progressively evolve into advanced plaques prone to rupture, precipitating acute thrombotic events such as MI.

As atherosclerotic lesions progress, macrophages and SMCs undergo apoptosis and necrosis, contributing to the formation of a lipid-rich necrotic core. This core represents a site of persistent inflammation characterised by the accumulation of macrophages, SMCs, and T lymphocytes.[107,109] Concurrently, SMCs originating from the medial layer undergo phenotypic modulation and migrate into the intima, where they synthesise extracellular matrix proteins, particularly collagen, leading to the development of a fibrous cap overlying the lipid core.[110]

Progressive plaque growth induces vascular remodelling, initially characterised by compensatory outward expansion of the arterial wall in an abluminal direction, thereby preserving luminal diameter.[5] However, continued plaque progression may eventually result in luminal narrowing and impaired coronary artery perfusion.[5] Such reductions in blood flow become particularly clinically significant during periods of increased myocardial oxygen demand, such as physical exertion.[111]

Complications of Atherosclerosis

The fibrous cap of an atherosclerotic plaque is a metabolically active structure that undergoes continuous and dynamic remodelling.[112] Macrophages and vascular SMCs play central roles in this process through the production of proteolytic enzymes, including matrix proteinases, which degrade components of the arterial extracellular matrix, particularly collagen.[113] The structural integrity of the fibrous cap is therefore determined by the balance

between extracellular matrix synthesis and degradation.[113] Disruption of this balance may weaken the fibrous cap, predisposing the plaque to rupture and subsequent thrombus formation. Plaque rupture is a major pathological event underlying acute thrombotic complications, including myocardial MI and ischaemic stroke.

Atherosclerotic plaques that are prone to rupture are commonly characterised by a large lipid-rich necrotic core covered by a thin fibrous cap and are termed *vulnerable plaques*.[114] In contrast, plaques containing smaller lipid cores and thicker, collagen-rich fibrous caps are generally considered *stable plaques*, as they are less susceptible to rupture. The distinction between vulnerable and stable plaques is clinically significant, as plaque vulnerability is more strongly associated with acute cardiovascular events than the degree of luminal stenosis alone.

Most individuals with ASCVD remain asymptomatic for prolonged periods, often for several decades, during which atherosclerotic lesions progressively develop.[110,112] Clinical manifestations typically arise only when plaque progression results in substantial luminal narrowing or when plaque rupture precipitates acute thrombotic occlusion of the affected vessel.[110,112,115] Consequently, symptoms are generally related to reduced tissue perfusion secondary to chronic stenosis or sudden vascular obstruction.

ASCVD in Youth

Although the clinical manifestations of ASCVD typically become apparent in adulthood, the atherosclerotic process is initiated much earlier in life due in response to exposure to established CVD risk factors during childhood and adolescence. The concept that atherosclerosis originates in early life is supported by substantial pathological and

epidemiological evidence demonstrating the presence of subclinical vascular changes in children and young adults.

The Bogalusa Heart Study was among the first major investigations to demonstrate associations between modifiable cardiovascular risk factors in childhood and structural alterations within the cardiovascular system.[116] In an autopsy sub-study involving 93 young individuals who died from non-cardiovascular causes, almost all participants demonstrated evidence of fatty streak formation within the aorta.[116] The prevalence of fatty streaks within the coronary arteries increased markedly with age, from approximately 50% among individuals aged 2–15 years to 85% among those aged 21–39 years.[116] The prevalence of more advanced fibrous plaques also increased substantially with age, rising from 8% in individuals aged 2–15 years to 69% in those aged 26–39 years. Importantly, the occurrence and extent of atherosclerotic lesions were significantly associated with established cardiovascular risk factors, including elevated body weight, increased BP, and higher total cholesterol (TC) concentrations.

The severity of subclinical CVD and the extent of early atherosclerotic lesions in coronary vessels increases significantly in young people with multiple risk factors.[117] Further evidence supporting the early origins of ASCVD was provided by the Pathobiological Determinants of Atherosclerosis in Youth Study, which examined coronary arteries, aortas, and related tissues from more than 3,000 individuals aged 15–34 years who died from external causes between 1987 and 1994.[4] Fatty streaks were identified in 25% of 15-19 year olds.[4] Moreover, the extent of fatty streaks and raised atherosclerotic lesions was positively associated with reduced levels of high-density lipoprotein cholesterol (HDL-C), elevated concentrations of non-HDL-C, increased body mass index (BMI), smoking, and hypertension.[4]

Collectively, these findings provide compelling evidence that atherosclerosis begins during childhood and progresses throughout the life course in response to cumulative exposure to cardiovascular risk factors. Early identification and modification of these risk factors are therefore considered essential strategies in the primary prevention of ASCVD and its associated clinical complications later in adulthood.

CRF and ASCVD

CRF is widely recognised as a robust predictor of both all-cause and cardiovascular mortality.[21,53,118] Longitudinal evidence has consistently demonstrated that low levels of CRF are associated with increased risk of premature mortality and adverse cardiovascular outcomes across the lifespan. In a 24-year follow-up study, women with lower levels of fitness exhibited a substantially greater risk of premature CVD-related mortality compared with women possessing higher fitness levels.[119] Similarly, among a cohort of approximately 1.3 million Swedish men, low aerobic fitness in late adolescence was positively associated with early mortality during a 29-year follow-up period.[120] In a subsample of 752,811 Swedish men with a mean baseline age of 18.5 years, CRF in late adolescence was inversely associated with the risk of MI over follow-up periods ranging from 5 to 41 years.[121] Similarly, low levels of CRF in late adolescence were associated with an increased risk of stroke later in life.[122]

A substantial body of evidence further demonstrates inverse associations between both directly measured $\dot{V}O_2$max and estimated $\dot{V}O_2$max derived from the 20mSRT, and clustered CVD risk profiles among children and adolescents.[19,20,123,124] Cross-sectional analyses from the Healthy Lifestyle in Europe by Nutrition in Adolescence Study identified significant inverse associations between 20mSRT performance and metabolic risk scores among European adolescents, independent of potential confounding variables such as

adiposity and muscular fitness.[20] In a cohort of 520 European adolescents, est$\dot{V}O_2$max thresholds of ≥34.6 mL·kg^{-1}·min^{-1} for females and ≥41.8 mL·kg^{-1}·min^{-1} for males were associated with healthier cardiovascular profiles.[125]

Longitudinal evidence has provided further support for the protective role of CRF during childhood. Castro-Piñero et al. (2017)[126] examined cardiovascular risk among 213 children aged 6–10 years at baseline and again at ages 8–12 years. The authors reported an inverse association between baseline 20mSRT performance and future cardiovascular risk.[126] Minimum est$\dot{V}O_2$max values associated with lower cardiovascular risk were identified as ≥39.0 mL·kg^{-1}·min^{-1} for males and ≥37.5 mL·kg^{-1}·min^{-1} for females.[126] Similarly, est$\dot{V}O_2$max values of 42.1 mL·kg^{-1}·min^{-1} for males and 37.0 mL·kg^{-1}·min^{-1} for females aged approximately 9.6 years were associated with lower metabolic risk profiles.[126] Males with CRF levels ≥42.1 mL·kg^{-1}·min^{-1} were 2.4 times more likely to exhibit low metabolic risk compared with males below this threshold.[126] These findings suggest that higher CRF during childhood is associated with a more favourable cardiometabolic profile.

Nevertheless, several methodological limitations warrant consideration when interpreting these threshold values. Longitudinal follow-up across periods of growth and pubertal maturation may introduce residual confounding, as biological maturation influences both CRF and cardiometabolic risk (CMR) markers.[123] In addition, clustered CMR scores represent surrogate rather than clinical outcomes, and inconsistencies in score construction across studies limit direct comparability between investigations. Consequently, although proposed CRF thresholds may serve as useful clinical and epidemiological reference points, their generalisability across populations, settings, and testing protocols remains uncertain.[126]

Large European cohort studies provide important supportive evidence but do not fully resolve these methodological limitations. Findings from the Healthy Lifestyle in Europe by Nutrition in Adolescence Study involving 3,428 adolescents (1,845 females) aged 12.5–17.5 years across five European countries demonstrated significant inverse associations between 20mSRT performance and metabolic risk independent of age, sex, pubertal status, and muscular fitness.[127] Performance on the 20mSRT was also inversely associated with TC, triglyceride (TG) concentrations, and clustered metabolic risk scores after adjustment for age, sex, and waist circumference (WC). The large sample size, multinational design, and adjustment for maturation status represent notable methodological strengths. However, much of the current evidence base remains cross-sectional in nature, thereby limiting causal inference and raising the possibility of reverse causality, whereby healthier adolescents may be more likely to engage in behaviours that sustain higher CRF levels.

Consistent findings have also been reported in Portuguese youth aged 10–18 years, where inverse associations between 20mSRT performance and metabolic risk were observed.[92] Furthermore, evidence from a study involving 224 adolescents demonstrated an inverse association between 20mSRT performance and waist-to-height ratio (WHtR), an established risk factor for CVD and MetS in youth.[128] Interpretation across studies, however, remains constrained by variability in adjustment for key confounding variables, including dietary intake, objectively measured PA, and biological maturation, as well as differences in participant motivation and maximal effort during field-based fitness testing.

The clustering of lifestyle behaviours further supports adolescence as a critical period for cardiovascular prevention, while simultaneously highlighting the complexity of interpreting behavioural associations. Lifestyle factors such as smoking, PA, and dietary

behaviours have been shown to be cross-sectionally associated with CRF among European adolescents.[125] In a two-year longitudinal study, Agostinis-Sobrinho et al. (2018)[129] reported that adolescents exhibiting three or four ideal cardiovascular health behaviours were significantly more likely to demonstrate higher levels of aerobic fitness compared with peers exhibiting fewer positive health behaviours.

Additional evidence indicates that low-fit children and adolescents aged 10–14 years exhibit higher clustered cardiometabolic risk compared with their high-fit counterparts, independent of age, sex, ethnicity, and socioeconomic status (SES).[123] In a cohort of children aged 7–10 years, Fernando Díaz et al. (2021)[130] reported reductions of 0.21 and 0.25 percentage points in systolic BP (SBP) and diastolic BP (DBP), respectively, for every unit increase in CRF. These associations remained independent of adiposity.[130]

Importantly, cardiovascular risk factors associated with ASCVD demonstrate significant tracking from childhood into adulthood.[131] Risk factors identified as early as 9 years of age have been shown to predict subclinical ASCVD later in life.[132] Given the substantial latency period between childhood exposure to modifiable risk factors and the eventual clinical manifestation of ASCVD in adulthood, early identification of subclinical cardiovascular abnormalities should represent a major public health priority. Structural and functional vascular remodelling, including arterial wall thickening and reduced vascular elasticity, are recognised indicators of subclinical CVD and can be assessed non-invasively.[133]

Overall, CRF, commonly assessed in youth using the 20mSRT, represents a robust marker of cardiometabolic health during childhood and adolescence. Nevertheless, further longitudinal studies employing standardised clustered-risk definitions and rigorous control for maturation, lifestyle behaviours, and adiposity are required to strengthen causal inference

and establish generalisable CRF cut-points. Given the persistence of cardiovascular risk from childhood into adulthood, adolescence remains a critical window for interventions aimed at promoting CRF and facilitating the early detection of subclinical vascular dysfunction.

Pulse Wave Velocity

Contraction of the left ventricle generates a pressure wave that propagates throughout the arterial tree. The velocity at which this pulse wave travels is determined largely by the elastic properties of the arterial wall.[134] In healthy, compliant arteries, systolic ejection from the left ventricle causes transient expansion of the arterial wall, allowing part of the stroke volume to be temporarily stored within the elastic conduit vessels. This buffering function reduces pulse wave velocity (PWV) and dampens fluctuations in arterial pressure. During diastole, elastic recoil of the arterial wall facilitates continuous blood flow and maintains tissue perfusion.[135]

In contrast, vascular stiffness, defined as the reciprocal of vascular compliance, is characterised by reduced arterial elasticity resulting from structural and cellular alterations within the arterial wall. These changes impair the ability of large conduit arteries to expand and recoil in response to fluctuations in intraluminal pressure. Increased arterial stiffness accelerates pulse wave propagation and is recognised as an important marker of ASCVD. Structural changes contributing to arterial stiffening include fragmentation of elastin fibres, increased collagen deposition, endothelial dysfunction, vascular smooth muscle cell remodelling, and low-grade vascular inflammation.[136]

PWV is a non-invasive measure of arterial stiffness and is calculated from the time required for the pulse wave to travel between two anatomical sites within the arterial system. Central PWV, commonly measured between the carotid and femoral arteries (carotid-femoral

PWV; cfPWV), is considered the gold-standard assessment of arterial stiffness due to its close association with aortic elasticity.[137] Peripheral PWV, often measured as brachial-ankle PWV (baPWV), reflects stiffness within both central and peripheral arterial segments.[138] During ventricular systole, the incident pressure wave travels distally through the arterial system and is subsequently reflected back towards the aorta from peripheral resistance vessels. The interaction between the forward-travelling and reflected waves contributes to the augmentation index, an indirect measure of arterial stiffness and wave reflection characteristics.

PWV and adult CVD

Substantial evidence supports the association between elevated PWV and CVD risk in adults. A systematic review examining cardiovascular risk factors in youth and subsequent subclinical and clinical CVD outcomes confirmed that elevated BP during adolescence is associated with higher PWV in later life[12] In a prospective population-based cohort study involving adults aged ≥55 years, a significant linear relationship was observed between cfPWV and CVD risk. Importantly, this association remained statistically significant following adjustment for age, sex, conventional cardiovascular risk factors, carotid intima-media thickness, and BP.[139] Participants within the highest cfPWV tertile demonstrated substantially greater risks of stroke and all-cause mortality compared with individuals in the lowest tertile.[139]

Similarly, findings from the Framingham Heart Study demonstrated a significant association between cfPWV and the incidence of first cardiovascular events.[140] Each (SD) increase in cfPWV was associated with a significant increase in future cardiovascular risk. Aortic PWV has also been shown to strongly predict all-cause mortality.[141]

PWV in Children

Compared with adults, fewer studies have investigated PWV among children and adolescents. Nevertheless, accumulating evidence indicates that exposure to cardiovascular risk factors during childhood is associated with increased arterial stiffness later in life.[142,143] In a prospective cohort study involving 2,082 Chinese children and adolescents, elevated BP trajectories from childhood into youth were associated with increased baPWV in adulthood.[144] Similarly, among 501 youth aged 8–18 years, cfPWV increased progressively across increasing BP categories[142]

Obesity has also been consistently associated with increased arterial stiffness during childhood. Arterial stiffness has been shown to be greater among obese children compared with peers of healthy BMI.[145] A school-based screening study further demonstrated that obese children were at increased risk of elevated arterial stiffness, primarily mediated through elevated BP.[146] In addition, visceral adiposity has been independently associated with increased arterial stiffness in obese youth, even after adjustment for BMI and WC.[147]

Among young individuals with type 1 diabetes mellitus (T1DM), persistent poor glycaemic control and higher levels of traditional cardiovascular risk factors, including obesity, hypertension, and hyperlipidaemia, have been independently associated with elevated PWV.[143] In a cohort of 1,809 18-year-old males and females, cfPWV increased significantly across tertiles of the TG-to-HDL-C ratio, increasing from 5.6 $m \cdot s^{-1}$ in the lowest tertile to 6.1 $m \cdot s^{-1}$ in the highest tertile.[143]

Interpretation of PWV during childhood and adolescence is complicated by the influence of growth and pubertal maturation.[148–150] Prepubertal sex differences in PWV are generally minimal and are largely attributable to differences in height and body mass.[138,151]

In a healthy population aged 3–18 years, PWV remained relatively stable throughout childhood.[148] Based on a cohort of 953 healthy Portuguese adolescents with a mean age of 12 years, Pereira, Maldonado, Carvalho (2018)[152] proposed mean cfPWV values of 6.2 ± 0.9 $m \cdot s^{-1}$ for males and 6.0 ± 0.9 $m \cdot s^{-1}$ for females.[152] Although these normative values provide useful reference data, variability in measurement protocols and maturation status across studies may limit direct comparability.

PWV and CRF in Children

A relatively small but growing body of literature has examined the relationship between arterial stiffness, CRF, and PA in youth.[153–158] Evidence from a representative cohort of young people in Northern Ireland demonstrated an inverse association between CRF and cfPWV.[154] This relationship remained statistically significant after adjustment for age, sex, BMI, body fatness, and additional lifestyle factors.[154] In contrast, a four-year longitudinal study involving 664 children aged 6–8 years found no significant association between CRF and PWV.[153]

Similarly, Weberruß et al. (2017)[155] identified a significant inverse relationship between CRF and PWV in a cohort of 697 youths aged 7-17 years, independent of sex, age, BMI, and blood BP. Significant differences in PWV were observed between participants with high fitness levels (>80th percentile) and those with low fitness levels (<20th percentile), in both males and females. Another study involving 1,171 children with a mean age of 7.2 years demonstrated a significant inverse association between CRF and PWV after adjustment for age and sex.[157] However, this association was attenuated and no longer statistically significant following additional adjustment for BMI and BP. Meyer et al. (2017)[158] also found a significant inverse relation between PWV and CRF in children and adolescents after

adjusting for sex, age, weight, height, HR and mean arterial pressure. In addition, low levels of CRF and increased BF% were associated with higher PWV among prepubertal children.[159] In contrast to these findings, no association was identified between estimated $\dot{V}O_2$max and cfPWV in either healthy children or children with an elevated cardiovascular risk profile aged 6–11 years.[156]

Carotid Intima Media Thickness

Carotid intima–media thickness (cIMT) is a non-invasive and indirect marker of subclinical ASCVD, assessed using B-mode ultrasonography to measure the combined thickness of the intimal and medial layers of the common carotid artery (CCA).[160] It is widely utilised in paediatric and adolescent research due to its capacity to detect early vascular alterations in otherwise asymptomatic populations and its established association with subsequent cardiovascular outcomes in adult cohorts.[161,162] However, interpretation of cIMT in youth requires caution, as absolute values are small and expected group differences are often in the order of hundredths of a millimetre. Consequently, measurement precision, operator expertise, and protocol standardisation can substantially influence observed findings.

Although several cIMT measurement protocols have been described, the most extensively validated approach involves assessment of the maximum cIMT of the near and far walls of the left and right CCA, carotid bifurcation, and internal carotid artery.[163] Evaluation of both the near and far arterial walls demonstrates stronger associations with CVD risk than measurements obtained from either wall alone.[163] In adult populations, each 0.1 mm increase in cIMT has been associated with a 10–15% greater risk of MI and a 13–18% increased risk of stroke.[161] Furthermore, cIMT progression exceeding 1.7 mm has been

associated with an elevated risk of future cardiovascular manifestations in adulthood.[162] These risk estimates are derived from adult cohorts. In children and adolescents, cIMT should therefore be interpreted primarily as an indicator of early vascular phenotype and cumulative cardiovascular risk exposure, rather than as a direct predictor of short-term clinical events. This distinction is particularly important when contextualising cIMT findings within preventive health frameworks in school-aged populations.

cIMT and Maturity

Carotid intima–media thickness increases throughout childhood and adolescence as part of normal growth and maturation, reflecting both physiological vascular development and the influence of emerging CMR factors.[164] Longitudinal evidence demonstrates measurable age-related increases in cIMT during childhood, with healthy children exhibiting an average annual increase of approximately 0.007 mm.[164] Pubertal development and body composition may also contribute to alterations in vascular structure. For example, a longitudinal study involving 102 Estonian boys followed from 12 to 18 years of age reported that BF% significantly influenced arterial structure at 18 years.[165]

Interpretation of cIMT during early adolescence is further complicated by substantial inter-individual variation in pubertal timing, particularly between 12 and 14 years of age. Consequently, associations between adiposity and cIMT may be confounded by biological maturation and growth-related haemodynamic changes when maturity status is not adequately measured or controlled. Normative cIMT reference values stratified by sex, age, and height have been reported in a cohort of 1,137 healthy children and adolescents.[166] Among males and females aged 12-13 years, cIMT values ranged from 0.38-0.62 mm (Table 2.5).

Table 2.5: Sex-specific normative data for carotid intima-media thickness (mm)

	Males		Females	
Centile	**12 years**	**13 years**	**12 years**	**13 years**
5	0.39	0.40	0.38	0.38
10	0.42	0.42	0.40	0.41
25	0.45	0.46	0.44	0.44
50	0.50	0.51	0.49	0.49
75	0.55	0.55	0.53	0.53
90	0.59	0.60	0.57	0.58
95	0.62	0.62	0.60	0.60

Source of the table: Drole Torkar et al. (2020)[166]

cIMT and CVD Risk Factors

Carotid intima–media thickness is associated with established cardiovascular CVD risk factors in children and adolescents,[167] supporting its use a subclinical vascular marker in youth. However, the magnitude and consistency of these associations vary across studies, partly due to heterogeneity in ultrasound protocols (segment selection, near vs far wall, mean vs maximum values), differences in pubertal timing, and the extent of covariate adjustment. These methodological and developmental factors are particularly relevant in early adolescence where maturational stage can influence both risk-factor expression and vascular structure.

Several observational studies have reported a positive association between obesity and increased cIMT in paediatric populations.[168,169] For example, after adjustment for key cardiometabolic covariates (SBP, LDL-C, HDL-C, and TG), mean cIMT has been shown to be significantly greater in both overweight and obese adolescents compared with healthy controls.[170] Given the haemodynamic and pro-inflammatory consequences of excess adiposity, however, this relationship is not consistently observed across all studies. In contrast, Weberruß et al. (2017) reported no significant differences in cIMT between a larger sample of obese children and adolescents aged 7-17 years and age-matched controls.[171]

Taken together, these discrepancies are more plausibly explained by methodological and sample differences than by true biological inconsistency. Leite et al. (2012)[170] examined a hospital-based cohort spanning overweight to obesity and adjusted BP and lipid fractions, whereas Weberruß et al. (2017)[171] assessed a population-based sample of obese youth in whom BP did not differ from controls. In the latter context, any obesity-related structural differences in cIMT may have been too small to detect. Collectively, these findings suggest that associations between adiposity and cIMT in youth are likely present but not universal and may depend on both methodological precision and the severity of metabolic dysfunction within "obese" classifications.

Longitudinal evidence provides stronger support for the notion that early-life exposure to cardiovascular risk factors contributes to later vascular phenotype. Childhood levels of SBP and DBP, body, BMI, and HDL-C have been shown to predict carotid artery properties in 3,700 young adults,[172] indicating that early risk clustering is associated with later arterial structure and function. Similarly, a French population-based cohort followed over 20 years demonstrated that higher adiposity during adolescence—assessed using BMI, WHt or WC was associated with increased cIMT in adulthood. However, these associations were attenuated after adjustment for childhood C-reactive protein (CRP), [173] suggesting that systemic inflammation may mediate or confound the relationship between early adiposity and later vascular remodelling. Further complexity is evident within the same cohort, where persistently elevated BMI from childhood into adulthood was associated with greater adult cIMT.[173] In addition, adult WHt demonstrated a stronger association with adult cIMT than childhood adiposity measures,[173] indicating that both the timing and persistence of exposure are important determinants of vascular outcomes. These findings further suggest that the

relative contribution of early versus later adiposity may vary depending on the adiposity metric employed and the degree to which inflammatory pathways are accounted for.

Diabetes represents a higher-risk metabolic context in which vascular alterations may be more readily detectable. Brazilian adolescents with T1DM have been shown to exhibit significantly greater cIMT compared with healthy controls.[174] However, other studies have reported increased aortic intima–media thickness but no differences in cIMT in children with T1DM relative to controls [175] while increased cIMT has been observed in children and adolescents with type 2 diabetes mellitus (T2DM).[176] Conversely, Babar et al. (2011)[177] found no significant differences in cIMT between prepubertal children with T1DM (mean age 8.3 years) and healthy age-matched controls.

These inconsistencies likely reflect differences in developmental stage, disease duration, glycaemic control, and the burden of co-existing cardiovascular risk factors. They may also indicate that alternative vascular measures, such as aortic intima–media thickness or functional indices (e.g., PWV or endothelial function), are more sensitive to early vascular changes in paediatric diabetes. Collectively, these findings suggest that cIMT may reflect cumulative vascular exposure rather than early pathophysiological change in all clinical and developmental contexts.

cIMT and CRF

Findings from studies examining the relationship between CRF and cIMT in children and adolescents are equivocal.[133,178,179] Several cross-sectional studies have reported an inverse association between CRF and cIMT, particularly in youth with elevated CMR profiles.[158,178,180] In a cross-sectional cohort of obese and non-obese adolescents, $\dot{V}O_2$max was inversely associated with cIMT.[180] Similarly, among obese adolescents, estimated

est$\dot{V}O_2$max was inversely associated with cIMT, independent of time spent in sedentary behaviour.[181]

Consistent with these findings, Portuguese children classified as “fit” versus “unfit” based on cycle-ergometer–derived $\dot{V}O_2$max demonstrated significant differences in cIMT, with low-fit participants exhibiting a 2.8-fold higher odds of increased cIMT compared with their high-fit peers.[178] In the same study, minimum $\dot{V}O_2$max thresholds of 45.8 $mL \cdot kg^{-1} \cdot min^{-1}$ for males and 34.4 $mL \cdot kg^{-1} \cdot min^{-1}$ for females were proposed as values associated with a greater likelihood of cIMT remaining within the normal range. However, such thresholds should be interpreted cautiously, as they are highly dependent on cohort-specific characteristics (including age, sex distribution, and adiposity), cIMT acquisition protocols, and the CRF assessment method employed. These factors substantially limit the generalisability of fixed cut-points beyond the original study population.[171]

Several additional observational studies have similarly reported inverse associations between CRF and cIMT across both obese and normal-weight youth.[158,178,180] Low CRF levels have been associated with increased intima–media thickness of the CCA and carotid bifurcation in obese children aged 9–16 years.[182] Likewise, Videira-Silva et al. (2014)[180] reported an inverse association between objectively measured $\dot{V}O_2$max and CCA intima–media thickness in both obese and non-obese adolescents aged 10–16 years. In children aged 11–13 years, est$\dot{V}O_2$max was also inversely associated with cIMT independently of moderate-to-vigorous PA and sedentary time.[178] However, the association was no longer significant when WC was added to the model, suggesting that central adiposity may partially mediate or confound the relationship between CRF and vascular structure. These findings indicate that the apparent vascular benefit of higher CRF may, at least in part, be contingent upon lower

central adiposity, with the most favourable cIMT profiles observed when higher fitness is accompanied by reduced WC.

In contrast, other studies have reported null findings. Among 355 adolescents with a mean age of 17 years, no association was observed between cIMT and CRF assessed via maximal cycle ergometer testing.[133] Methodological differences likely contribute to these inconsistencies. Studies vary in carotid segment assessment (e.g., CCA versus bulb-adjacent regions), imaging methodology (manual edge detection versus radiofrequency tracking), definitions of elevated cIMT (continuous versus categorical thresholds), and the operationalisation of CRF (continuous versus categorised variables). Such heterogeneity may reduce sensitivity to detect small vascular differences during growth and maturation.

The Amsterdam Growth and Health Longitudinal Study, a multidisciplinary cohort established to examine adolescent growth and health, provides important longitudinal evidence.[183] After adjustment for height, weight, sum of skinfolds, mean BP, TC, RHR, and smoking status, adolescent CRF was inversely associated with cIMT at 36 years of age in both males and females.[183] This finding suggests that CRF during adolescence may represent a meaningful exposure influencing later-life vascular structure. However, not all longitudinal studies support this relationship. Data from the European Youth Heart Survey, which examined multiple cardiovascular risk factors in youth, found no association between CRF and cIMT in adolescence.[179]

Metabolic Syndrome

MetS describes a clustering of cardiometabolic abnormalities that include central adiposity, dyslipidaemia (hypertriglyceridaemia and low HDL-C), elevated BP, and impaired glucose regulation/insulin resistance,[184] which collectively indicate increased CMR.[185]

However, the application of a categorical MetS definition in adolescents remains contentious. This is largely due to the influence of normal growth and pubertal maturation on component variables (for example, transient pubertal insulin resistance[186]), as well as the absence of universally agreed paediatric diagnostic cut-offs across existing definitions.[184] Consequently, prevalence estimates and case classification vary considerably depending on the criteria applied and the timing of biological maturation, particularly around mid-adolescence (approximately 13–14 years), which may introduce misclassification and limit comparability across studies.

Despite these limitations, clustering of CMR in adolescence is clinically meaningful, as it is associated with adverse vascular and inflammatory phenotypes and demonstrates tracking into adulthood. MetS in youth has been associated with increased arterial stiffness, as reflected by PWV,[187] and greater carotid cIMT.[13] Elevated inflammatory burden has also been observed, with longitudinal evidence indicating that persistently raised continuous metabolic risk throughout childhood is associated with higher high-sensitivity C-reactive protein (hs-CRP) in adolescence.[188] Long-term cohort studies further suggest that paediatric MetS predicts adult MetS, T2DM, and subclinical atherosclerosis,[13] and is associated with increased CVD incidence in adulthood.[132] However, Magnussen et al. (2010)[13] highlighted a key limitation of the MetS construct in paediatric populations, demonstrating that MetS does not necessarily improve risk prediction beyond adiposity alone. This finding raises important questions regarding the incremental clinical utility of a binary MetS classification during growth and supports a more physiologically grounded approach in which CMR is conceptualised as continuous and multifactorial rather than dichotomous.

Accordingly, many paediatric studies now favour the use of continuous clustered risk scores or composite cardiovascular health metrics over binary MetS classification, as these approaches reduce reliance on arbitrary thresholds and better accommodate developmental variability.[188] Evidence from the PANIC (Physical Activity and Nutrition in Children) study further supports this approach, demonstrating that higher mid-childhood American Heart Association cardiovascular health scores predicted lower PWV in adolescence, while higher adolescent BMI and systolic BP were associated with increased PWV and cIMT.[189] These findings underscore that different risk constructs may exhibit distinct relationships with vascular outcomes across developmental stages. Collectively, this evidence supports the assessment of CMR in early adolescence using continuous risk clustering and vascular phenotyping rather than categorical MetS definitions during periods of rapid biological maturation.

Markers of cardiometabolic risk

Beyond conventional lipid measures (TC, LDL-C, HDL-C, and TG), lipidomics enables high-resolution characterisation of hundreds of lipid species, including ceramides, phospholipids, lysophospholipids, and oxylipins, which are increasingly implicated in cardiometabolic health and insulin resistance.[190] Exercise represents a valuable physiological model for lipidomic research, as both acute and chronic exercise exposure can induce alterations in lipid species that are not captured by standard clinical lipid panels. For example, a single acute bout of exercise has been shown to increase circulating lipid mediators such as 12,13-diHOME, a lipokine identified through lipidomic profiling that is responsive to exercise and associated with metabolic adaptations in peripheral tissues.[191] Longer-term interventions in adults further demonstrate that structured exercise training can induce

clinically relevant lipidomic remodelling. In individuals with obesity and T2DM, 16 weeks of moderate-intensity combined training was associated with changes in lipid profiles alongside improvements in insulin resistance and body composition, suggesting that lipid species may capture mechanistic adaptations not reflected by conventional lipid measures alone.[190] Similarly, a 24-week randomised concurrent exercise trial in young sedentary adults, profiling approximately 800 plasma lipid species, demonstrated intensity-dependent lipidomic modulation, supporting the concept that exercise dose and intensity produce distinct molecular signatures.[192]

Experimental evidence from animal models further supports these observations. Endurance training in rodents has been shown to induce tissue-specific lipid remodelling, including alterations in triacylglycerols, phospholipids, oxylipins, and ceramides, occurring in parallel with improvements in fitness and reductions in adiposity.[193] These findings provide mechanistic support for lipidomic adaptation as part of the biological pathway linking habitual exercise to improved metabolic and vascular health.

The adolescent evidence base remains limited and heterogeneous. Systematic reviews indicate that while school-based PA interventions consistently improve CRF, effects on traditional lipid profiles are less consistent, with some higher-dose interventions reporting increases in HDL-C, whereas effects on TG, LDL-C, and TC remain inconclusive.[194] In obese adolescent cohorts, only modest changes in circulating lipid concentrations have been observed, suggesting that lipid responsiveness in youth may depend on baseline adiposity, pubertal stage, intervention duration and intensity, and analytical methodology.[195] Collectively, current evidence highlights the need for future longitudinal studies integrating lipidomic profiling with robust measures of CRF and subclinical vascular structure to

determine whether exercise-induced lipidomic adaptations occur during puberty and whether they contribute to trajectories of cardiometabolic and vascular risk.

Socio-Economic Status

In high-income countries such as Ireland, income level, educational attainment, employment status, and environmental factors are strongly associated with CVD.[196,197] A large study conducted in the United States and Finland reported an increased risk of non-fatal MI and sudden cardiac death among low-income cohorts, even after adjustment for smoking and alcohol consumption.[198] Similarly, among 15,000 Dutch patients admitted with acute MI or CVD, mortality rates at both 1 month and 1 year post-MI were significantly higher among individuals in the lowest income quintile.[199] Higher mortality rates have also been reported among patients from low-income areas in Taiwan who were hospitalised with acute MI.[200]

The strong inverse association between educational attainment and CVD has been recognised for decades in high-income countries. Lower educational attainment is associated with an increased risk of acute MI, as well as poorer short-term (<1 month)[201] and long-term (≥1 year)[202–204] outcomes following MI. Educational attainment may influence health status and outcomes through several mechanisms. Individuals with lower levels of education are more likely to present with multiple CVD risk factors compared with those who attain higher levels of education.[196] Among Dutch adults with low educational attainment, 57% of CHD risk was attributable to a combination of behavioural and biological risk factors.[205] In contrast, third-level education was inversely associated with the presence of modifiable CVD risk factors among adults in Australia and New Zealand.[206]

Health literacy is defined as "the degree to which individuals have the capacity to obtain, process, and understand basic health information and services needed to make

appropriate health decisions.[207] Poor health literacy is associated with reduced healthcare knowledge, lower medication adherence, decreased utilisation of preventative services, poorer mental and physical health, and increased hospitalisations.[208] Educational attainment and health literacy are highly correlated and represent important contributors to CVD risk.[208]

In addition to individual SES, neighbourhood characteristics are also associated with CVD risk factors, adverse cardiovascular events, and all-cause mortality.[209] Features such as access to walking paths, green spaces, transportation, and healthy food options, together with social characteristics including safety, deprivation, social support, and community cohesion, collectively influence neighbourhood quality.[210] Data from the Jackson Heart Study demonstrated that residence in a disadvantaged neighbourhood was positively associated with biomarkers of cardiovascular, metabolic, inflammatory, and neuroendocrine dysfunction among African American adults.[211]

After controlling for individual income, education, and employment status, Ana Diez Roux et al. (2001)[210] reported that residence in deprived areas was independently associated with higher CHD prevalence. However, it is unlikely that any single component of SES adequately predicts CVD risk, given the complex interactions between SES indicators, regional variations in SES–CVD associations, and changes in SES-related risk across the lifespan.[197]

Several studies have examined the relationship between childhood SES and adult cardiovascular health.[26,212,213] In Brazil, female adolescents attending fee-paying schools demonstrated more favourable cardiovascular health profiles than students attending non-fee-paying schools, based on traditional CVD risk factors including BMI, PA, smoking, BP, fasting glucose, and TC.[214] The Wroclaw Longitudinal Growth Study investigated health trajectories among men and women aged 8–50 years and identified a significant association

between childhood SES and adult cardiovascular health in women, but not in men.27 Women from higher SES backgrounds in childhood demonstrated better health outcomes at age 50.[26] This sex-specific effect was confined to retrospectively self-assessed childhood SES rather than objective SES indicators, suggesting that perceived social position during childhood may be particularly relevant to later cardiovascular risk in women. The authors also proposed that selective premature mortality among lower-SES males may have attenuated comparable associations in men, although sample sizes were insufficient to confirm this hypothesis.[26]

In a study involving 111,799 students from grades 1–10, overweight and obesity were strongly associated with low-income status.[215] Each 1% increase in low-income prevalence was associated with a 1.17% increase in overweight/obesity prevalence.[215] Collectively, the evidence suggests that childhood socioeconomic disadvantage is associated with less favourable cardiovascular health trajectories into adulthood.

In Ireland, the Delivering Equality of Opportunity in Schools (DEIS) programme was established to reduce disparities in educational attainment between schools serving lower and higher SES communities.[216] Data from Growing Up in Ireland indicate that DEIS post-primary schools serve substantially more socioeconomically disadvantaged populations than non-DEIS schools, including higher proportions of students from the lowest income quintile (32.6% vs 18.4%) and lower proportions of mothers with third-level qualifications (9.0% vs 24.1%).[27] These findings support the use of DEIS status as a pragmatic school-level proxy for socioeconomic disadvantage in studies examining health and fitness outcomes.

School SES may also influence the likelihood of adolescents presenting with low CRF. O'Keeffe et al. (2020)[31] profiled several HRPF variables among 13-year-old Irish adolescents and reported significant differences between 221 students attending DEIS schools and 994

students attending non-DEIS schools. Adolescents attending non-DEIS schools demonstrated significantly lower BMI values, superior standing broad jump performance, higher push-up scores, and significantly greater performance on the 20mSRT compared with students attending DEIS schools.[31] This pattern is consistent with a school-level socioeconomic gradient in adiposity-related risk,[217] although BMI remains a relatively crude proxy for adiposity because it cannot distinguish fat mass from lean mass.[218] Nevertheless, the coexistence of higher BMI and lower CRF among students attending DEIS schools supports the interpretation that excess body weight/adiposity and lower CRF may cluster within socioeconomically disadvantaged school settings.[31] These findings highlight the importance of considering both individual- and school-level SES when interpreting adolescent health and fitness profiles.

Comparable trends have been observed internationally. A study involving more than 7,000 Australian children and adolescents found that students attending schools with average or high SES were more likely to achieve higher CRF scores than those attending schools with low SES.[219] Similarly, an observational study involving 15,052 students in Dallas, Texas reported that schools with higher proportions of economically disadvantaged students were associated with lower odds of achieving a "Healthy Fit Zone" score on the 20mSRT.[217] Additional analyses demonstrated that female students attending schools in which more than 90% of students were from low-SES backgrounds had particularly low odds of achieving Healthy Fit Zone standards.[217]

Children aged 9.3-11.5 years attending DEIS primary schools have also been shown to have significantly greater odds of obesity than their peers attending non-DEIS schools.[220] In 2002, rates of overweight and obesity among economically disadvantaged and non-

disadvantaged Irish children aged 4-13 years were broadly similar (26.1% vs 25.7%).[221] However, over the subsequent 12 years, prevalence increased to 28% among economically disadvantaged children while declining to 20.9% among non-disadvantaged children. These findings suggest that although overall prevalence may have stabilised, overweight and obesity have become increasingly socially patterned, with a widening socioeconomic disparity emerging over time. The authors identified this widening gap as a major public health concern and argued for targeted interventions within disadvantaged schools and communities.[221]

School-based exercise interventions have demonstrated effectiveness in reducing sedentary behaviour, increasing PA levels, and improving CRF among adolescents from low-SES backgrounds.[222] Similarly, after-school programmes and community-based initiatives that provide accessible and low-cost opportunities for PA have been shown to address barriers such as financial constraints, transportation difficulties, and safety concerns.[222–224]

The Physical Activity 4 Everyone (PA4E1) study implemented a multicomponent intervention in secondary schools located in low-SES areas of New South Wales, Australia.[225] The 12-month intervention included modifications to physical education curricula, increased opportunities for school sport, and promotion of active travel to school.[225] Significant improvements were observed in both moderate to vigorous PA and 20mSRT performance, indicating that comprehensive school-based interventions can effectively improve PA and CRF among adolescents in disadvantaged communities.[225]

Interventions addressing broader SES-related challenges, including parental involvement, community engagement, and teacher professional development, appear particularly effective. The Together an Active Future initiative demonstrated that

collaborative approaches involving schools, local authorities, and community organisations can reduce physical inactivity among children and adolescents from disadvantaged backgrounds.[226] Programmes that address socioeconomic barriers holistically, including improved access to resources and consideration of cultural and environmental relevance, are critical for achieving sustained improvements in PA and CRF among adolescents from low-SES backgrounds.[223,226] These findings emphasise the importance of designing interventions that are tailored to the specific needs and contexts of disadvantaged populations.

Irish data demonstrate a substantial increase in adolescent overweight and obesity between 1990 and 2020. Using national survey data, Moore Heslin et al. (2023)[227] reported that the combined prevalence of overweight and obesity increased from 13% in 1990 to 18% in 2006 and 24% 2020. Obesity prevalence alone increased from 0.5% in 1990 to 3% in 2006 and 8% in 2020).[227] Importantly, the shift reflects not only an increase in average body weight, but also a marked rise in the proportion of adolescents living with clinical obesity.

These trends are also increasingly socially patterned. By 2020, overweight and obesity were more prevalent among adolescents from lower socioeconomic groups, with significantly higher odds of overweight/obesity observed among adolescents in the lowest affluence social class.[227] In practical terms, these findings suggest that the determinants of obesity among Irish adolescents are not evenly distributed across society and should therefore be interpreted within the context of socioeconomic inequality when describing risk and designing school-based prevention strategies.

Behavioural change associated with interventions

School-based CRF programmes function as complex interventions whose outcomes depend on both content and implementation quality.[228,229] Their efficacy relies not merely on participation, but on accurate prescription and faithful delivery, as deviations from the intended intervention may obscure the mechanisms underpinning success or failure.[230,231] Meta-analytic evidence demonstrates that greater improvements in CRF are associated with specific dose characteristics, appropriate intensity regulation, and the integration of aerobic and resistance-based exercise modalities.[232] Intervention effects appear to be partly mediated by vigorous-intensity PA, highlighting the importance of exercise intensity rather than the simple accumulation of activity time.[54] Although intensity is commonly prescribed using HR thresholds or perceived exertion scales, school-based trials frequently under-report verification of these targets, thereby contributing to heterogeneity in intervention outcomes.[229]

The effectiveness of an intervention can be determined by contextual feasibility and the delivery of the intervention. Researcher-led delivery may enhance the standarisation of the intervention, whereas teacher-led delivery may improve ecological validity and scalability, particularly when supported through adequate training and curricular resources.[228,230] These factors have consistently been identified as key determinants of implementation quality within school-based interventions.

Social Cognitive Theory

Social Cognitive Theory (SCT) proposes behaviour is shaped through the reciprocal interaction of personal factors, behaviour, and the environment.[233] Within PE, SCT helps

explain why identical exercise prescriptions may produce divergent outcomes, as opportunity structures, social norms, and peer dynamics may either facilitate or constrain participation.[54,234,235]

Self-efficacy and social support have consistently been identified as correlates of PA participation, with evidence suggesting that self-efficacy partially mediates the relationship between social support and PA behaviour.[11,236] However, the relative importance of SCT constructs appears context dependent; Barbosa et al. (2025)[234] reported that autonomous motivation mediated behaviour more strongly than self-efficacy in certain populations, suggesting that the motivational quality of the environment may be particularly influential. Although intervention outcomes are commonly quantified using device-based and self-report measures,[237,238] qualitative research continues to identify barriers such as perceived safety concerns, low confidence, and fear of social evaluation, particularly among adolescents from lower SES backgrounds.[239] SCT constructs may be operationalised through behaviour change techniques (BCTs), including graded tasks, self-monitoring, and performance feedback.[240] Such strategies are particularly important within CRF interventions, as achieving sustained vigorous-intensity effort requires structured progression and supportive learning climates rather than assuming that high-intensity engagement will occur spontaneously.[225]

Self-Determination Theory

Self-Determination Theory (SDT) posits that sustained behavioural engagement is more likely when motivation is autonomous rather than externally controlled.[241,242] Autonomous motivation is facilitated through satisfaction of the three basic psychological needs of autonomy, competence, and relatedness, which collectively support behavioural

internalisation and self-regulation.[241,242] SDT therefore provides a useful framework for understanding variation in participant engagement within school-based interventions. Specifically, need-supportive pedagogical practices tend to promote adaptive motivational outcomes, whereas highly evaluative or performance-oriented climates may undermine perceptions of competence and relatedness, thereby increasing amotivation.[243]

Autonomy refers to experiencing meaningful choice and volition, whereas competence reflects an individual's perception of capability and effectiveness. Meta-analytic evidence suggests that competence may demonstrate the strongest association with autonomous motivation within PA contexts.[244] Operationalising competence through BCTs such as graded progression and achievable task structures[240] may therefore help sustain engagement while simultaneously supporting the exercise intensity required for physiological adaptation.[245] Relatedness concerns feelings of social connection and belonging; qualitative evidence suggests that peer interactions may either support or threaten this need, highlighting the importance of cooperative tasks and positive group norms within PE environments.[243]

Meta-analytic evidence further indicates that game-based PE programmes can enhance enjoyment, which may represent a plausible mechanism for sustaining the vigorous exercise intensity required for CRF improvements.[246,247] However, recent research cautions that forms of "support" perceived as controlling, evaluative, or pressuring may reduce engagement unless autonomy, competence, and relatedness are authentically fostered.[248] A 2024 meta-analysis of 16 controlled studies examining the Sport Education Model (SEM), grounded in games-based educational theory, concluded that SEM exerted a positive and statistically significant effect on students' basic psychological needs and intrinsic motivation,

although effects varied according to maturational status.[249] Specifically, improvements in basic psychological needs were greatest among post-peak height velocity (PHV) students, followed by pre-PHV participants, whereas comparatively smaller effects were observed in mid-PHV adolescents. In contrast, gains in intrinsic motivation appeared to diminish with increasing age.[249] Similarly, a study conducted in a Spanish secondary school sample (mean age approximately 13 years) reported that students taught through Teaching Games for Understanding (TGfU) demonstrated greater motivation and achievement perceptions than those exposed to traditional instructional approaches.[250] Collectively, these findings suggest that games-based PE approaches may enhance adolescents' enjoyment and psychological need satisfaction, thereby supporting sustained engagement in the high-intensity activity necessary for CRF development, provided that delivery avoids controlling or pressuring forms of support.

Ultimately, SDT complements frequency, intensity, time and type -based approaches within CRF interventions. Whereas physiological adaptations are primarily driven by exercise prescription variables, need-supportive delivery influences the extent to which students meaningfully engage with the prescribed stimulus within authentic school setting.[243,245–247] Although specific dose characteristics underpin physiological adaptation, intervention outcomes are also heavily influenced by the delivery model and broader socio-ecological context,[251] as conceptualised within SCT, where self-efficacy and social support interact with environmental opportunities and constraints.[233] SDT further suggests that sustaining the effort necessary for meaningful CRF adaptation requires autonomous motivation supported through autonomy, competence, and relatedness, rather than reliance on external pressure or control.[241] Consequently, effective school-based CRF interventions should integrate

evidence-based physiological prescriptions with pedagogical strategies, including BCTs and games-based approaches, in order to create environments that encourage students to willingly engage at the intensity required to elicit meaningful physiological adaptation.

Aims

- To retrospectively evaluate temporal trends in CRF among first-year male and female post-primary school students.
- To retrospectively evaluate the effect of a nationwide six-week school-based PA/exercise intervention on CRF levels among first-year male and female post-primary school students.
- To evaluate the effect of a school-based exercise intervention on selected cardiovascular risk factors and indices of vascular health among first-year male and female post-primary school students.
- To evaluate the HR response during the 20mSRT among first-year male and female post-primary school students.

CHAPTER III

STUDY 1

A RETROSPECTIVE ANALYSIS OF 20M SHUTTLE RUN TEST PERFORMANCE AMONG IRISH ADOLESCENTS

INTRODUCTION

Higher levels of cardiorespiratory fitness (CRF) are associated with more favourable cardiometabolic health profiles in children and adolescent.[123,126,252,253] Conversely, low levels of CRF during adolescence have been associated with the early onset of chronic disease,[254] poorer cognitive and mental health outcomes,[255] and an increased risk of premature mortality in adulthood.[120,121] The 20 meter shuttle run test (20mSRT) is the most commonly used validated, field-based assessment for estimating $\dot{V}O_2$max in children and adolescents.[23,44,46] The test consists of progressive stages, each lasting approximately one minute and comprising a series of 20 m shuttles paced by audio signals. Owing to its ease of administration and suitability for testing large groups simultaneously, the 20mSRT is particularly useful for assessing CRF within school settings. Previous research has demonstrated strong-to-very-strong test–retest reliability and moderate validity relative to directly measured $\dot{V}O_2$max in adolescent population.[23,45,256,257]

Normative reference values for the 20mSRT have been published for European children and adolescents; however, Ireland has largely been excluded from these datasets.[52,258–263] The availability of normative CRF data permits individual and population-level performance comparisons against reference populations. Over the past three decades, temporal declines in CRF among children and adolescents have been reported internationally.[43] Nevertheless, evidence regarding shorter-term trends is less consistent and

may be influenced by factors such as testing protocols, methods of school-based delivery, and cohort characteristics.[261] Consequently, it is important to determine whether CRF levels changed within this Irish school-based sample across the six-year study period. Annual assessment of CRF also enables the identification of temporal trends that may inform future public health policy and school-based health promotion strategies.

Although large international and European datasets provide normative 20mSRT values, Ireland has historically lacked nationally representative CRF data, limiting direct comparison with European peers.[52,264] Given that physical education is compulsory across Europe and generally shares similar health-related objectives, Irish first-year post-primary school students might be expected to demonstrate broadly comparable CRF distributions. However, substantial between-country variation exists in physical education time allocation[265] while differences in PA participation, sedentary behaviour, dietary habits[266], and socioeconomic gradients inequalities,[267] may also influence population-level CRF distributions. Establishing whether CRF levels among Irish adolescents align with or differ from European norms is therefore important for benchmarking performance and interpreting potential population health risk.

In addition, sex-specific minimum CRF thresholds associated with reduced CVD risk have been identified,[125] and CRF during adolescence has been shown to predict future risk of premature CVD.[121] If the majority of Irish adolescents achieve these sex-specific thresholds, this may indicate a relatively favourable population health profile. Conversely, a substantial proportion falling below these thresholds would identify an at-risk group within the school population. Given that CRF is modifiable and demonstrates moderate tracking from adolescence into adulthood,[268] determining the proportion of adolescents meeting these risk-

related thresholds has important implications for population surveillance and school-based prevention strategies.

Socio-economic status (SES) is strongly associated with health inequalities and is a robust predictor of disparities in youth health outcomes.[269] Compared with adolescents from more affluent backgrounds, young people from lower SES groups are more likely to experience poorer health outcomes due to earlier exposure to chronic disease risk factors, including sedentary behaviour, lower participation in regular PA, and poorer nutritional habits.[270] This is of particular concern given that health behaviours established during childhood and adolescence frequently persist into adulthood.[271] In the Republic of Ireland, adolescents typically attend post-primary school between the ages of 12 and 18 years. Most schools are non-fee-paying (93%) and mixed-sex (68%). The Delivering Equality of Opportunity in Schools (DEIS) programme is a government initiative designed to support schools serving communities with lower SES and increased risk of educational disadvantage. As of 2022, approximately 28% of Irish schools were designated as DEIS schools.[272]

The primary aim of this study was to retrospectively examine the 20mSRT performance scores among first-year post-primary school students over a 6-year period and to evaluate the impact of a school's SES on CRF levels.

Aims

1. To retrospectively evaluate the change in CRF levels among first-year post-primary school male and female students between 2013 and 2018.
2. To compare CRF levels of first-year post-primary school students to European norms.
3. To determine the proportion of first-year post-primary school students achieving the threshold 20mSRT associated with reduced CVD risk.
4. To evaluate the influence of school SES on CRF levels among first-year post-primary school students.

Hypothesis

1. There will be no significant change in CRF levels among first-year post-primary school students between 2013 and 2018.
2. The distribution of CRF levels among Irish first-year post-primary school students will not differ significantly from established European normative values.
3. The majority of first-year male and female post-primary school students in Ireland will achieve the 20mSRT threshold associated with reduced CVD risk.
4. There will be a significant difference in the mean 20mSRT performance score between first-year post-primary school students attending fee-paying schools and those attending DEIS schools.

METHODS

Study overview

The Schools' Fitness Challenge (SFC) was established in 2012 by Aviva Health in collaboration with Professor Niall Moyna, Dublin City University (DCU), as a national initiative aimed at increasing awareness of the importance of CRF during adolescence. From 2015 onwards, the programme was coordinated by Irish Life Health until its conclusion in 2020.

The SFC involved first-year post-primary school students completing the 20mSRT before (baseline) and after (post-intervention) participation in a six-week school-based physical activity (PA) and exercise intervention. The programme was conducted annually between 2013 and 2018. Participating schools submitted results following completion of the intervention, and incentives, including awards and prizes (e.g., sports equipment vouchers for the most improved class), were provided to encourage participation and engagement.

Study 1 utilised baseline data collected between 2013 and 2018 only, owing to limitations associated with the 2012 and 2019 datasets and disruptions arising from the COVID-19 pandemic in 2020. The study involved a retrospective analysis of routinely collected SFC data that did not contain personally identifiable participant information; consequently, informed consent and participant assent were not required.

Each year, a letter outlining the aims of the SFC and inviting participation from first-year male and female students was distributed to all post-primary school principals in the Republic of Ireland. Schools agreeing to participate received an information pack containing data recording sheets and detailed instructions outlining: (i) how to download the 20mSRT

audio file; (ii) procedures for entering data onto the online portal; and (iii) standardised administration procedures for conducting the 20mSRT.

The study protocol was conducted in accordance with the ethical standards of the 1961 Declaration of Helsinki, as revised in 2000, and received ethical approval from the Research Ethics Committee of Dublin City University (DCU/REC/2018/208) (Appendix F).

20m Shuttle Run Test

Participants were instructed to run continuously between two lines positioned 20 m apart while synchronising their pace with a series of pre-recorded audio signals ("bleeps"). The test commenced at a running speed of 8.5 $km \cdot h^{-1}$, with speed increasing by 0.14 $m \cdot s^{-1}$ at one-minute intervals. Participants received a warning if they failed to reach the line before the audio signal. However, if the participant successfully reached the subsequent line in time with the next signal, the test continued. The test was terminated when a participant either voluntarily withdrew or failed to maintain the required pace on two consecutive occasions following a warning.

Estimated $\dot{V}O_2max$

$\dot{V}O_2max$ was estimated from the performance in the 20mSRT using the equation by Léger *e*t al. (1986)[23] y=31.025 + 3.238 x – 3.248a + 0.1536ax where y represents est$\dot{V}O_2max$ ($mL \cdot kg^{-1} \cdot min^{-1}$), x represents running speed ($km \cdot h^{-1}$), and *a* represents age (years).

Data storage

A cloud-based data collection system was used to collate all study data. The following information was recorded for each participant: school, class, sex, final 20mSRT level achieved,

and final shuttle number completed. Additional school-level data were obtained from the publicly available Department of Education database.[272] This database provided information relating to school type, student sex composition, attendance status, fee-paying status, DEIS designation, Irish-language status, island location, school population size, and school address. No personally identifiable student data were collected. All data were stored in a password-protected MySQL database.

Statistical analysis

The primary outcome variable was the total number of shuttles completed during the 20mSRT. Boxplots were used to screen for outliers. Scores greater than ±2.5 standard deviations from the mean were classified as outliers and excluded from the analysis. Data normality was assessed using histograms, boxplots, and quantile–quantile (Q–Q) plots. Visual inspection indicated that the data were approximately normally distributed, with skewness values ≤1.2 and kurtosis values ≤1.6.

A chi-square analysis was conducted to compare the distribution of participating schools across classification categories with the national repository of post-primary schools published by the Department of Education and Skills.

A three-way analysis of variance (ANOVA) was performed to examine the effects of student sex (male or female), year of participation in the SFC (2013–2018), and school status (DEIS, non-fee-paying non-DEIS, or fee-paying) on the dependent variable, namely total 20mSRT shuttle performance. Main effects and interaction effects were examined using Bonferroni-adjusted post-hoc comparisons where appropriate. Follow-up univariate ANOVAs were conducted when necessary. Statistical significance was set at $\alpha \leq 0.05$.

Participants were subsequently categorised according to whether their 20mSRT performance was ≥50th percentile or <50th percentile for sex-specific normative values. A logistic regression generalised linear model was used to calculate regression coefficients. Odds ratios (ORs) were derived from the natural logarithm of the coefficients, and 95% confidence intervals were calculated accordingly[273] to determine the likelihood of achieving a score ≥50th percentile.

A metabolic equivalent (MET) represents the ratio between working metabolic rate and estimated resting metabolic rate. MET values for the selected percentile categories were calculated using a resting oxygen uptake value of 3.5 $mL \cdot kg^{-1} \cdot min^{-1}$.

The Pearson chi-square statistic was used to compare the performance of Irish adolescents in the 20mSRT with established European normative data.[264] Differences between expected frequencies (European normative data) and observed frequencies (Irish data) within each quintile category were examined. All statistical analyses were performed using SPSS for Windows statistical software (Version 28.0; SPSS Inc., Chicago, IL, USA). Statistical significance was set at $p < 0.05$.

RESULTS

Over the six-year study period, 66% of all post-primary schools registered with the Department of Education participated in the Schools' Fitness Challenge (SFC). A chi-square test of independence was conducted to determine whether the distribution of school characteristics differed between schools participating in the SFC and the overall national distribution of schools registered with the Department of Education. No significant differences were observed in the distribution of school characteristics, including fee-paying status, DEIS designation, mixed- or single-sex status, boarding status, and school ethos, between participating schools and the national school population ($\chi^2 = 3.44$, $p = 0.992$), as presented in Table 3.1.

A total of 53,996 first-year post-primary school students from 432 schools completed the 20 m shuttle run test (20mSRT) between 2013 and 2018. Preliminary screening identified 1,570 outliers (2.9%), which were subsequently removed from the dataset. Statistical analyses were therefore conducted on data from 52,426 participants who successfully completed the 20mSRT. Study 1 included baseline 20mSRT data from 26,675 female participants and 25,751 male participants.

Table 3.1: Schools and their relevant characteristics that participated in the SFC (observed) in comparison with the count of school types (expected) as published by the Department of Education

	SFC – Schools Participated (as %)	Department of Education and Skills Data
Fee Paying		
Fee	29 (57%)	51
Non fee paying	403 (60%)	672
Ethos		
Interdenominational & Multidenominational	216 (61%)	352
Catholic	202 (59%)	344
Quaker, Jewish, Methodist & Presbyterian	14 (52%)	27
DEIS		
Yes DEIS	131 (67%)	195
No DEIS	301 (57%)	525
Attendance		
Day	420 (60%)	697
Mixed	14 (60%)	23
Boarding	2 (67%)	3
School sex		
Female only	74 (57%)	129
Male only	50 (50%)	101
Mixed	308 (62%)	493

SFC, Schools Fitness Challenge; DEIS, Delivering Equality in Schools

20mSRT – Sex Comparisons

There was no significant three-way interaction between sex, DEIS status, and year for the dependent variable, 20 m shuttle run test (20mSRT) total shuttles ($F(10, 52{,}390) = 1.736$, $p = 0.067$, partial $\eta^2 = 0.000$). However, a statistically significant sex × year interaction was observed for 20mSRT total shuttles ($F(5, 52{,}390) = 6.971$, $p < 0.001$, partial $\eta^2 = 0.001$). On average, female participants completed 37.8 ± 17.9 shuttles, whereas male participants completed 51.9 ± 23.0 shuttles. The annual mean number of shuttles completed between 2013 and 2018 is illustrated in Figure 3.1.

Across all years, male participants consistently outperformed female participants, completing significantly more shuttles ($p < 0.001$). Among female students, mean 20mSRT performance from 2014 to 2018 was significantly higher ($p < 0.001$) than in 2013. Overall, female performance showed a gradual upward trend over time, increasing from 34.3 ± 17.0 shuttles in 2013 to a peak of 40.6 ± 18.8 shuttles in 2018.

Male performance peaked in 2017, with a mean of 53.7 ± 24.0 shuttles, which was significantly higher ($p < 0.001$) than all other years except 2016. However, a significant decline was observed in 2018 ($p < 0.001$), with performance returning to levels comparable to 2013.

A detailed breakdown of annual sex-specific differences is provided in Appendix G.

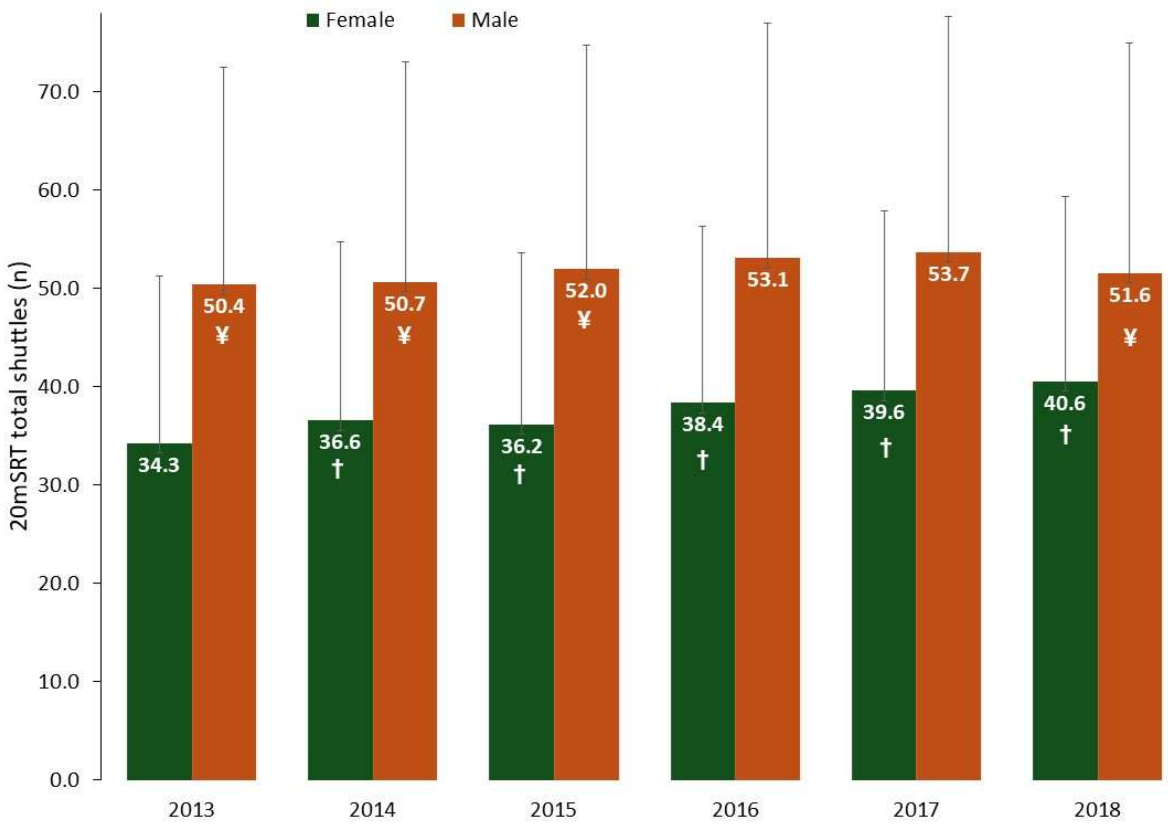


Figure 3.1: *Mean 20mSRT total shuttles by year and sex. † p<0.001 v 2013 for female 20mSRT scores; ¥ p<0.001 v 2017 for male 20mSRT scores*

Centile scores for the total number of shuttles performed, associated est$\dot{V}O_2$max and MET scores for first year post primary students are presented in Table 3.2.

Table 3.2: Total number of shuttles performed, est$\dot{V}O_2$max and MET capacity percentile scores for female and male students, based data collected between 2013 – 2018

	Centiles						
	5th	**10th**	**25th**	**50th**	**75th**	**90th**	**95th**
Female							
20mSRT Shuttles (n)	12	16	24	35	49	63	72
Est$\dot{V}O_2$max (mL·kg^{-1}·min^{-1})	36.8	38.1	40.6	43.7	47.4	51.4	53.7
MET capacity	10.5	10.9	11.6	12.5	13.5	14.7	15.3
Male							
20mSRT Shuttles (n)	16	22	34	52	71	87	95
Est$\dot{V}O_2$max (mL·kg^{-1}·min^{-1})	38.1	39.7	43.4	48.2	52.3	55.8	57.4
MET capacity	10.9	11.3	12.4	13.8	14.9	15.9	16.4

20mSRT, 20 meter shuttle run test; Est$\dot{V}O_2$max, estimated maximal oxygen consumption

Socioeconomic status

A significant sex × school DEIS status interaction was observed for total 20mSRT shuttle performance ($F(2, 52{,}390) = 39.280$, $p < 0.001$, partial $\eta^2 = 0.001$).

On average, first-year male and female students attending DEIS schools completed substantially fewer shuttles than their peers in fee-paying and non-fee non-DEIS schools. Specifically, males in DEIS schools completed 11.5 shuttles (20%) fewer than those in fee-paying schools and 8.3 shuttles (15%) fewer than those in non-fee non-DEIS schools. A similar pattern was observed in females, with DEIS students completing 15.1 shuttles (32%) fewer than their fee-paying counterparts and 5.9 shuttles (15.5%) fewer than females in non-fee non-DEIS schools (see Table 3.3).

Table 3.3: 20mSRT total shuttle score based on school status and participant sex

	Female		**Male**	
	n	**20mSRT**	**n**	**20mSRT**
Non-Fee Non-DEIS	19,867	38.0±17.9†	18,153	53.8±22.8†
DEIS	4,551	32.1±17.2*	6,239	45.5±23.1*
Fee Paying	2,257	47.2±17.5$^{\dagger *}$	1,359	57.0±21.4$^{\dagger *}$

Values presented are mean ± SD; 20mSRT, 20 meter shuttle run test; DEIS, delivering equality in schools † p<0.001 v DEIS; * p<0.001 v Non-Fee Non-DEIS

Female students attending fee-paying schools had 4.3 times higher odds of achieving 20mSRT score at or above the 50th percentile compared with their DEIS counterparts (95% CI: 3.89–4.76). Similarly, male students attending fee-paying schools had 2.17 times higher odds of achieving this benchmark than males attending DEIS schools (95% CI: 1.92–2.42), as illustrated in Figure 3.2.

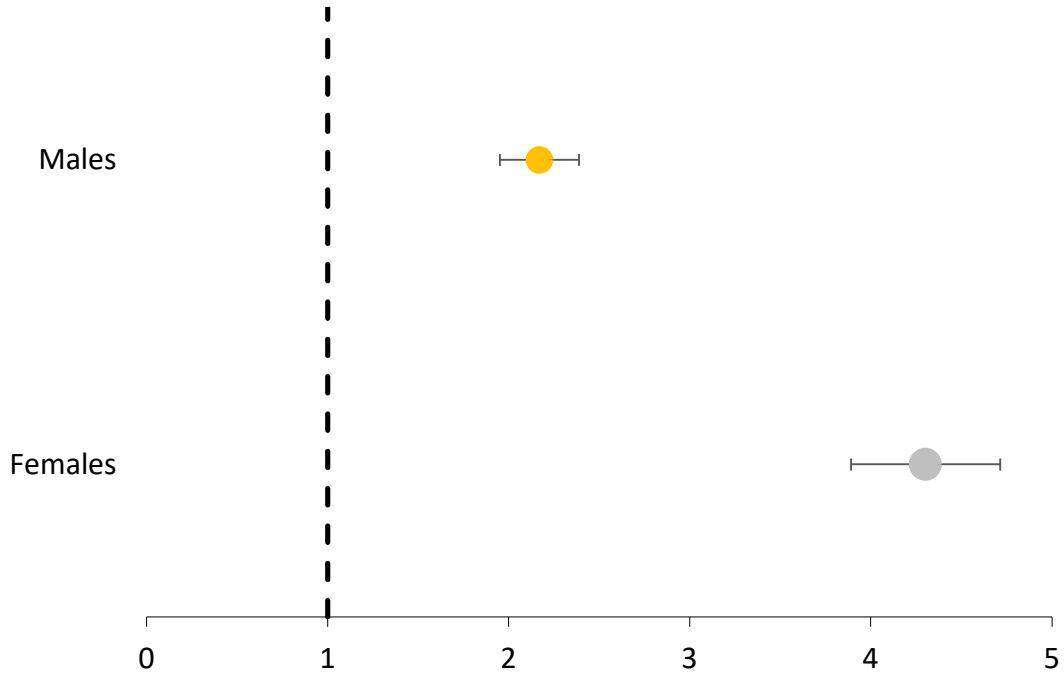


Figure 3.2: *The odds of fee-paying school students being above the 50th percentile in comparison with DEIS school students*

Comparison with European normative values

The distribution of Irish 20mSRT scores across European normative quintile categories, as defined by Tomkinson et al. (2018)[264] is presented in Figure 3.3A-B. Statistically significant differences were observed between the observed distribution of Irish scores and the expected European distribution for both males ($\chi^2 = 322.7$, $p < 0.001$) and females ($\chi^2 = 621.3$, $p < 0.001$).

Among males, the proportion of Irish 20mSRT scores in the lowest quintile (≤20th percentile) was 6% higher than expected, with 21% of scores falling within this category. In contrast, proportions in the intermediate quintiles (40th, 60th, and 80th percentiles) were slightly lower than expected, with 18%, 16%, and 19% of scores, respectively. Conversely, a greater-than-expected proportion of male scores was observed in the highest fitness quintile (>80th percentile), accounting for 25% of all male 20mSRT results.

A similar but more pronounced pattern was observed among females. The proportion of Irish female 20mSRT scores in all quintiles up to the 80th percentile was lower than European normative expectations, with 19%, 18%, 16%, and 19% of scores in the 20th, 40th, 60th, and 80th quintiles, respectively. In contrast, the proportion of female scores in the highest quintile (>80th percentile) exceeded the expected distribution, with 29% of Irish female results falling within this category.

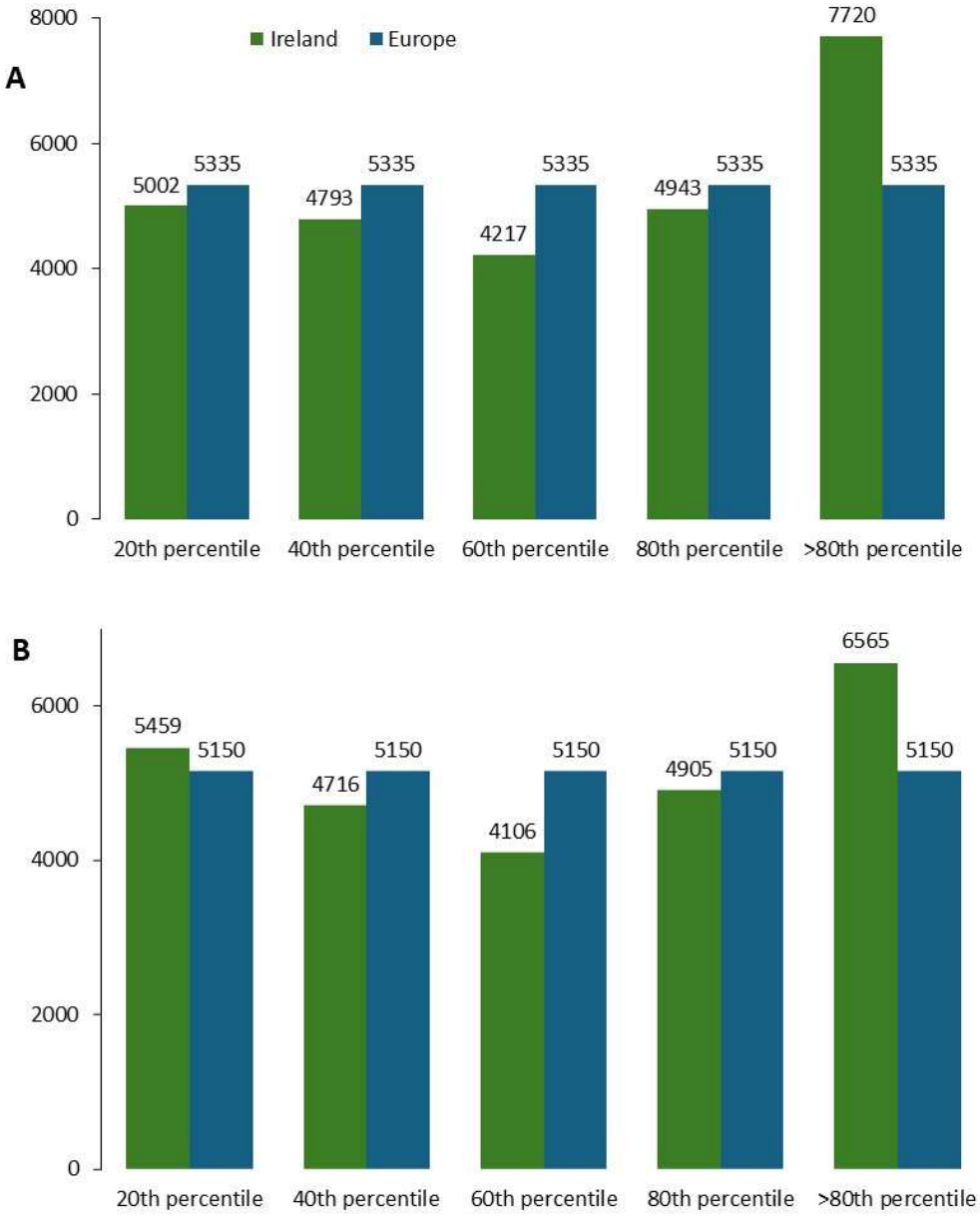


***Figure 3.3A-B**: Female (A) and male (B) quintile distributions of Irish vs. expected European 20mSRT stage scores by percentile group*

Cardiovascular Health

Among male students, 63% of those attending DEIS schools achieved a 20 m shuttle run test (20mSRT) score above the threshold for good cardiovascular health, as defined by Ruiz et al. (2016).[125] This proportion was substantially lower than that observed in fee-paying schools (84%) and non-fee non-DEIS schools (77%) (Figure 3.4).

Among female students, the proportion meeting the minimum 20mSRT threshold for good cardiovascular health was high across all school types. Specifically, 94% of females attending DEIS schools met the threshold, compared with 99% in fee-paying schools and 97% in non-fee non-DEIS schools.

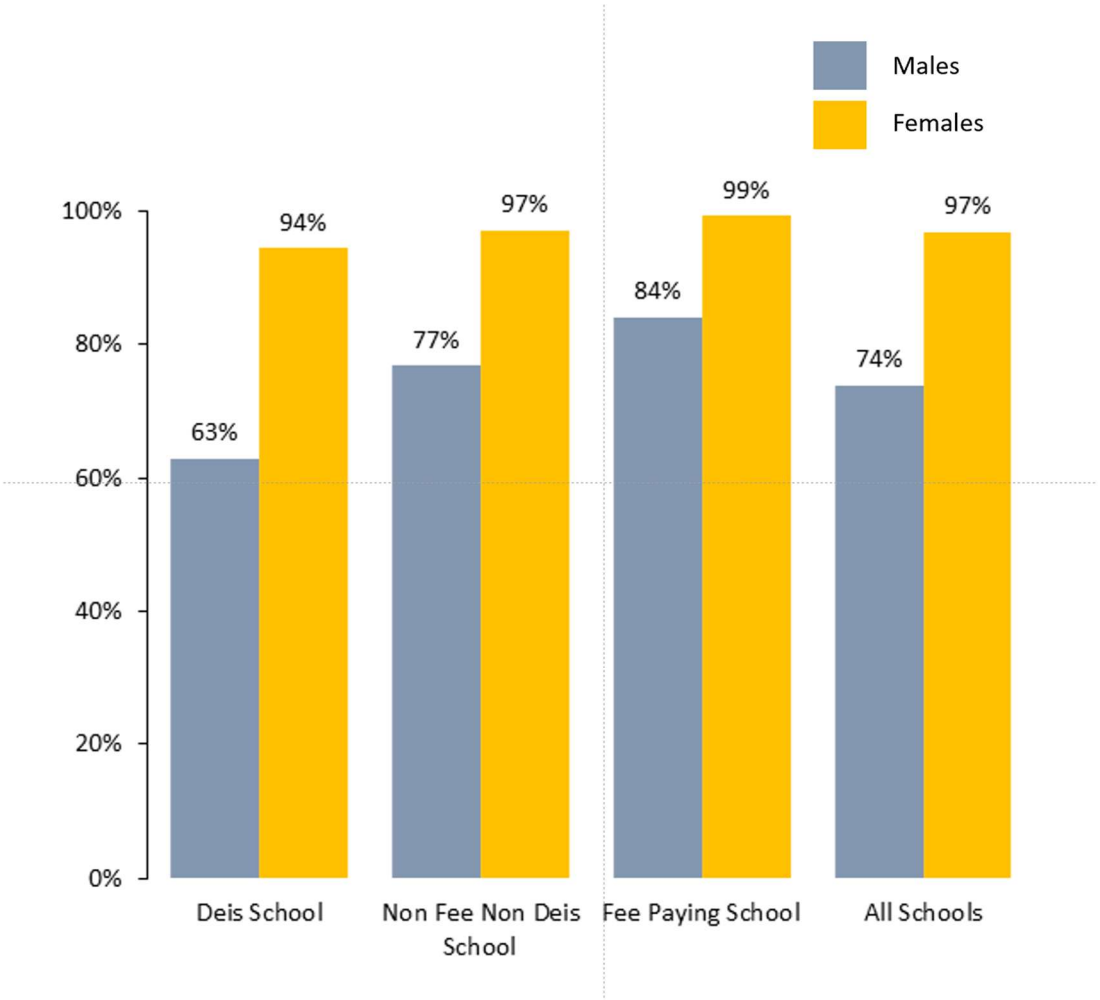


Figure 3.4: *Percentage of students by DEIS and Fee-paying status that attain the minimum levels of CRF for good heart health*

DISCUSSION

Globally, the 20mSRT is the most commonly used field-based assessment pf CRF in children and adolescents.[52,258,274] International[52] and European-specific[264] normative date sets for 20mSRT performance have been established, along with sex-specific minimum thresholds associated with favourable cardiovascular health outcomes.[20,126] Among 13-year-old European males and females across 30 countries, the shuttle run threshold corresponding to the top centile group (>80th percentile), based on the expected distribution of 20 m shuttle run test (20mSRT) scores, was 69 shuttles for males and 46 shuttles for females.[264] Based on data from 53,996 first-year post-primary school students, the threshold corresponding to the 80th percentile was 10% higher for Irish males and 28% higher for Irish females, respectively, compared with the 80th percentile values reported for European countries excluding Ireland. Consequently, a greater proportion of Irish first-year post-primary school students exceeded the threshold associated with the 80th percentile for 13-year-olds in Europe. In a previous study involving 1,200 first-year Irish post-primary school students, it was reported that 61% of females and 41% of males achieved scores at or above the 80th percentile of European normative data when profiling health-related physical fitness (HRPF).[31]

When averaged across the six-year period, first-year male and female students completed a mean of 52 and 37 shuttles, respectively, 20mSRT. These values fall within 10% of those reported in a recent study of first-year post-primary school students in Ireland.[31] Male students outperformed females in the 20mSRT during each of the 6 years of data collection. The total number of shuttle-runs performed by first-year male students during the 6 years of the SFC ranged between 50.4 and 53.7. During the same period, the total number of shuttle-runs performed by first-year female students increased from 34.3 to 40.6, resulting

in the gender gap decreasing from 37% in 2013 to 25% in 2018**.** The study cohort, first-year post-primary school students, arrive at secondary school with the majority of their PA and sporting experiences having been shaped at both primary-school and community level. Over this 6-year period, 2013 to 2018, students may have experienced different primary-school policy environments; therefore, any observed trend should be interpreted in the context of evolving school-based PA provision over the preceding 5 to 10 years.

Both PA and sport participation are influenced by broader policy and curriculum developments in school and community settings, including initiatives such as Green-Schools Travel (introduced in 2008) and the Active School Flag programme (introduced in 2009). In addition, governmental policy developments, including the expansion of local sports partnerships from 2007[275] to nationwide coverage in 2013,[276] alongside increases in associated funding from €4.5 million in 2007 to €13 million in 2013,[275] may have contributed to changes in youth physical activity opportunities over time. These contextual factors suggest that observed trends may not necessarily reflect the longer-term secular declines in youth physical activity and fitness reported internationally.

Accordingly, the modest improvement observed in female performance, contrasted with relative stability in males, may reflect cohort-specific variations in primary school and community-based PA opportunities in the years preceding secondary school entry, rather than solely longer-term secular trends.

DEIS status may be considered a relatively broad proxy measure of SES, as it reflects area- and school-level disadvantage rather than individual-level socioeconomic circumstances.[277] However, school-level SES remains a significant determinant of 20mSRT performance.[31,278] In the present study, DEIS status strongly differentiated performance

outcomes, with the magnitude of the SES gradient more pronounced in females than males (DEIS vs fee-paying: 32% vs 20% fewer shuttles; odds ratio for achieving ≥50th percentile: 4.3 vs 2.17). Notably, fee-paying females achieved a similar mean shuttle score to DEIS males (47.2 v 45.5), suggesting that socioeconomic context may attenuate the typically observed male advantage in CRF. This pattern is consistent with established socioeconomic gradients in adolescents' sport participation and access to coaching exposure, particularly within community sport settings.[279] Such disparities may be further compounded by the weight-bearing nature of the 20mSRT, whereby greater fat mass imposes an additional physiological load and increases the oxygen cost of running These findings align with previous research in Irish adolescents, which has reported higher 20mSRT performance among schoolchildren from more socioeconomically advantaged areas.[280]

School structure may further contribute to these observed patterns. In Ireland, 55% of fee-paying post-primary schools are single-sex, whereas DEIS post-primary schools are predominantly co-educational.[272] A plausible explanation for this pattern is that single-gender environments may enhance girls' engagement and intensity during physical education (PE), particularly in game-based activities, by reducing self-consciousness and altering the motivational and participation climate. In support of this, an accelerometer-based study of 12–15-year-old girls participating in basketball PE lessons found that students accumulated significantly more moderate-to-vigorous PA (MVPA) and vigorous physical activity during single-sex classes compared with co-educational settings. In addition, girls spent less time engaged in low-intensity activity and reported a preference for the single-sex environment.[281] Despite this evidence, a large UK study assessing CRF reported no significant differences in females' fitness between those attending co-educational schools and those attending single-

sex schools. The same study also demonstrated a clear association between school socioeconomic status and fitness, with pupils attending schools in less deprived areas exhibiting higher CRF levels.[282]

DEIS initiatives have demonstrated positive effects on educational outcomes, particularly in relation to literacy and numeracy in primary school settings.[29] Given that low CRF is an independent risk factor for CVD and all-cause mortality,[283] there is a clear rationale for the development and implementation of targeted interventions aimed at reducing disparities in CRF between students attending DEIS and non-DEIS schools. The introduction of a mandatory annual, nationwide school-based health-related fitness assessment, including objective measures of CRF, would substantially enhance the availability of national normative health-related fitness data and enable robust evaluation of temporal trends, particularly among students attending DEIS schools.

Such a system would also support teachers, sports coaches, and allied health professionals in the early identification of children and adolescents at increased cardiometabolic risk due to low CRF levels, thereby facilitating timely, targeted, and individualised intervention strategies.

Performance in the 20mSRT can be used to estimate $\dot{V}O_2$max (est$\dot{V}O_2$max). Ruiz et al. (2016)[125] proposed sex-specific CRF cut-points across youth aged 8-19 years, with commonly cited shuttle-stage equivalents illustrated for a 15-year-old population. In this framework, an est$\dot{V}O_2$max of 42 $mL \cdot kg^{-1} \cdot min^{-1}$ for males and 35 $mL \cdot kg^{-1} \cdot min^{-1}$ for females has been associated with increased odds of a favourable cardiovascular (CV) health profile in adolescents with a mean age of 15 years.[125] The application of these cut-points to first-year post-primary school students, who are predominantly aged 12–13 years, warrants careful

consideration. Younger adolescents may not yet have undergone the full maturational adaptations that contribute to increases in peak $\dot{V}O_2$ during later adolescence, including enhanced stroke volume, increased haemoglobin concentration, and age- and maturation-related changes in skeletal muscle metabolism.[284] Given that age- and maturation-related changes in CRF during adolescence are sex-specific, [41] the application of thresholds derived from older adolescent reference populations to younger cohorts may introduce classification bias. This is particularly relevant in males, in whom both CRF and shuttle-run performance typically exhibit more pronounced improvements across adolescence.

The vast majority (97%) of first-year female post-primary school students achieved an estimated $\dot{V}O_2$max (est$\dot{V}O_2$max) ≥35 mL·kg^{-1}·min^{-1}. The proportion of female students meeting the threshold associated with a favourable CV health profile was 94% in DEIS schools, 97% in non-fee non-DEIS schools, and 99% in fee-paying schools. The mean est$\dot{V}O_2$max for first-year Irish female students was 44 mL·kg^{-1}·min^{-1}, which is approximately 25% higher than the threshold value associated with a favourable CV health profile in 13-year-old girls as defined by Ruiz et al. (2016).[125] As the proportion of female students achieving an estimated $\dot{V}O_2$max indicative of a favourable cardiovascular health profile was 97%, only those in approximately the lowest 3rd percentile failed to meet the target est$\dot{V}O_2$max threshold. These proportions, should however, be interpreted with caution. Classification against the 35 mL·kg^{-1}·min^{-1} threshold is based on estimated rather than directly measured $\dot{V}O_2$max values. In addition, 20mSRT prediction equations are associated with a standard error of estimate of approximately ±5-7 mL·kg^{-1}·min^{-1},[44] which may influence individual-level classification accuracy.

At the individual level, this uncertainty is non-trivial. A student with an estimated $\dot{V}O_2$max of 36 mL·kg^{-1}·min^{-1} cannot be confidently classified as exceeding the threshold, given the standard error associated with 20mSRT prediction equations. This issue may be particularly relevant for the DEIS cohort, where a greater proportion of students appear to cluster closer to the lower boundary of the health-related cut-point.

However, given the well-established relationship between lower socioeconomic status (SES) and cumulative health inequalities across the life course,[26] the reduced attainment of CRF thresholds among students in DEIS schools represents a finding of public health significance. CRF in adolescence is a meaningful and modifiable determinant of long-term cardiovascular health, and socioeconomic disparities observed at this developmental stage may act as an early indicator of diverging health trajectories[26]

In contrast, 25% of male students did not achieve an estimated $\dot{V}O_2$max associated with a favourable CV health profile, with evidence of a clear socioeconomic gradient. Approximately one in five first-year male students attending fee-paying schools failed to meet the est$\dot{V}O_2$max threshold of ≥43.8 mL·kg^{-1}·min^{-1} associated with optimal CV health. This proportion increased to approximately one in four among males attending non-fee non-DEIS schools, and to one in three among those attending DEIS schools.

The published threshold for achieving an estimated $\dot{V}O_2$max associated with a favourable CV health profile is 21% higher in males than in females, corresponding to a difference of approximately 2 metabolic equivalents (METs).[125] Compared with female students, first-year male students needed to complete approximately 20 additional shuttles to achieve the level of CR associated with a favourable CV health profile. It is therefore not unexpected that the mean est$\dot{V}O_2$max for male students was only 10% higher than the

threshold required for a favourable CV health profile, and that a lower proportion of males (74%) achieved this cut-off value. Notably, all male students in the lowest quartile failed to attain the est$\dot{V}O_2$max threshold associated with favourable CV health.

Interpretation of these findings should be made with caution. The cut-points applied were originally derived from directly measured CRF values, whereas the present classification is based on est$\dot{V}O_2$max obtained from a field-based prediction equation. As such, misclassification around the threshold is possible. Furthermore, some authors have questioned the validity of using the 20mSRT as a surrogate for $\dot{V}O_2$max and for the application of fixed cut-offs in paediatric populations.[48]

Evidence from vascular function studies in older Irish male adolescents indicates poorer brachial artery flow-mediated dilation among individuals with low CRF; however, these findings were derived from an older cohort using directly measured $\dot{V}O_2$max in a laboratory setting.[285] Accordingly, they should be interpreted as supporting the biological plausibility of the observed associations rather than providing direct validation of threshold-based CRF classification in early adolescence.[285]

The high proportion of first-year post-primary school females achieving a CRF threshold associated with a favourable CV health profile is encouraging. This pattern may, in part, reflect relatively high levels of engagement in organised physical activity at this age, with approximately 82% of first-year females reported to participate in sport, while 18% do not.[279] However, sport participation should be interpreted primarily as a potential mechanism for achieving sufficient MVPA, particularly at vigorous intensity, rather than as inherently superior to broader physical activity promotion. This is because adaptations in CRF are driven principally by the overall dose and intensity of activity, regardless of the context or setting in

which it is accumulated.[286] From a public health perspective, the marked decline in organised sport participation across adolescence is concerning. By sixth year, the proportion of females not participating in any sport increases substantially to 52%[279] thereby reducing opportunities for exposure to PA through sport and limiting access to its associated health benefits.[287]

In conclusion, this retrospective analysis of over 52,000 first-year post-primary school students provides the most comprehensive profile to date of CRF among Irish adolescents. Overall, CRF levels were broadly favourable when compared with European normative data, with particularly strong performance observed at the upper end of the distribution and the majority achieving levels associated with a healthier cardiovascular profile.

However, these overall findings mask important inequalities. Clear sex- and socioeconomic-related disparities were evident, with students attending DEIS schools consistently demonstrating lower CRF performance, and males in these settings representing a particularly vulnerable subgroup. The modest improvement in female performance over time, alongside relative stability in males, further suggests that both school and community environments continue to shape youth fitness trajectories.

Taken together, these findings underscore the need for targeted school-based strategies to support the development of CRF, alongside the establishment of a national fitness surveillance system capable of monitoring temporal trends, identifying at-risk groups, and informing interventions aimed at reducing health inequalities among Irish youth.

CHAPTER IV

STUDY 2

A RETROSPECTIVE ANALYSIS OF A 6-WEEK EXERCISE INTERVENTION ON CARDIORESPIRATORY FITNESS LEVELS AMONG FIRST YEAR POST-PRIMARY SCHOOL STUDENTS

INTRODUCTION

Cardiorespiratory fitness (CRF) reflects the integrated capacity of multiple physiological systems to transport and utilise oxygen in support of skeletal muscle activity during sustained physical activity (PA).[288] High levels of CRF in children and adolescents are consistently associated with a more favourable cardiometabolic risk profile[19,123,264,29] and are strong predictors of future health outcomes across the life course. [289] Low CRF contributes to cardiovascular disease (CVD) risk through both direct and indirect pathways. Directly, low CRF is associated with structural and functional alterations of the heart and vasculature. Indirectly, it contributes to adverse cardiometabolic risk factors, including insulin resistance, hypertension, and dyslipidaemia, thereby compounding long-term disease risk. [290]

Given that CRF tracks from childhood into adulthood,[268] there is a strong rationale for prioritising strategies that optimise CRF during childhood and adolescence. Schools represent a key setting for the promotion of PA in children and young people.[291] In addition to providing near-universal reach across socioeconomic groups, schools have access to appropriate facilities and trained personnel capable of delivering structured PA opportunities. School-based interventions that increase opportunities for children and adolescents to engage in PA during the school day have been shown to be effective in increasing overall PA level[292] CRF,[156,293,294] enhancing a range of health outcomes,[295] including executive functioning.[296]

School-based exercise interventions may be implemented at varying scales, ranging from single-school programmes to regional or national initiatives. The Schools Fitness Challenge (SFC) was developed as a national initiative aimed at enhancing awareness of CRF among Irish youth. The programme comprised a baseline 20mSRT, followed by a repeat assessment after a six-week school-based PA/exercise intervention.

Notably, approximately 45% of participating schools that completed the baseline 20mSRT did not engage in the subsequent six-week intervention and follow-up assessment. This pattern of non-submission is unlikely to be random. If schools or classes with lower engagement, fewer resources, or greater logistical constraints are systematically under-represented at follow-up, estimates of intervention effectiveness may be biased, thereby potentially misinforming future national implementation strategies.

School-level characteristics, such as DEIS status, fee-paying status, school ethos, prior participation in the SFC, class size, and year of delivery - may reflect variation in organisational capacity, competing curricular demands, staffing and time constraints, facility access, and levels of student engagement. These factors are likely to influence both intervention implementation and completion of follow-up testing.

Given that these relationships may be non-linear and may involve complex interactions (for example, between socioeconomic disadvantage, school size, and school ethos), machine learning (ML) represents an appropriate analytical approach. ML comprises a set of data-driven methods designed to identify patterns within multivariable datasets and to generate predictive models capable of supporting classification and decision-making tasks. In this context, ML can be used to identify predictors of non-submission and to develop a practical risk-stratification tool to inform targeted implementation support.[297] ML has been

successfully applied in a range of classification and predictive contexts, including identifying schoolchildren at risk of dropout,[298] distinguishing between individuals based on sedentary behaviour patterns derived from accelerometer data,[299] and predicting customer engagement and usage within a home-based exercise platform.[300]

The primary purpose of this study was to evaluate the effect of a 6-week school-based PA/exercise intervention on 20mSRT performance among first-year post-primary school students. The study also examined the effect of school socioeconomic status (SES) on the change in 20mSRT performance and used ML to predict classes that did not submit a post-training 20mSRT result.

Aims

1. To evaluate the effect of a 6-week school-based PA/exercise programme on 20mSRT performance among first-year post-primary students each academic year between 2013 and 2018
2. To compare the changes in 20mSRT performance between first year, post-primary students attending DEIS and non-DEIS schools following participation in a 6-week school-based PA/exercise programme
3. To develop a machine learning model to predict classes that did not submit a post-intervention 20mSRT result

Hypothesis

1. Participation in a 6-week exercise programme will result in a statistically significant improvement in 20mSRT performance among both male and female first-year post-primary students
2. Improvements in 20mSRT performance following participation in a six-week exercise programme will be greater among male and female students attending non-DEIS schools compared with those attending DEIS schools.
3. School year, DEIS status, fee-paying status, religious ethos, and socioeconomic indicators, when included in a machine learning model, will predict non-submission of post-intervention 20mSRT data with high accuracy.

METHODS

Study Overview

The Irish Life Health Schools' Fitness Challenge (SFC) was launched in 2013 as a national initiative aimed at raising awareness of the importance of CRF during adolescence. The programme involved post-primary school students completing the 20mSRT before (baseline) and after (post-intervention) a six-week school-based physical activity (PA) and exercise intervention and was conducted annually between 2013 and 2018. The present study utilised pre- and post-intervention 20mSRT scores from classes participating in the programme over this period.

As previously described in the methods section of Chapter III.

Participant recruitment

As previously described in the methods section of Chapter III.

20mSRT

As previously described in the methods section of Chapter III.

Training Programme

Teachers were encouraged to design activities that were enjoyable, challenging and appropriate for the students' fitness levels. No guidance was provided regarding the frequency or duration of exercise sessions.

Statistical Analysis

The primary outcome variable was the change in class average for the total number of 20 m shuttles completed. Boxplots were used to screen for outliers at baseline and post-

training. A 20mSRT score > ±2.5 standard deviations from the mean was classified as an outlier and removed from the analysis. Data were assessed for normality using histograms, kernel density plots, and Q–Q plots.

A factorial mixed ANOVA was conducted to determine whether there was an interaction effect between four independent variables (sex: male or female; school DEIS/fee-paying status: DEIS or non-DEIS; year: 2013–2018; and percentile category: coded 1–4 based on baseline 20mSRT score) and one within-subjects factor (time: baseline and post-training) on the continuous dependent variable (20mSRT shuttles completed). The Greenhouse–Geisser correction was applied when Mauchly's test indicated a violation of sphericity. Significant main effects and interactions were further examined using pairwise comparisons with Bonferroni post hoc adjustment. Effect sizes were calculated using partial η^2 and interpreted as small (>0.01), medium (>0.06), and large (>0.14). Follow-up univariate ANOVAs were conducted to further explore significant interactions. Statistical analyses were performed using SPSS for Windows (Version 28.0; SPSS Inc., Chicago, IL, USA). Statistical significance was set at $p < 0.05$.

It was not possible to compare individual participants' baseline and post-training scores directly, as no personally identifiable data were collected. Consequently, a count-based approach was used to evaluate the effect of the six-week training programme on 20mSRT performance. This involved matching the number of participants by sex within each class at baseline and post-training. Where discrepancies existed in the number of male or female students between assessment phases, the highest 20mSRT scores were sequentially removed until equal participant numbers were achieved. The rationale for removing the highest scores was to minimise the risk of a Type II error.

Machine learning

The primary outcome variable for the ML analysis was a binary outcome: participation or non-participation in the post-training assessment following the six-week exercise programme. All class groups containing students from any year group participating in the SFC were included in the analysis. A flowchart illustrating the ML model is presented in Figure 4.1. The ML analysis was conducted using Python version 3.8.8, and the associated code is provided in Appendix I.

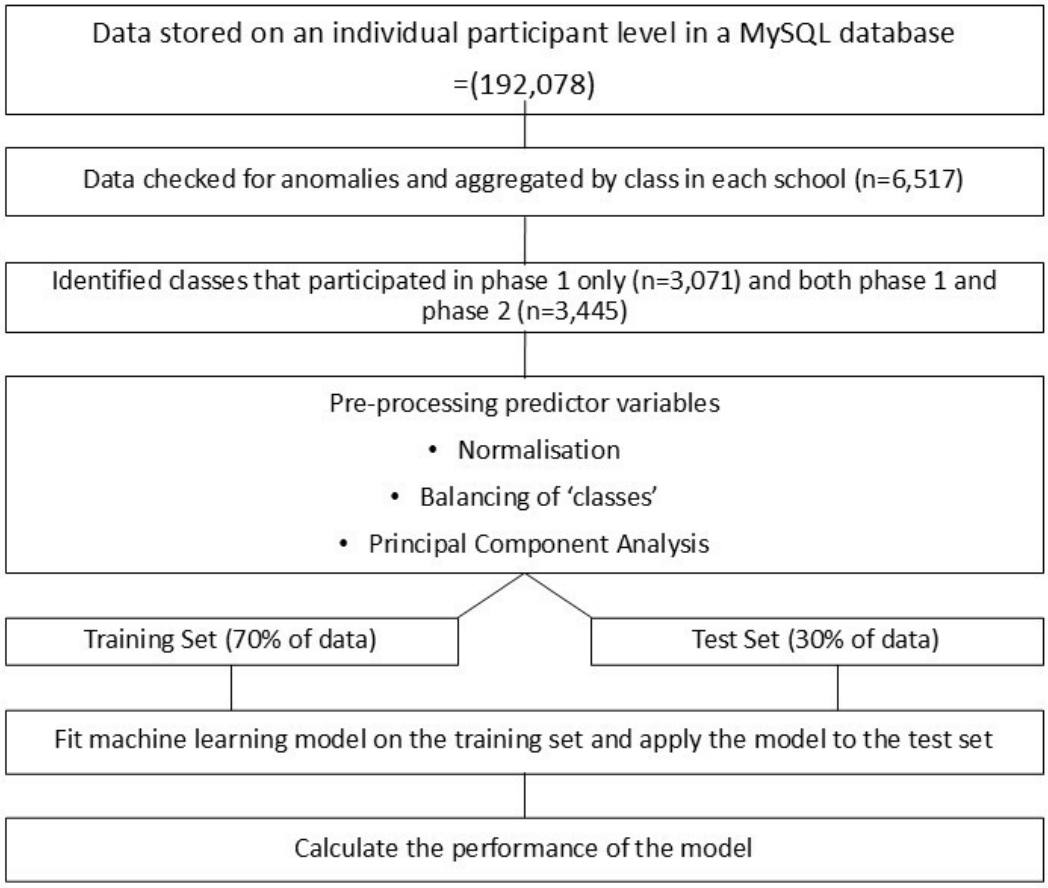


Figure 4.1: *Flowchart diagram of the machine learning model experimental process*

The predictor variables underwent several pre-processing procedures. For each class, the mean, standard deviation (SD), and 25th, 50th, and 75th percentiles were calculated for level, shuttle, and total number of shuttles completed.

- A z-score transformation was applied to the numerical data to account for sex differences in the total number of shuttles completed.
- One-hot encoding, which represents categorical variables as binary vectors, was used to generate binary dummy variables (0 or 1) for categorical variables in which no ordinal relationship existed between categories (e.g., school boarding type: day, mixed, or full boarding).
- Variables were entered into a principal component analysis (PCA) due to the high correlation between several predictor variables. Principal components explaining 99% of the variance were retained for analysis.

There was a 'class' imbalance in the dataset as more classes (groups of students) completed phase 2 than did not. Prior to running the ML algorithm, 3 copies of the dataset were created and a sampling strategy of a) 'under,' b) 'over,' and c) 'SMOTE' was applied. This allowed the datasets to be balanced based on a) 'under': removing random data points from the majority class; b) 'over': increasing the minority through random replication of the minority class (the classes who did not complete phase 2); and c) 'SMOTE': synthetic minority oversampling technique (SMOTE),[301] which generated synthetic observations from the minority class to numerically balance both classes.

The ML model was trained and tested using the SFC dataset across the six-year study period and included all year groups. Gradient Boosting Decision Tree (GBDT) modelling was employed, which builds an additive model using a forward stepwise approach to optimise loss functions. The model iteratively learns from prediction errors by adjusting the weights assigned to variables according to the loss function, which quantifies the discrepancy between predicted outputs and target values. The complete dataset was divided into training

and testing sets. The model was trained using the training dataset and subsequently applied to the testing dataset to evaluate predictive performance. Although derived from the same source, the testing dataset was treated as unseen data.

A grid search procedure was applied to the x-train and y-train datasets prior to model fitting to identify optimal hyperparameters, including the number of estimators, learning rate, and maximum tree depth. Improved weighting of parameters results in greater predictive accuracy and a lower cost function. Gradient descent minimises the cost function by iteratively updating model weights over successive runs. Boosting refers to the increased weighting assigned to previously misclassified observations, thereby improving their classification in subsequent iterations of the model.

The performance of the ML model was evaluated using four metrics: accuracy, recall, precision, and F1 score.[297] These metrics are derived from the following four outcomes:

- **True Positives (TP):** Classes correctly predicted to submit post-testing data.
- **True Negatives (TN):** Classes correctly predicted not to submit post-testing data.
- **False Positives (FP):** Classes that did not submit post-testing data but were incorrectly predicted to have submitted.
- **False Negatives (FN):** Classes that submitted post-testing data but were incorrectly predicted not to have submitted.

The equations used to calculate accuracy, precision, recall, and F_1 score are presented below.

1 $$accuracy = \frac{TP + TN}{TP + TN + FP + FN}$$

2 $$precision = \frac{TP}{TP + FP}$$

3 $$recall = \frac{TP}{TP + FN}$$

4 $$f_1 = \frac{2TP}{2TP + FP + FN}$$

RESULTS

The dataset analysed included first-year post-primary school students who participated in the SFC between 2013 and 2018 and is summarised in Table 4.1. A total of 2,688 classes, comprising 53,996 students, completed baseline testing, while 2,141 classes, comprising 25,791 students, completed post-training testing. Approximately 20% of first-year classes did not submit results for post-training testing.

Table 4.1: Count data of schools, students and classes by school type for each year of the SFC

	Year						
	2013	**2014**	**2015**	**2016**	**2017**	**2018**	**Total**
Schools	84	76	77	72	79	80	468
Students							
Total	4,376	4,376	4,075	3,433	4,790	4,741	25,791
Male	2,400	2,515	2,064	1,604	1,992	2,118	12,693
Female	1,971	1,861	2,011	1,829	2,798	2,623	13,093
Class Participation							
Classes	384	370	329	314	396	348	2,141
DEIS-Fee status							
Non-Deis-Non-Fee	239	246	213	221	268	257	1,444
DEIS	125	96	85	63	79	50	498
Fee paying	20	28	31	30	49	41	199
School sex							
Mixed	328	285	279	265	313	261	1,731
Single Sex	56	85	50	49	83	83	406

A significant interaction effect was observed for time × DEIS, $F(1, 2256) = 46.339$, $p < 0.001$, partial $\eta^2 = 0.021$; time × percentile category, $F(3, 2256) = 76.153$, $p < 0.001$, partial $\eta^2 = 0.092$; and time × year, $F(6, 2256) = 7.642$, $p < 0.001$, partial $\eta^2 = 0.020$ in the 20mSRT. No significant main effect of sex was found.

Between 2013 and 2018, a consistent year-on-year increase ($p < 0.001$) was observed in the mean number of shuttles completed post-training compared with baseline for both males and females. Figure 4.2 summarises the annual class means for total shuttles completed at baseline and post-training, stratified by sex. A detailed breakdown of baseline

and post-training 20mSRT results by year and sex is provided in Appendix J, with additional stratification by year, sex, and school type (DEIS, non-fee-paying non-DEIS, and fee-paying) presented in Appendix K.

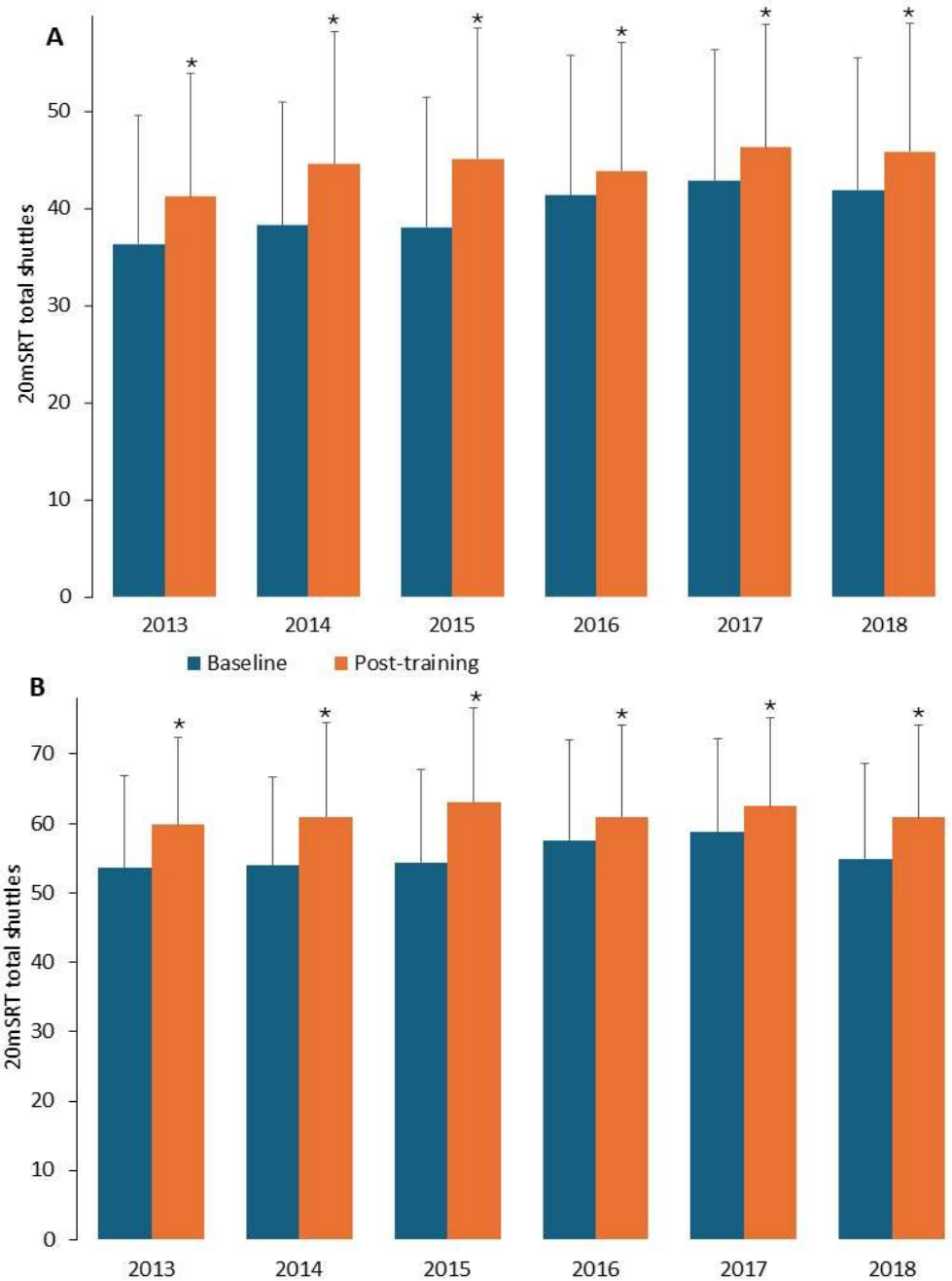
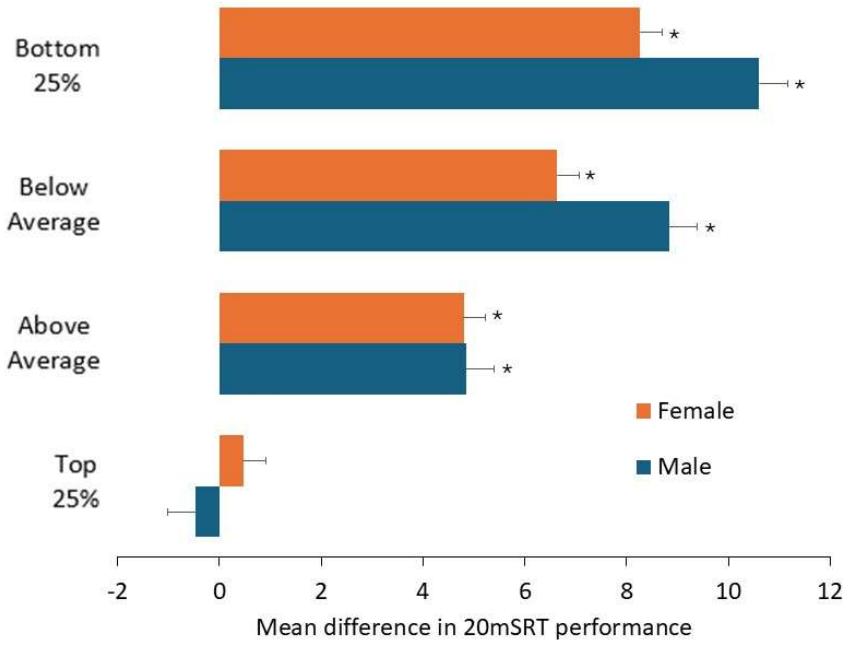


Figure 4.2A-B: *Average 20mSRT performance score at baseline and post-training between 2013 and 2018 for female (A) and male (B) participants; Values presented are means ± SD; * p<0.001 v baseline in each year*

Classes were categorised into quartiles (1–4) based on mean 20mSRT percentile scores. Figure 4.3 presents the absolute change in total 20mSRT shuttle performance according to baseline quartile classification.

Students in the lowest baseline quartile demonstrated the greatest improvements in performance, with increases of 10.6 and 8.3 shuttles for males and females, respectively ($p <$ 0.001 versus baseline). In contrast, students in the highest baseline quartile showed no meaningful improvement from baseline to post-training, with changes of 0.459 shuttles for females and −0.047 shuttles for males.

Among females, those in the above-average and below-average quartiles showed mean improvements of 4.8 and 6.6 shuttles, respectively (both $p < 0.001$). Similarly, males in the above-average and below-average quartiles demonstrated mean improvements of 4.8 and 8.8 shuttles, respectively (both $p < 0.001$).



***F*igure 4.3:** Absolute change in 20mSRT performance in male and female participants by percentile category;* p<0.001 v Baseline

Appendix L presents a fan chart illustrating the distribution of change in 20mSRT performance by class and percentile category from baseline to post-training over the 6-year period.

DEIS Status

A statistically significant time × DEIS × year interaction was observed, $F(6, 2256) = 3.897$, $p < 0.001$, partial $\eta^2 = 0.010$. Following the 6-week exercise intervention, both DEIS and non-DEIS school students demonstrated improvements in 20mSRT performance.

Figure 4.4 illustrates the total number of shuttles completed by male and female students attending DEIS and non-DEIS schools. Male students attending non-DEIS schools completed a greater number of shuttles at both baseline (57.3 ± 12.9 vs 50.3 ± 14.1; $p < 0.001$) and post-training (63.5 ± 11.8 vs 55.2 ± 14.4; $p < 0.001$) compared with males attending DEIS schools. Similarly, female students attending non-DEIS schools completed a higher number of shuttles at baseline (41.0 ± 11.3 vs 34.0 ± 11.3; $p < 0.001$) and post-training (46.2 ± 10.4 vs 38.3 ± 12.0; $p < 0.001$) than females attending DEIS schools (Figure 4.4). A yearly breakdown of baseline and post-test 20mSRT scores by sex and school type is provided in Appendix C.

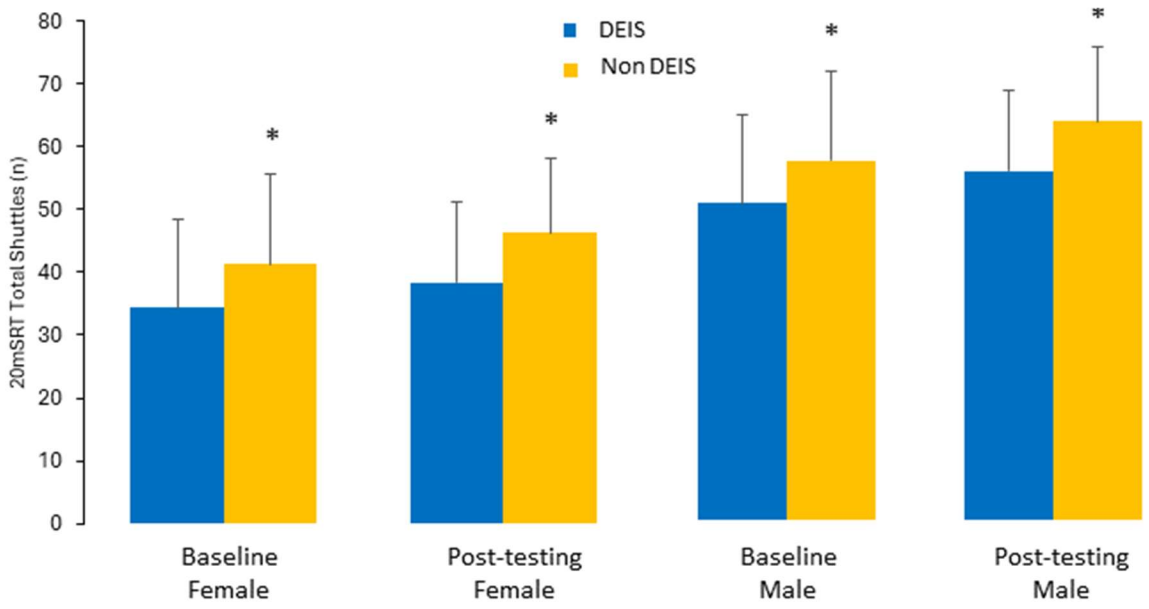


Figure 4.4: Average number of shuttles performed by first-year female and male participants at baseline and post-training grouped by school DEIS status; * p<0.001 v DEIS.

Machine Learning – Prediction Model

Approximately 42% of all classes across all year groups—not limited to first-year students—that completed baseline testing did not submit post-test 20mSRT scores. Overall, the GBDT machine learning model accurately identified the majority of classes that failed to provide post-training results.

Model performance metrics indicated higher precision and recall for the oversampling and SMOTE approaches compared with the undersampling technique. The F1 scores for each sampling method are summarised in Table 4.2.

Table 4.2: Gradient boosting decision tree results

Sampling Method	Accuracy	Precision	Recall	F1-Score
Under-sampling majority	0.744±0.001	0.726±0.002	0.750±0.002	0.738±0.001
Over-sampling minority	0.850±0.005	0.840±0.005	0.853±0.006	0.850±0.005
SMOTE	0.830±0.002	0.844±0.002	0.830±0.003	0.836±0.002

DISCUSSION

Higher levels of CRF have been associated with a more favourable cardiovascular profile in youth,[302–304]and CRF has been shown to track from adolescence into adulthood.[21] Accordingly, every effort should be made to increase and/or maintain CRF during adolescence. Schools provide an ideal setting for the delivery of exercise-based interventions, given the availability of appropriate facilities and trained personnel, as well as the substantial proportion of waking hours young people spend in the school environment.[305,306]

Study 2 examined changes in 20mSRT performance among 25,791 first-year post-primary students following a six-week (Phase 2 of the SFC), semi-structured, school-based, teacher-led physical activity/exercise intervention. Performance in the 20mSRT increased by approximately 11% in both males and females following the six-week school-based physical activity/exercise intervention. These findings are consistent with previous studies examining the effects of school-based exercise interventions on CRF. A comparable improvement in estimated $\dot{V}O_2$max (derived from the 20mSRT) following a six-week high-intensity training programme has been reported in both males and females with a mean age of 13 years.[307] No significant difference was observed in the mean change in 20mSRT performance between students attending DEIS and non-DEIS schools following the intervention.

Considerable variability was observed in class-level responses in 20mSRT performance following the six-week school-based physical activity/exercise intervention. Factors known to influence changes in CRF in response to exercise training include sex, age, health status, genetic factors, habitual physical activity levels, baseline fitness, and training variables such as modality, intensity, and duration.[308] In children and adolescents, morphological and physiological changes associated with growth and maturation[284,289,309] further contribute to

variability in physiological responses to exercise training. Overall, these findings indicate that the six-week school-based intervention elicited meaningful improvements in CRF; however, substantial inter-class variability in training response was evident.

Irrespective of school type, students in the lowest CRF quartile had the largest improvement in 20mSRT performance. Male and female students in the lowest CRF quartile completed an extra 11 and 8 shuttle runs, respectively, compared to baseline values. The improvements in 20mSRT performance in the lowest CRF quartile equated to an increase in est$\dot{V}O_2$max of 3.7 $mL \cdot kg^{-1} \cdot min^{-1}$ (1.0 MET) and 2.4 $mL \cdot kg^{-1} \cdot min^{-1}$ (0.7 MET) for males and females, respectively. Among adults, a 1 MET improvement in CRF is associated with a 13% and 15% reduction in all-cause and CV mortality, respectively.[310] Importantly, a substantial proportion of males in the lowest CRF quartile achieved estimated $\dot{V}O_2$max values associated with a more favourable cardiovascular risk profile (≥ 42 $mL \cdot kg^{-1} \cdot min^{-1}$) following participation in the six-week school-based exercise intervention.

The six-week duration of the SFC intervention is relatively short compared with other school-based physical activity/exercise interventions,[311] and may have constrained the magnitude of improvement in 20mSRT performance. This shorter duration was selected to facilitate baseline and post-testing while aligning with the school term structure. In addition, higher attrition rates have been reported in school-based interventions exceeding 12 weeks, particularly among more sedentary individuals. [312]

The absence of formal guidance for teachers likely increased between-school variability in intervention dose, intensity, and delivery, which may partly explain the modest average changes in 20mSRT performance. Empowering teachers to tailor programmes to the specific needs of their students, school infrastructure, and surrounding community has been

shown to influence programme effectiveness.[313] Furthermore, teacher autonomy in intervention design has been associated with increased ownership, improved fidelity of delivery, and more sustainable integration of programmes into routine school practice.[251] This approach recognises that a "one-size-fits-all" model is often insufficient in diverse school settings and supports the view that interventions are more effective when educators act as active co-creators rather than passive implementers.[313,314] It must also be acknowledged that uptake of the SFC may have been influenced by selection effects. Schools that did not participate may have included educators who lacked confidence, competence, or capacity to deliver the programme and therefore chose not to enrol their school. Consequently, participating schools may not be fully representative of all post-primary schools and estimates of programme feasibility and effectiveness should be interpreted in light of this potential self-selection bias.

At the same time, the decision not to impose a prescriptive "one-size-fits-all" programme may have enhanced feasibility in schools with constraints related to facilities, timetabling, staffing, or local opportunity structures - conditions that may be more prevalent in socioeconomically disadvantaged settings. This flexibility may therefore have reduced the risk that an externally designed programme would be impractical to implement in certain contexts. However, the present findings suggest that flexibility in the absence of minimum implementation standards (e.g., clear FITT principles, progression, and simple intensity-monitoring guidance) may have contributed to variability in programme delivery.

If the SFC is re-established, future iterations may benefit from a hybrid model comprising a small number of non-negotiable core components (e.g., minimum weekly dose, intensity targets, and progression criteria), alongside adaptable session formats (e.g., games-

based or circuit-based options). Such an approach would allow teachers to tailor delivery to local context while preserving the physiological stimulus necessary to elicit improvements in CRF.

A Scientific Statement from the American Heart Association emphasises that CRF adaptations in youth are driven primarily by exposure to sufficiently intense physical activity, which was not controlled for in the present study. The greatest improvements in fitness are observed when programmes incorporate vigorous-to-near-maximal bouts (i.e., HIIT-type structures), rather than relying solely on increases in overall activity volume.[38] Intervention effects are sensitive to core design features; intensity targets, session frequency, work:rest structure, and progression. Moreover, the evidence base remains uncertain regarding the precise minimum dose required to elicit consistent improvements in CRF across diverse youth populations.[38] Consequently, as the SFC intervention did not specify minimum intensity or progression standards, it is likely that schools delivered substantially different "doses" of exercise, which may help to explain the observed variability in post-intervention 20mSRT performance.

Dropout rates in the SFC were highest among fourth-year students (52%), and overall participation was substantially lower among senior cycle students compared with junior cycle students. This pattern is consistent with the well-documented decline in sport and physical activity participation across the post-primary school years.[279] These observations are concerning, as low levels of CRF in late adolescence are associated with increased risk of CVD, cancer, and all-cause mortality over the subsequent 30 years.[120,315]

Approximately 350 classes from 80 schools completed the six-week SFC. Across all year groups, 42% of classes that participated in baseline testing did not subsequently take

part in the six-week exercise intervention. This attrition was particularly evident among fourth-year classes, although year-group specific dropout data are not presented in this thesis. A plausible explanation is that participation among fourth-year students may have been more difficult to sustain due to school-level timetabling constraints and competing academic demands during the school year. Given the magnitude of the improvements in CRF observed among first-year students, identifying factors contributing to the substantial reduction in class participation during Phase 2 of the SFC may inform the design and implementation of future school-based exercise interventions.

ML is a data-driven approach to constructing analytical models[297] that automates learning from key variables, identifies patterns, and supports decision-making with minimal human intervention.[316] A range of ML algorithms are available, with selection dependent on the nature of the data and the specific problem being addressed. Study 3 employed a gradient-boosted decision tree (GBDT) algorithm to identify classes that did not submit post-testing SFC results, correctly classifying approximately 85% of such cases. The GBDT approach combines multiple weak models to form a stronger predictive model by iteratively improving performance through correction of prior errors, thereby enhancing both accuracy and generalisability. Feature extraction helps identify the key variables of a ML model.

In the present analysis, dimensionality reduction was implemented using principal component analysis (PCA) prior to model development. PCA transforms the original set of correlated variables into a smaller number of uncorrelated components that capture the maximum variance in the dataset.[317] Each principal component is a weighted linear combination of the original variables (i.e., “loadings”), with earlier components explaining more variance and later components progressively less.[317] This approach can reduce

multicollinearity, compress information, and improve model stability and computational efficiency, particularly when many predictors are correlated.[317] However, because PCA produces composite components derived from multiple variables, it was not possible to isolate the specific school-level variables that most strongly contributed to the correct identification of classes that did not submit post-intervention SFC results.

Further research should examine whether the dropout model generalises beyond the schools used for training by adopting a school-level holdout strategy (i.e., withholding entire schools rather than individual classes). This approach provides a more stringent assessment of model performance and reduces the risk of school-level information leakage. Model interpretability could also be enhanced by re-estimating the model without PCA and examining variable contributions using SHapley Additive exPlanations (SHAP)[318] SHAP values attribute an importance score to each feature for individual predictions, thereby facilitating clearer identification of the school- and class-level characteristics associated with non-submission.

Finally, prediction should be complemented with explanation through a mixed-methods follow-up, in which classes classified as higher- and lower-risk are sampled for brief teacher surveys or interviews. This would help to elucidate key barriers to post-testing and data reporting (e.g., time constraints, facilities, staffing, competing priorities, student engagement, and administrative burden). These factors could subsequently be operationalised as additional predictors (e.g., teacher confidence, space constraints, resource availability, reporting burden), thereby enhancing model utility and informing targeted strategies to reduce dropout.

In conclusion, Study 2 demonstrates that a brief, six-week, teacher-led school-based exercise intervention can produce meaningful improvements in CRF among Irish adolescents, with an average 11% increase in 20mSRT performance across both sexes. The greatest benefits were observed among students with the lowest baseline fitness, many of whom transitioned into more favourable cardiovascular health categories, highlighting the potential of such interventions to support those at greatest health risk.

Although improvements were broadly similar across DEIS and non-DEIS schools, persistent disparities in overall fitness levels remained, suggesting that short-term interventions alone may be insufficient to address underlying inequalities. At the same time, substantial variability in outcomes and a 42% class-level dropout rate highlight the challenges associated with real-world implementation.

In this context, the strong performance of the GBDT model in predicting non-submission provides a useful basis for proactively identifying and supporting classes at risk of dropout. Collectively, these findings support a hybrid intervention model that combines teacher autonomy with clearly defined physiological targets and targeted implementation supports, in order to improve programme fidelity, sustain engagement, and maximise equitable improvements in fitness outcomes within school settings.

CHAPTER V

STUDY 3

INDIVIDUAL AND COMBINED EFFECTS OF HEALTH-RELATED FITNESS COMPONENTS AND SCHOOL SOCIOECONOMIC STATUS ON SUBCLINICAL CVD AMONG FIRST-YEAR POST-PRIMARY SCHOOL STUDENTS

INTRODUCTION

Cardiovascular disease (CVD) is the leading cause of death in Ireland and encompasses a range of disorders affecting the heart and blood vessels. Atherosclerosis, characterised by the progressive accumulation of fibro-fatty plaque within the intima-media layer of large and medium-sized arteries, is the principal pathological process underlying CVD.[110] Although atherosclerotic cardiovascular disease (ASCVD) typically manifests clinically in middle-aged and older adults, early vascular changes, including fatty streak formation, are already evident in large conduit arteries of children and adolescents with adverse lifestyle-related CVD risk profiles.[117]

Non-invasive imaging techniques, such as echo-Doppler assessment of the carotid arteries and pulse wave velocity (PWV), provide robust methods for quantifying arterial structure and function, enabling the detection of subclinical vascular changes and the estimation of future cardiovascular risk. Carotid intima–media thickness (cIMT) is defined as the distance between the lumen-intima interface and the media–adventitia interface of the carotid artery wall. [160] The validity of ultrasonographically determined cIMT as a non-invasive surrogate marker of ASCVD is well established.[8]

Systemic vascular compliance refers to arterial function and describes the ability of blood vessels to accommodate the volume of blood ejected by the left ventricle during systole, thereby reflecting the capacity of the arterial system to maintain relatively constant

blood flow.[319] In contrast, vascular stiffness describes the rigidity of arterial vessel walls and their reduced capacity to expand and recoil. Pulse wave velocity represents the speed at which the pressure wave propagates along the arterial tree and is widely used as a surrogate marker of arterial stiffness. Increased vascular stiffness and reduced compliance are associated with higher PWV values. Low levels of cardiorespiratory fitness (CRF) and elevated blood pressure (BP) have both been shown to contribute to the progression of arterial stiffness.[320]

Reducing exposure to modifiable risk factors has the potential to prevent the development of ASCVD. Health-related physical fitness (HRPF) is a multidimensional construct encompassing CRF, muscular strength, muscular endurance, flexibility, and body composition. Physical activity, is defined as any bodily movement produced by skeletal muscles that results in energy expenditure, encompassing activities across light-, moderate-, and vigorous-intensity domains and distinct from structured exercise.[288] CRF reflects the physiological capacity to deliver and utilise oxygen during sustained physical exertion.[288] Although PA and CRF represent distinct constructs, engagement in higher-intensity PA is a principal stimulus for improvements in CRF.[321]

It is well established that individuals with higher levels of HRPF are more likely to exhibit a favourable cardiometabolic health profile and a reduced risk of ASCVD, obesity, and type 2 diabetes.[32,322–324] Currently, only 25% of Irish children and adolescents aged 10-18 years meet the recommended 60 min of daily PA, with males more likely than females to achieve this guideline level.[279]

Beyond behavioural and anthropometric risk factors, socioeconomic disadvantage in adolescence appears to be reflected in early vascular phenotype. In European adolescents,

lower family affluence has been associated with greater cIMT,[325] and similar findings have been reported in US cohorts, where lower SES indices were associated with higher PWV and, to a lesser extent, increased cIMT, even after adjustment for adiposity and BP.[326] Collectively, these findings support the inclusion of school-level SES as a contextual determinant when interpreting variability in PWV and cIMT during early adolescence.

Sex differences in HRPF are expected during early adolescence due to the combined influence of biological maturation and sex-specific patterns of PA.[35,327] Differences in habitual PA are well documented, with males more likely than females to achieve recommended levels of daily MVPA and to participate in higher-intensity sport,[279] both of which are key determinants of CRF and muscular fitness.[328] During this developmental period, sex-specific changes in body composition associated with puberty further contribute to observed differences, with males typically accruing greater fat-free mass,[35] alongside higher upper-body strength,[31] larger waist and hip circumferences, higher waist-to-hip ratio (WHR), and superior CRF. [52,329]

Grip strength is a practical field-based indicator of muscular strength, and higher levels of muscular fitness in youth have been associated with more favourable cardiometabolic profiles, independent of CRF.[127] In Irish adolescents, males exhibit higher grip strength than females, while students attending Delivering Equality in Schools (DEIS) schools demonstrate lower grip strength than their peers in non-DEIS schools. Irish adolescents have also been shown to perform below European normative values for grip strength.[31]

Children growing up in lower SES environments are more likely to experience poorer cardiovascular health due to earlier and greater exposure to risk factors such as sedentary behaviour, low levels of PA, and suboptimal dietary patterns.[26] They also participate in less

sport than their higher SES peers.[330] Only 34% of 13-year-old Irish children in the lowest SES group participate in paid organised sport or exercise, compared with 56% in the higher social class group,[277] and higher family affluence has been associated with a broader range of sport participation among Irish adolescents.[331]

Given that health behaviours track from childhood into adulthood,[332] greater emphasis is needed on the development and implementation of ecological and sustainable primordial prevention strategies to reduce the risk of CVD among young people from lower SES communities. The purpose of this study is to examine the individual and combined effects of HRPF components, sex, and school socioeconomic status on subclinical CVD risk in first-year post-primary school students.

Aims

1. To compare HRPF variables among first-year male and female post-primary school students.
2. To compare HRPF variables between students attending DEIS and Non-DEIS schools.
3. To evaluate the impact of CRF, sex and school SES on PWV and cIMT in male and female students attending DEIS and non-DEIS schools.
4. To determine the contribution of HRPF and anthropometric variables to the variance in cfPWV and baPWV.

Hypothesis

1. Male students will have higher grip strength, CRF and lower waist to hip ratio and body fat than female students

2. First year post primary students attending non-DEIS schools will have higher grip strength, CRF and lower waist to hip ratio and body fat than those attending DEIS schools
3. CRF level, sex and school SES will each have a significant effect PWV and cIMT
4. HRPF and anthropometric variables will explain at least 50% of the variance in cfPWV and baPWV

METHODS

Study Overview

A letter outlining the research project was sent to seven school principals drawn from a convenience sample of mixed- and single-sex, DEIS and non-DEIS post-primary schools. All first-year male and female students attending the seven schools were invited to participate. Participants and their guardians were fully informed of the study procedures and provided with a plain language statement, written assent, and informed consent forms, all of which were completed prior to participation. Data collection was conducted on-site within each participating school.

The study protocol was conducted in accordance with the ethical standards of the 1961 Declaration of Helsinki (as revised in 2000) and received ethical approval from the Research Ethics Committee of Dublin City University (DCU/REC/2018/209; Appendix H).

Participant Recruitment

A total of 840 students were invited to participate in the study, of whom 540 first-year male and female students provided written consent and assent (Appendix H). Participants were instructed to attend school on the designated morning in their PE attire. Each participant was assigned a unique identification code for anonymisation and data tracking purposes.

Measurements

Height

Height was measured to the nearest 0.1 cm using a portable stadiometer (SECA). Participants removed their footwear and were instructed to stand upright with their heels

together, arms by their sides, and head positioned in the Frankfort plane. Measurements were taken at end-expiration following a deep inhalation.

Weight

Body weight was measured to the nearest 0.1 kg using a TANITA body composition analyser (TBF300WA, TANITA Europe). Participants were instructed to remove their footwear, empty their pockets, and remove any heavy clothing (e.g., school sweaters) prior to measurement. A standard tare weight of 1.0 kg was entered into the analyser to account for the residual weight of light clothing.

Body composition

Fat mass, fat-free mass (FFM), and percentage body fat (%) were estimated using a leg-to-leg TANITA bioelectrical impedance analysis (BIA) system (TBF300WA, TANITA Europe). BIA estimates body composition by passing a low-level electrical current through the body. As tissue conductivity varies according to water content, electrical current flows differently through fat and lean tissues. Impedance measurements are subsequently used to estimate body composition, as adipose tissue exhibits greater impedance than lean tissue and therefore slows current transmission. Prior to measurement, participants' sex, age, and height were entered into the analyser to inform the predictive equations used by the device.

Body Mass Index (BMI)

Body mass index (BMI) was calculated using the standard formula: weight (kg) divided by height squared (m^2). Participants were classified as underweight, normal weight, or overweight/obese according to age- and sex-specific reference data derived from the UK-World Health Organization (WHO) growth charts for adolescents.[333]

Waist circumference

Waist circumference was measured at the narrowest point of the torso, level with the umbilicus and superior to the suprailiac crest, using a SECA 201 measuring tape (Seca, Hamburg, Germany). Measurements were recorded to the nearest 0.1 cm. Participants were instructed to take a deep breath, and measurements were obtained at the end of expiration. Two measurements were initially taken; if these differed by more than 2 cm, a third measurement was obtained. The mean of the recorded measurements was used for analysis. The inter-rater coefficient of variation was 3.8%.

Hip circumference

Hip circumference was measured at the widest point over the greater trochanters using a SECA 201 measuring tape (Seca, Hamburg, Germany). Two measurements were initially obtained; if these differed by more than 2 cm, a third measurement was taken. The mean of the recorded measurements was used for analysis. The inter-rater coefficient of variation was 2.9%.

Waist-to-hip ratio

The waist-to-hip ratio was calculated by dividing waist circumference (cm) by hip circumference (cm).

Waist-to-height ratio

Waist-to-height ratio was calculated by dividing waist circumference (cm) by height (cm).

20m Shuttle Run Test

As described previously in the Methods section of Chapter III, participants were assigned a brightly coloured numbered bib prior to the 20mSRT. Each participant's identification number was matched to the corresponding bib number and colour. The 20mSRT was conducted in groups of ≤16 participants, with a researcher-to-participant ratio of 1:4. Immediately following the test, maximal effort was verbally verified by asking participants whether they had stopped due to exhaustion, rather than discomfort or confusion, and whether they believed they could have completed additional shuttles at the prescribed pace.

Estimated $\dot{V}O_2$max

As previously described in the methods section of Chapter III.

Blood Pressure

Prior to BP assessment, participants rested in a supine position for 5 min in a quiet room. BP was subsequently measured using a mercury sphygmomanometer (Dekamet Model, Accoson Sphygmomanometers, Harlow, Essex, UK) and a stethoscope (Classic II, 3M Littmann, St Paul, MN, USA). Measurements were obtained in duplicate with a 1-min interval between readings, and the mean of the two measurements was used for analysis.

Upper Body Muscle Strength

Isometric handgrip strength of the dominant hand was measured to the nearest 0.1 kg using a handheld dynamometer.[334] Participants were seated upright at the edge of a chair with knees flexed at 90°. The test procedure was explained and visually demonstrated prior to assessment. The dynamometer was adjusted to fit each participant's hand to ensure a

comfortable grip. With the elbow flexed at 90°, participants were instructed to squeeze the dynamometer maximally for approximately 3 sec while remaining seated. Following a 60-sec rest period, the trial was repeated. An additional trial was conducted if there was a >2 kg discrepancy between the first two measurements. The highest recorded value was used for analysis.

Pulse Wave Velocity

Carotid–femoral pulse wave velocity (cfPWV) and brachial–ankle pulse wave velocity (baPWV) were assessed using a Vicorder 2 Electronics module (Skidmore Medical, Bristol, UK). Participants rested in a supine position with shoes, socks, and/or tights removed. A pillow was provided to support the head and shoulders, and the bed was adjusted to ensure the neck was not flexed against the chin, positioning the upper body at approximately 30°. BP cuffs were placed at the neck, upper arm, upper thigh, and ankle. Following cuff placement, the distance from the sternoclavicular joint to the midpoint of the ankle cuff was measured using a SECA 201 measuring tape (Seca, Hamburg, Germany). After a 5-min rest period, measurements were recorded.

Separate assessments were conducted for cfPWV and baPWV. Two trained investigators performed all PWV measurements. Within-day intra-rater reliability was assessed by repeating anatomical distance and cfPWV measurements by the same investigator on the same day; the intra-rater coefficient of variation (CV) was 2.2% for distance and 4.7% for PWV. Between-day reliability was not assessed.

Carotid Intima-Media Thickness

Carotid intima–media thickness (cIMT) was assessed using a multifrequency linear-array transducer (Siemens Acuson P500) and a Siemens portable ultrasound system (Acuson

P500 FROSK). Ultrasound images of the carotid artery were obtained with participants in a supine position, with the head slightly rotated to the contralateral side. The common carotid artery, including the carotid bulb, was visualised, and longitudinal B-mode images of both the left and right common carotid arteries were acquired and digitally stored.

cIMT was measured using Carotid Studio software (Quipu), which performs real-time processing of B-mode ultrasound image sequences from longitudinal arterial segments. The system employs an edge-detection algorithm operating at 25 frames per sec. Intima–media thickness was calculated over the final 8 sec of each examination.

Vascular assessments were performed by two trained investigators. Within-day intra-rater reliability was assessed via repeat analysis of a subset of recordings by the same investigator, yielding an intra-rater coefficient of variation (CV) of 4.9% for cIMT. Between-day reliability was not assessed.

Statistical Analysis

Statistical analyses were performed using SPSS software (version 28.0; IBM SPSS Inc., Chicago, IL, USA). Data distributions were assessed for normality using histograms, kernel density plots, and Q–Q plots. Descriptive statistics were calculated for all anthropometric and physiological variables, including participant characteristics, CRF, HRPF, BP, PWV, and carotid cIMT, with means and standard deviations reported.

A multivariate analysis of variance (MANOVA) was used to examine differences across three independent variables: sex (male/female), DEIS school status (yes/no), and 20mSRT performance quartiles (≤25th percentile = “Poor”; ≤50th percentile = “Below Average”; ≤75th percentile = “Above Average”; >75th percentile = “Excellent”, stratified by age and sex). Dependent variables included anthropometric measures, 20mSRT performance, PWV, and

cIMT, with age entered as a covariate. Both main effects and interaction effects were evaluated. Where significant effects were identified, follow-up univariate ANOVAs or independent-samples t-tests were conducted. Post hoc comparisons were adjusted using the Bonferroni correction, with statistical significance set at $p < 0.05$. Due to missing data across variables, final sample sizes were 469 for PWV and cIMT analyses, 493 for anthropometric and BP analyses, and 481 for 20mSRT analyses.

Linear Regression

Health-related physical fitness and anthropometric variables were entered into a backward stepwise linear regression model. Non-significant predictors were sequentially removed at each step to optimise model fit. Variables exhibiting moderate-to-high multicollinearity (variance inflation factor [VIF] > 2) were excluded from the model.

ROC Analysis

ROC analyses were conducted using Python (pandas, NumPy, and scikit-learn). Variables included body mass index (BMI), body fat percentage (BF%), systolic BP(SBP), carotid–femoral pulse wave velocity (cfPWV), resting heart rate (RHR), total 20mSRT shuttles, and sex (male/female). Participants with missing data for any included variable were excluded from the analysis.

Participants and data processing

Data were analysed using Python (pandas, NumPy, and scikit-learn libraries). Variables extracted for analysis included BMI, BF%, SBP, cfPWV, RHR, total 20 m shuttles completed during the 20mSRT, and sex (male/female). Participants with missing data for any of the included variables were excluded from the analysis.

Clustered cardiometabolic risk-factor burden

Clustered cardiometabolic risk (CMR) factor burden was calculated using a continuous composite score derived from standardised (z-scores) risk factors. This approach is commonly used in paediatric cardiometabolic epidemiology[302,335] to quantify "risk clustering" on a continuous scale. Clustered CMR is typically expressed as the sum or mean of standardised values across multiple subcomponents, providing a continuously distributed composite risk score. In the present study, the clustered burden score comprised seven components: BMI, BF%, SBP, cfPWV, weight, WHt, and RHR. Within each training fold (see Cross-validation section), each component was z-standardised using parameters derived from the training data

$$z = \frac{x - \mu_{\text{train}}}{\sigma_{\text{train}}}$$

The risk-factor burden score was then calculated as the sum of the seven z-scores.

Definition of "higher CMR burden"

To create a binary classification outcome suitable for ROC analysis, a "higher burden" category was defined within each training fold as the upper quartile (≥75th percentile) of the continuous burden score. This threshold, derived exclusively from the training data, was then applied without modification to the corresponding held-out test fold to assign the binary outcome for evaluation. Defining the outcome using training-fold information only ensured that information leakage from the test set into outcome construction was avoided.

Cross-validation framework

To ensure robust estimation and prevent data leakage, a repeated 5-fold cross-validation procedure (20 repeats) was employed. For the full sample, folds were stratified by sex. Within each training fold, z-score normalisation parameters, the 75th percentile threshold for "high burden" (the target variable), and the optimal 20mSRT cut-off point derived using Youden's J index were calculated exclusively from the training data. These parameters were then applied to the held-out test fold. This process was repeated across 100 resampled fold partitions, and performance metrics (area under the curve [AUC], sensitivity, and specificity) were averaged across all folds to provide a generalised estimate of model performance.

ROC analysis, AUC, and cut point derivation

In each fold, discrimination was quantified using the area under the receiver operating characteristic curve (AUC), calculated on the held-out test fold. To identify a pragmatic 20mSRT shuttle threshold, an optimal cut-point was derived within the training fold by maximising Youden's J index:

$$J = \text{Sensitivity} + \text{Specificity} - 1$$

The corresponding 20mSRT cut point (in shuttles) was then applied to the test fold. Test-fold sensitivity and specificity were computed from the resulting confusion matrix.

RESULTS

A total of 540 first-year, post-primary school students (males; *n*=301 and females; *n*=239) with a mean (±SD) age of 13.0±0.4 years participated in the study. Approximately 40% of the participants were recruited from three DEIS schools. The approximate geographical location on the participating schools is shown in Figure 5.1.

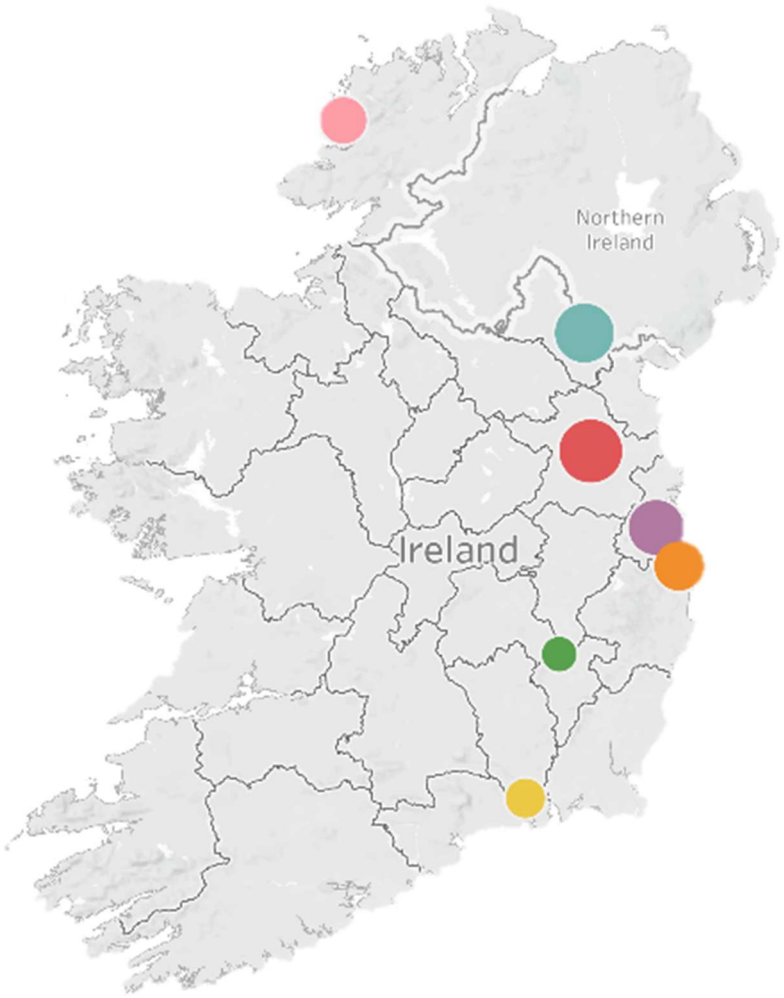


Figure 5.1: *Approximate location of the schools (colours highlighting the different schools, with the size of the circles scaled to match the size of the sample size from each school)*

Anthropometric measures

A MANOVA was conducted to evaluate differences in selected anthropometric variables based on sex and DEIS school status. A significant overall main effect was observed for sex (Pillai's Trace = 0.6407, $F(1,465) = 91.92$, $p<0.001$).

Table 5.1 summarises participant demographics, selected anthropometric variables, and HRPF measures for both male and female participants. Males had a significantly lower BF% ($p<0.001$) and waist-to-hip ratio ($p<0.001$) than females. In contrast, grip strength ($p < 0.001$) and 20 m shuttle run performance ($p < 0.001$) were significantly higher in males than females.

Table 5.1: Anthropometric and HRPF characteristics of female and male participants

	Sex	
	Female	**Male**
n	220	261
Age (y)	13.0±0.4	13.0±0.4
Weight (kg)	50.9±11.5	51.1±12.3
Height (cm)	158.0±6.8	160.2±8.8
BMI (kg/m^2)	20.3±3.9	19.8±3.4
BMI percentile	57.3±28.7	54.9±29.8
Body fat %	24.5±7.1	15.7±7.0**
Waist (cm)	67.9±9.5	69.3±9.0
Hip (cm)	88.5±10.0	85.9±8.7
Waist to hip	0.77±0.05	0.81±0.05**
Waist to height	0.43±0.05	0.43±0.05
Grip (kg)	23.1±4.4	25.9±6.3**
20mSRT (shuttles)	40.3±18.2	57.8±24.0**
estVO_2max ($mL \cdot kg^{-1} \cdot min^{-1}$)	43.4±5.1	47.8±6.1
METs	12.4±1.5	13.7±1.8

Values presented are means ± SD; BMI, body mass index; 20mSRT, 20-meter shuttle run test; estVO_2max, estimated maximal oxygen uptake; METs, metabolic equivalents; ** $p<0.001$.

Table 5.2 summarises sex differences in BP and measures of arterial stiffness. There was no significant difference between males and females in SBP, DBP, cfPWV, baPWV or cIMT.

Table 5.2: Blood pressure and vascular measurements

	Sex	
	Female	**Male**
n	220	261
Systolic BP (mmHg)	116.9±12.3	115.4±10.5
Diastolic BP (mmHg)	65.2±7.6	64.7±6.1
cfPWV ($m \cdot s^{-1}$)	6.3±0.7	6.3±0.6
baPWV ($m \cdot s^{-1}$)	9.7±1.0	9.5±1.0
cIMT (mm)	0.454±0.10	0.453±0.05

Values are means ± SD; BP, blood pressure; cfPWV, carotid femoral pulse wave velocity; baPWV, brachial ankle pulse wave velocity; cIMT, carotid intima media thickness

DEIS v Non DEIS - Anthropometric and HRPF characteristics

A comparison of anthropometric and HRPF characteristics among female and male participants attending DEIS and non-DEIS schools is presented in Table 5.3. Males attending DEIS schools demonstrated significantly higher BF% ($p < 0.05$) and body weight ($p < 0.05$) than males attending non-DEIS schools. No significant differences in anthropometric variables were observed between females attending DEIS and non-DEIS schools.

There was a statistically significant main effect of school status (DEIS vs non-DEIS) for 20 m shuttle run test (20mSRT) performance, $F(1, 465) = 5.63$, $p = 0.018$, partial $\eta^2 = 0.012$, and diastolic blood pressure (DBP), $F(1, 465) = 5.627$, $p = 0.018$, partial $\eta^2 = 0.012$. Participants from DEIS schools completed, on average, 21.5 fewer shuttles (males) and 8.9 fewer shuttles (females) compared with their non-DEIS counterparts ($p < 0.001$). Mean DBP was higher in DEIS students (66.1 ± 6.7 mmHg) compared with non-DEIS students (64.0 ± 6.8 mmHg, $p < 0.001$).

Table 5.3: Anthropometric and HRPF characteristics for female and male participants attending DEIS or non-DEIS schools

	Female		Male	
	DEIS	**Non-DEIS**	**DEIS**	**Non-DEIS**
n	89	131	101	160
Age (y)	12.9±0.4	13.0±0.4	12.9±0.4	13.1±0.4
Weight (kg)	52.5±13.4	49.8±10.3	53.0±15.3	50.0±10.4
Height (cm)	158.3±7.6	157.5±6.2	160.0±8.6	160.4±9.2
BMI ($kg \cdot m^2$)	21.1±4.4	19.7±3.3	20.5±4.8	19.3±2.7
BMI (percentile)	61.9±29.6	53.9±28.1	56.5±32.7	54.2±28.4
Body fat (%)	25.9±7.9	23.5±6.6	17.8±8.7	14.7±5.6*
Waist (cm)	68.6±10.5	67.4±9.0	71.6±11.7	67.7±6.8*
Hip (cm)	88.8±10.8	88.2±9.6	87.9±10.7	84.8±7.2*
Waist to hip	0.77±0.06	0.76±0.05	0.81±0.05	0.80±0.05
Waist to height	0.44±0.06	0.43±0.05	0.45±0.07	0.42±0.04*
Grip strength (kg)	22.7±4.8	23.4±3.9	24.6±6.5	26.4±5.9
20mSRT (shuttles)	35.0±16.5	43.9±18.4***	44.9±23.8	66.2±22.4***
estVO_2max ($mL \cdot kg^{-1} \cdot min^{-1}$)	41.9±4.9	44.3±5.0	44.6±5.5	49.9±5.6
METs	12.0±1.4	12.7±1.4***	12.7±1.6	14.2±1.6***

Values presented are mean ± SD; DEIS, delivering equality in schools; BMI, body mass index; 20mSRT, 20-meter shuttle run test; estVO_2max, estimated maximal oxygen uptake; METs, metabolic equivalents * $p<0.05$, *** $p<0.001$

Vascular Measurements - DEIS v Non-DEIS and Sex

There was a significant sex × DEIS school status interaction effect for brachial–ankle pulse wave velocity (baPWV), $F(1, 465) = 4.112$, $p = 0.043$, partial $\eta^2 = 0.009$. Males attending DEIS schools exhibited significantly higher baPWV values (9.76 ± 0.99 $m \cdot s^{-1}$) compared with males attending non-DEIS schools (9.34 ± 0.97 $m \cdot s^{-1}$; $p = 0.043$; Table 5.4). No significant differences in baPWV were observed between females attending DEIS and non-DEIS schools. There were also no significant differences in carotid–femoral pulse wave velocity (cfPWV) or carotid intima–media thickness (cIMT) between DEIS and non-DEIS students in either sex.

Table 5.4: Vascular measures categorised by DEIS and sex status

	Female		Male	
	DEIS	**Non-DEIS**	**DEIS**	**Non-DEIS**
n	89	131	101	160
baPWV ($m \cdot s^{-1}$)	9.73±0.99	9.79±1.5	9.76±0.99	9.34±0.97*
cfPWV ($m \cdot s^{-1}$)	6.32±0.66	6.32±0.87	6.43±0.70	6.38±0.66
cIMT (mm)	0.432±0.06	0.469±0.04	0.446±0.05	0.486±0.05

Values presented are mean ± SD; DEIS, delivering equality in schools; baPWV, brachial ankle pulse wave velocity; cfPWV, carotid femoral pulse wave velocity; cIMT, carotid intima-media thickness; * $p<0.05$

20mSRT Quartile and Sex

20mSRT quartile categories stratified by sex are summarised in Table 5.5. There was a statistically significant interaction effect between sex and fitness quartile for carotid–femoral pulse wave velocity (cfPWV), $F(3, 442) = 3.178$, $p = 0.024$, partial $\eta^2 = 0.021$. Male participants in the lowest fitness quartile (bottom 25%) of the 20mSRT demonstrated significantly higher cfPWV values than those in the highest fitness quartile (6.65 ± 0.78 vs. 6.29 ± 0.87 $m \cdot s^{-1}$, $p = 0.017$; Figure 5.2) and the below-average fitness quartile (6.65 ± 0.78 vs. 6.21 ± 0.78 $m \cdot s^{-1}$, $p = 0.001$). No significant differences in cfPWV were observed across fitness quartiles in female participants.

Table 5.5: 20mSRT quartiles categories by sex

	25	**50**	**75**
Male	42	56	76
Female	26	36	53

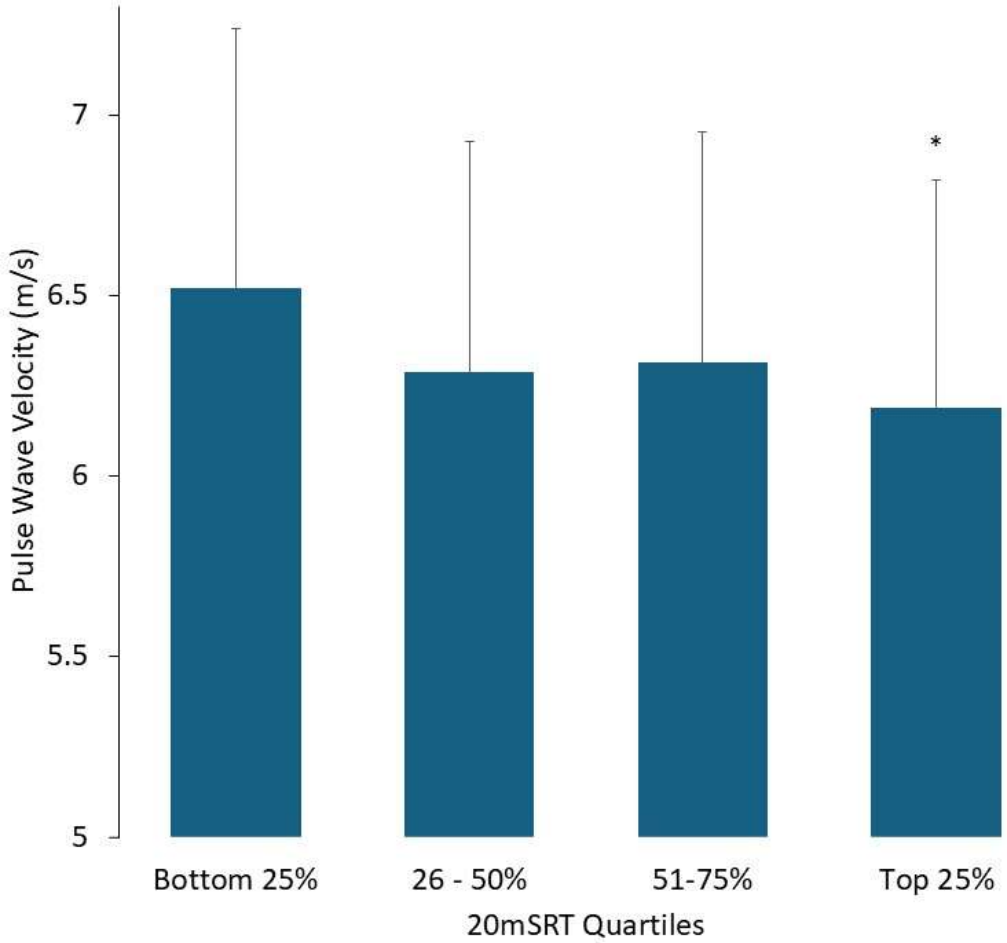


Figure 5.2: *Carotid-femoral pulse wave velocity ($m \cdot s^{-1}$) scores grouped by 20mSRT quartiles for males. * p<0.05 v bottom 25%.*

20mSRT Quartile

There was a significant main effect of fitness quartiles on brachial–ankle pulse wave velocity (baPWV), $F(3, 465) = 3.32$, $p = 0.019$, partial $\eta^2 = 0.021$. Participants in the lowest fitness quartile (bottom 25%) exhibited significantly higher baPWV values than those in the highest fitness quartile (9.87 ± 1.06 vs. 9.45 ± 1.02 $m \cdot s^{-1}$, $p = 0.012$) and the above-average fitness quartile (9.87 ± 1.06 vs. 9.46 ± 0.95 $m \cdot s^{-1}$, $p = 0.035$; Table 5.6).

There was also a significant main effect of fitness quartiles on SBP, $F(3, 489) = 5.45$, $p = 0.001$, partial $\eta^2 = 0.024$. Participants in the lowest fitness quartile demonstrated

significantly higher SBP compared with those in the highest quartile (119.1 ± 12.3 vs. 113.8 ± 11.5 mmHg, p = 0.001).

Table 5.6: Vascular measurements categorised fitness quartile and sex

	Bottom 25%	Below Average	Above Average	Top 25%
All				
N	116	127	127	111
Systolic BP (mmHg)	119.1±12.3	115.4±11.3	115.8±10.1	113.8±11.5*
Diastolic BP (mmHg)	66.1±6.6	65.3±6.7	64.4±5.3	63.9±6.1
baPWV ($m \cdot s^{-1}$)	9.87±1.06	9.60±1.08	9.46±0.95*	9.45±1.02*
cfPWV ($m \cdot s^{-1}$)	6.52±0.71	6.29±0.64	6.31±0.64	6.19±0.63
cIMT (mm)	0.442±0.07	0.459±0.07	0.458±0.08	0.462±0.09
Female				
N	51	57	57	56
Systolic BP (mmHg)	120.7±13.0	117.4±12.5	117.4±10.5	113.7±12.7
Diastolic BP (mmHg)	66.2±7.2	66.0±6.9	64.5±5.8	64.1±5.8
baPWV ($m \cdot s^{-1}$)	9.96±0.98	9.89±1.16	9.52±0.91	9.55±1.0
cfPWV ($m \cdot s^{-1}$)	6.35±0.90	6.38±0.86	6.29±0.86	6.09±0.88
cIMT (mm)	0.447±0.05	0.450±0.05	0.456±0.08	0.461±0.09
Male				
N	65	70	70	55
Systolic BP (mmHg)	118.2±11.7	114.3±10.4	115.4±9.3	114.0±10.3
Diastolic BP (mmHg)	66.0±6.4	64.5±6.5	64.3±5.0	63.8±6.5
baPWV ($m \cdot s^{-1}$)	9.80±0.98	9.39±1.0	9.49±0.96	9.34±1.0
cfPWV ($m \cdot s^{-1}$)	6.65±0.78	6.21±0.78*	6.34±0.77	6.29±0.87*
cIMT (mm)	0.442±0.08	0.466±0.08	0.458±0.09	0.463±0.09

N, sample size; BP, blood pressure; baPWV, brachial ankle pulse wave velocity; cfPWV, carotid femoral pulse wave velocity; cIMT, carotid intima-media thickness; * p<0.05 v Bottom 25%

Regressing Vascular Measures

Two backward stepwise regression models were developed to explain variance in carotid–femoral pulse wave velocity (cfPWV; Model 1) and brachial–ankle pulse wave velocity (baPWV; Model 2). Model 1 identified sex, age, 20mSRT shuttles, waist-to-height ratio, grip strength, and BP as significant predictors, collectively explaining 20% of the variance in cfPWV ($r = 0.451$, $F(7, 465) = 17.0$, $p < 0.001$). All retained coefficients were statistically significant, with low multicollinearity (variance inflation factor [VIF] < 2), as summarised in Table 5.7.

Model 2 indicated that age, total number of 20mSRT shuttles completed, waist-to-height ratio, and BP collectively explained 19% of the variance in baPWV ($r = 0.440$, $F(5, 464) = 22.2$, $p < 0.001$). The significant predictors in this model are presented in Table 5.8.

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Table 5.7: Model coefficients from cfPWV (Model 1*)*

Predictor	Estimate	Standard Error	95% Confidence Interval		t	p	Standard Estimate	95% Confidence Interval	
			Lower	Upper				Lower	Upper
Intercept	2.43	0.89	0.641	4.152	2.68	0.008			
20mSRT shuttles	-0.004	0.001	-0.007	-0.002	-3.34	<.001	-0.164	-0.262	-0.069
Waist to Height	-1.83	0.510	-2.833	-0.826	-3.58	<.001	-0.163	-0.252	-0.074
Grip	0.016	0.005	0.005	0.0257	3.11	0.002	0.140	0.052	0.229
Systolic BP	0.016	0.002	0.011	0.0208	6.68	<.001	0.296	0.209	0.384
Diastolic BP	0.009	0.0047	3.11E-04	0.0175	2.04	0.042	0.089	0.003	0.176
Male - Female	0.12	0.057	0.006	0.230	2.06	0.04	0.190	0.009	0.371
Age	0.16	0.062	0.035	0.279	2.53	0.012	0.109	0.0243	0.194

20mSRT, 20-meter shuttle run test; BP, blood pressure; t, test statistic/t-value; p, p-value or Prob > |t|)

Table 5.8: Model coefficients from baPWV (Model 2)

Predictor	Estimate	Standard Error	95% Confidence Interval		t	p	Standard Estimate	95% Confidence Interval	
			Lower	Upper				Lower	Upper
Intercept	3.191	1.418	0.403	5.978	2.25	0.025			
20mSRT Shuttles	-0.006	0.002	-0.009	-0.002	-2.86	0.004	-0.128	-0.216	-0.04
Waist to Height	-1.772	0.807	-3.357	-0.186	-2.2	0.029	-0.099	-0.187	-0.010
Systolic BP	0.029	0.004	0.022	0.036	7.57	<.001	0.336	0.249	0.423
Diastolic BP	0.020	0.007	0.006	0.034	2.84	0.005	0.125	0.039	0.212
Age	0.212	0.098	0.018	0.405	2.15	0.032	0.092	0.0079	0.176

20mSRT, 20-meter shuttle run test; BP, blood pressure; t, test statistic/t-value; p, p-value or Prob > |t|)

Discrimination (AUC)

20mSRT shuttles demonstrated good discrimination for higher CMR burden, with a mean test AUC of 0.802 in the total sample (95% cross-validation percentile interval: 0.718–0.879). Summary estimates from the cross-validated ROC analysis are presented in Table 5.9.

Table 5.9: Cross-validated discrimination and cut point performance for identifying upper quartile clustered CMR burden, using 20mSRT total shuttles

Group	N	Test AUC (95% CI)	20mSRT Cut point (IQR)	Sensitivity (95% CI)	Specificity (95% CI)
Total	464	0.802 (0.718–0.879)	44 (41–44)	0.733 (0.475–0.917)	0.690 (0.587–0.802)
Male	253	0.807 (0.656–0.911)	44 (44–44)	0.673 (0.353–0.905)	0.809 (0.612–0.923)
Female	211	0.752 (0.573–0.884)	32 (28–33)	0.574 (0.235–0.821)	0.728 (0.547–0.931)

CMR, cardiometabolic risk factor; AUC, area under the curve; CI, confidence interval; IQR, inter-quartile range

In males, discrimination was similar (AUC = 0.807; 95% cross-validation percentile interval: 0.656–0.911). In females, discrimination was lower but remained acceptable (AUC = 0.752; 95% cross-validation percentile interval: 0.573–0.884), with greater variability across folds. Figures 5.3 and 5.4 present the mean ROC curves across 100 held-out folds (5-fold × 20 repeats) for males (Figure 5.3) and females (Figure 5.4), with shaded bands representing the 2.5th–97.5th percentile range of interpolated true-positive rates across folds.

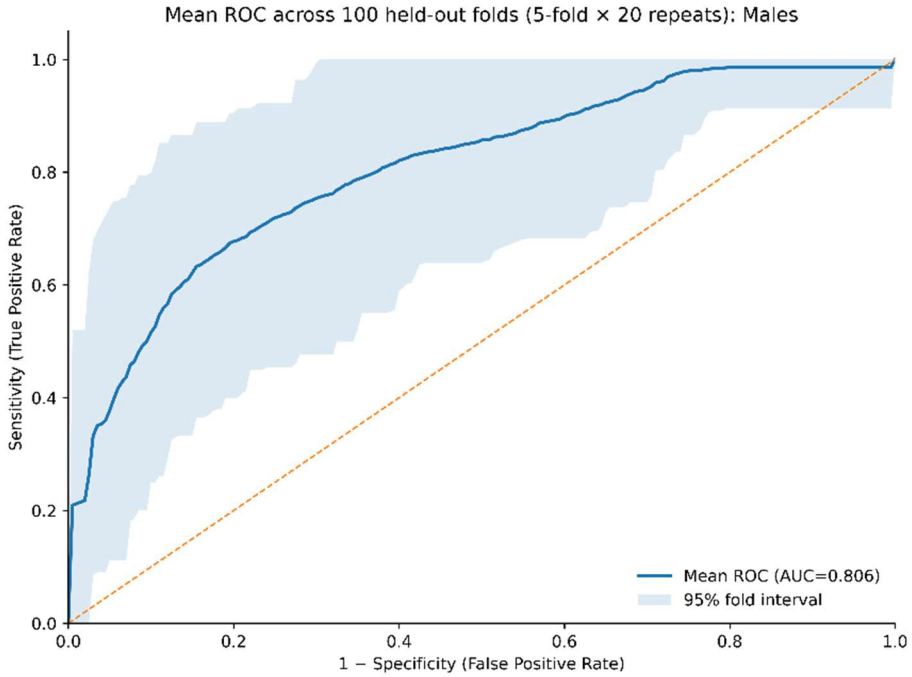


Figure 5.3: *Mean ROC across 100 held-out (test) folds for the male participants*

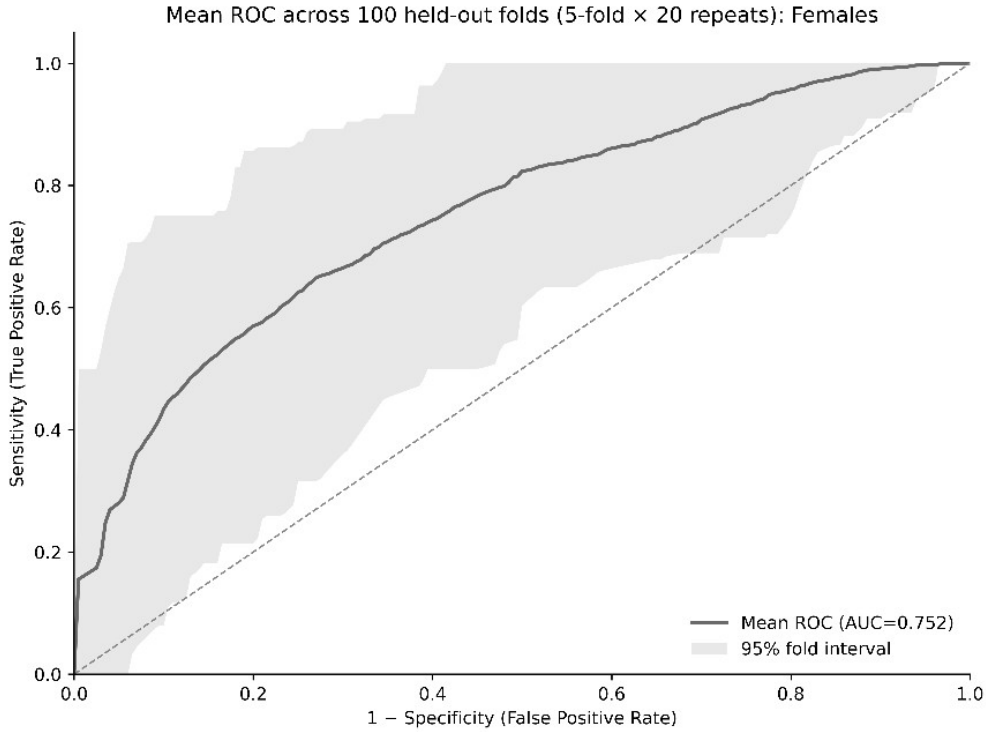


Figure 5.4: *Mean ROC across 100 held-out (test) folds for the female participants*

Training-derived shuttle cut points and stability

The median training-derived cut point in the total sample was 44 shuttles (IQR 41–44), indicating a relatively stable threshold across folds. In males, the cut point was highly consistent, with a median of 44 shuttles and no IQR spread (44-44), suggesting very strong stability. In females, the optimal cut point was lower and less stable, with a median of 32 shuttles (IQR 28-33), indicating that the most discriminative threshold varied more across resamples.

When applying the training-derived cut-points to held-out test folds, the total sample demonstrated balanced classification performance, with mean sensitivity of 0.733 (0.475–0.917) and mean specificity of 0.690 (0.587–0.802). In males, the cut-point yielded higher specificity (0.809; 0.612–0.923) than sensitivity (0.673; 0.353–0.905). In females, sensitivity was lower (0.574; 0.235–0.821) with moderate specificity (0.728; 0.547–0.931), indicating comparatively weaker case detection at the Youden-derived threshold. Across analyses, the test positive rate remained close to the expected 0.25 (mean ≈ 0.252), consistent with the upper-quartile definition of higher burden.

Overall, these findings indicate that 20mSRT performance provides good discrimination for identifying adolescents with higher clustered CMR burden, with clear sex differences in the most stable and discriminative shuttle thresholds (approximately 44 shuttles in male's and 32 shuttles in females). This corresponds to the shuttle count at which elevated risk may be identified for screening purposes (Level 5-3 for males and 4-2 for females).

To aid interpretation of the distribution-based endpoint, the 75th percentile threshold used to define "higher CMR burden" was expressed in standard deviation (SD) units of the composite burden score within each training fold. Across cross-validation folds, the upper-quartile threshold corresponded to a median value of 0.52 SD above the mean in the total sample (IQR 0.50–0.54), 0.43 SD in males (IQR 0.41–0.45), and 0.56 SD in females (IQR 0.54–0.59), as shown in Figure 5.5. Among participants classified as having higher CMR burden, the mean elevation across included risk components (expressed as the average per-component z-score) was approximately 0.81 SD in the total sample (95% fold interval 0.79–0.84), 0.83 SD in males (0.79–0.86), and 0.78 SD in females (0.75–0.81).

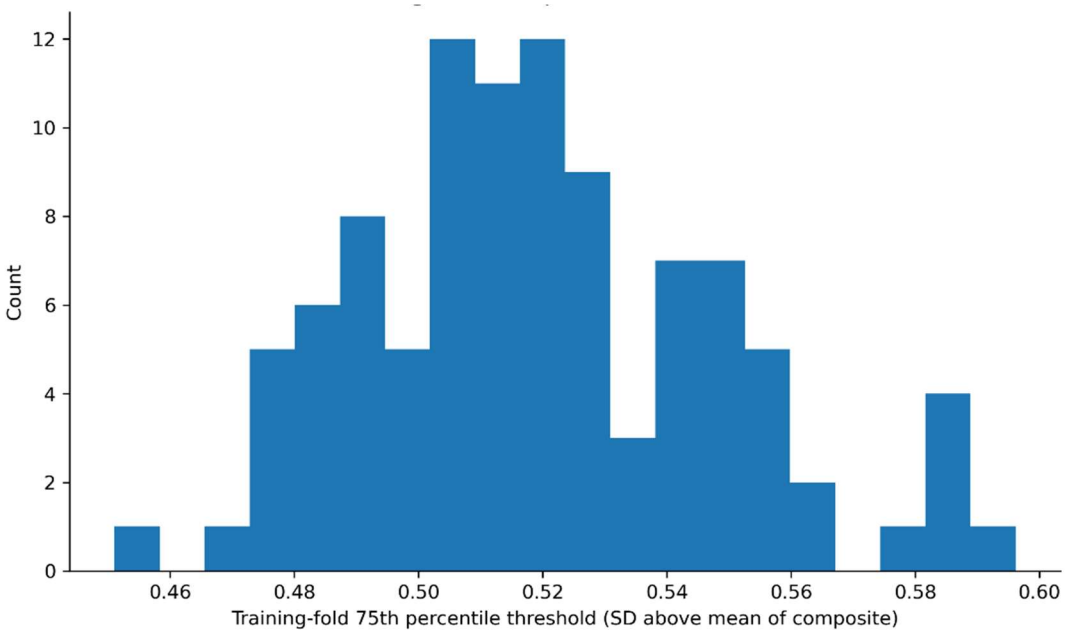


Figure 5.5: *Distribution of fold-specific 75th percentile thresholds (SD units)*

Investigating ≥1 SD above the mean

Investigating a stricter definition of higher CMR burden (≥1 SD above the training mean), similar to Bo Andersen et al. (2006),[302] reduced the positive classification rate (14–15% vs 25%) and increased discrimination (AUC) in both males and females. However, this approach also widened the cross-validation uncertainty intervals. The derived 20mSRT

shuttle cut-point remained stable in males (44 shuttles), whereas in females the optimal cut-point decreased to 28 shuttles.

DISCUSSION

There is a growing body of evidence that low CRF during childhood and adolescence is independently associated with an increased risk of CVD, type 2 diabetes, and premature mortality in adulthood.[336,337] These associations persist even after adjustment for traditional risk factors such as BMI and SES.[338] Study 3 examined the association between CRF levels and subclinical CVD in a sample of 442 first-year post-primary school students (40% DEIS) drawn from seven schools across the country. Consistent with Study 1, first-year male students outperformed females in the 20mSRT. These findings align with previous research consistently reporting higher 20mSRT performance in males compared with females throughout adolescence.[44,52,264] However, given that the 20mSRT is a weight-bearing, volitional field-based test, sex sex-specific patterns in maturation, body composition, and exposure to vigorous physical activity and sport, which may influence test tolerance and pacing strategies.[48,52,286]

Additionally, CRF was significantly lower among both male and female students attending DEIS schools compared with their non-DEIS counterparts. In males, the magnitude of this difference was substantial, with DEIS males completing only 66% of the shuttles achieved by non-DEIS males, corresponding to an approximate 1.5 MET difference in estimated fitness. Given the established associations between CRF and cardiometabolic risk,[286] this level of inequalities by age 13 are concerning and highlight socioeconomic disparities in early-life cardiovascular health.[217] In practical terms, a marked fitness deficit is already evident in DEIS students by early adolescence. Although these data are cross-sectional and do not permit causal inference, the pattern of lower CRF alongside higher PWV is biologically plausible, given established associations between CRF and arterial stiffness in

youth.[155,339] Lower CRF may reflect reduced exposure to vigorous PA and lower levels of aerobic conditioning,[340] which can influence arterial distensibility through effects on BP regulation,[341] inflammation, and endothelial function, including nitric oxide bioavailability.[342,343] Compared with males in non-DEIS schools, males attending DEIS schools also exhibited less favourable body composition, characterised by higher body mass and greater BF%, which may increase the energetic cost of shuttle running and contribute to lower performance on this test. This less favourable body composition may further contribute to arterial stiffening through increased haemodynamic load The less favourable body composition observed in DEIS males may contribute to arterial stiffening through higher haemodynamic load[344] and a higher metabolic risk-factor burden (e.g., adiposity-related elevations in BP and adverse metabolic profiles),[345] both of which have been associated with higher PWV in paediatric populations.[344,345]

An important finding of this study was that the DEIS – non-DEIS pattern appeared more pronounced in males than in females. Although both male and female students attending DEIS schools demonstrated lower 20mSRT performance than their non-DEIS peers, the magnitude of the difference was greater in males, with DEIS males completing approximately 21.5 fewer shuttles compared with 8.9 fewer shuttles in females. In addition, male students attending DEIS schools exhibited a less favourable anthropometric profile and higher baPWV than males attending non-DEIS schools, whereas comparable differences were not observed in females. This suggests that, by early adolescence, socioeconomic disadvantage may cluster more strongly with lower CRF, less favourable body composition, and poorer vascular function in males. One possible explanation is that males and females may differ in the extent to which socioeconomic disadvantage constrains opportunities for

habitual physical activity and organised sport participation, particularly given well-established sex differences in physical activity patterns across adolescence and the social gradient in sport participation.[279,327] In addition, sex-specific changes in growth and body composition during puberty may influence the expression of these differences at this age.[35] The absence of significant differences in females should, however, be interpreted with caution and not taken as evidence that socioeconomic disadvantage is unimportant in girls, particularly given that female students in DEIS schools also demonstrated lower CRF. These findings are broadly consistent with previous Irish research demonstrating a school-level socioeconomic gradient in adolescent health-related physical fitness.[31]

The assessment of subclinical atherosclerosis using non-invasive techniques such as cIMT and arterial PWV enables both structural and functional markers of early, preclinical cardiovascular health to be quantified in young, apparently healthy, and asymptomatic individuals.[161] In Study 3, cfPWV was significantly higher among male students in the lowest quartile of CRF, based on 20mSRT performance, compared with those in all other quartiles. BaPWV, a composite measure of central and peripheral arterial stiffness, was also significantly higher among both male and female participants in the lowest fitness quartile compared with students with CRF above the median. Among females, no differences in cfPWV were observed across fitness quartiles. Elevated PWV increases cardiac workload due to higher pulse pressure and increased arterial wall stress.[346]

None of the males in the lowest CRF quartile met the estimated $\dot{V}O_2$max threshold associated with a favourable cardiovascular health profile.[125] Against this backdrop, the higher cfPWV observed in this group relative to the highest quartile of CRF is unsurprising. However, the added value of the present study is that it demonstrates that this "low-fitness

tail" is not merely a descriptive fitness category in early adolescence but is associated with measurable differences in central arterial stiffness in an apparently healthy, asymptomatic cohort. The 20mSRT-derived CRF distribution therefore appears to have functional vascular relevance by age 13, supporting the potential clinical utility of identifying very low CRF even before overt cardiometabolic disease is evident.

These findings are consistent with evidence that low CRF during adolescence is associated with higher PWV in youth, while higher moderate-to-vigorous PA during adolescence is inversely associated with aortic stiffness in adulthood,[179] but extend this literature by demonstrating a clear sex-specific pattern in early adolescence. Specifically, cfPWV differences were evident across CRF quartiles in males, whereas cfPWV did not differ by CRF quartile in females, despite low fitness being associated with higher baPWV in both sexes. This pattern suggests that the relationship between CRF and arterial stiffness may differ by sex at this age, and/or that baPWV may be more sensitive to lower CRF across both sexes in early adolescence.

Results from epidemiological, clinical, and basic science studies indicate that higher levels of CRF are associated with lower PWV through effects on traditional cardiovascular risk factors,[347] as well as through adaptations in cardiac and vascular structure and function,[348] autonomic nervous system regulation,[349] and metabolic function.[350] Exercise training improves arterial distensibility by lowering BP, reducing inflammation, and preserving the structural and functional integrity of vascular smooth muscle, the endothelium, and extracellular matrix components.[341] Exercise training also increases the bioavailability of nitric oxide, a potent vasodilator produced in the vascular endothelium from L-arginine via endothelial-derived nitric oxide synthase.[343]

The finding that males attending DEIS schools exhibited higher baPWV than their non-DEIS counterparts indicates that socioeconomic inequalities are evident not only in CRF but also in vascular function by early adolescence. This is consistent with previous studies reporting higher PWV among youth from lower socioeconomic backgrounds and lower PWV in higher socioeconomic groups,[157,326,346] and it strengthens the interpretation that the DEIS–non-DEIS differences observed in Study 1 may not merely reflect performance differences in the 20mSRT, but may also indicate broader disparities in cardiometabolic and vascular health.

Importantly, while these data cannot establish causality, the combined pattern of lower CRF, higher PWV, and less favourable body composition among socioeconomically disadvantaged males suggests an emerging risk profile in early adolescence that may warrant attention in both surveillance and the development of targeted prevention strategies.

There were no differences in IMT across fitness quartiles among first-year students attending either DEIS or non-DEIS schools. cIMT reflects structural changes in the arterial wall associated with early atherosclerotic development[351] whereas PWV is influenced by both acute and chronic physiological states, including vascular smooth muscle tone, endothelial function, and the biomechanical properties of the arterial wall.[352] These functional properties may be more dynamically responsive to variations in CRF than the structural changes captured by cIMT.

Unlike PWV, cIMT is a structural marker that may require prolonged exposure to adverse cardiometabolic conditions to show measurable differences, potentially over years or decades of vascular remodelling.[353] By contrast, PWV can change more rapidly in response to interventions such as exercise training or other lifestyle modifications.[339] This greater

physiological responsiveness may explain why significant differences in PWV were observed across fitness quartiles, whereas cIMT differences were not evident.

The 75th percentile is inherently arbitrary and should be interpreted as identifying adolescents with relatively elevated CMR burden within this sample rather than strict evidence of clinical disease. A unique aspect of this study was including arterial stiffness in the ROC analysis to establish 20mSRT thresholds for "higher CMR burden." Consistent with paediatric epidemiology,[3,302,354,355] a continuous clustered risk score was derived from standardised values of BMI, BF%, SBP, cfPWV, waist to height ratio, and RHR. The inclusion of cfPWV as a functional vascular component within this risk score provides a more comprehensive phenotype of cardiovascular health than studies relying solely on metabolic markers.[354,355] The analysis identified an optimal 20mSRT cut point of 44 shuttles (or Level 5-3) for males and 32 shuttles (or Level 4-1) for females to detect the upper quartile of clustered risk. These statistically derived thresholds offer robust validation for the distribution-based quartiles applied in Study 3. Specifically, the ROC-derived cut point for males aligns almost perfectly with the upper boundary of the "Bottom 25%" fitness category (<45 shuttles) observed. Male participants in the lowest fitness quartile, who presented with significantly higher cfPWV (6.65 $m \cdot s^{-1}$) compared to their high-fit peers, were not only the least fit relative to the sample but fell below a threshold for elevated CMR burden within this sample. Similarly, the female ROC cut point (32 shuttles) encompasses the "Bottom 25%" female cohort (<29 shuttles) from Study 3, verifying their classification as a high-risk group.

The clinical relevance of the school-level SES disparities reported in Study 1 is highlighted by the ROC-derived cut points. In Study 1, females attending DEIS schools demonstrated a mean 20mSRT performance of 32.1 shuttles. The ROC analysis in the present

study identified 32 shuttles as the optimal threshold for detecting higher CMR. Consequently, the average female student in a DEIS school is performing exactly at the threshold of elevated risk as described in study 3. Similarly, the mean performance for DEIS males (45.5 shuttles) sits just above the male risk threshold of 44 shuttles, whereas their peers in fee-paying schools (57.0 shuttles) are performing well beyond this high CMR zone. Furthermore, while Study 1 estimated that 94% of DEIS females met European norms for cardiovascular health, the population-specific ROC cut point of 32 shuttles suggests a much larger proportion of this cohort may be at risk of clustered CMR burden than previously estimated.

Study 3 provides important evidence that the disparities observed in 20mSRT performance in study 1 are reflected in measurable differences in subclinical vascular health by early adolescence in this cohort. Specifically, adolescents in the lowest quartile of 20mSRT performance demonstrated significantly higher central and peripheral arterial stiffness, indicating that lower CRF is associated with a less favourable vascular profile even within an apparently healthy, asymptomatic cohort. While no differences were evident in cIMT, these findings suggest that functional vascular alterations may emerge before structural changes are detectable at this developmental stage. The identification of stable, population-specific 20mSRT thresholds for elevated clustered CMR further strengthens the clinical and practical relevance of school-based fitness testing as a tool for early risk stratification. Results from Study 3 suggest that students in socioeconomically disadvantaged school settings, in particular this study cohort, may be performing at, or close to, thresholds associated with increased cardiometabolic burden, reinforcing the need for targeted primordial prevention and school-based health surveillance to identify and support those most at risk.

CHAPTER VI

STUDY 4

EFFECT OF A SCHOOL-BASED EXERCISE INTERVENTION ON CARDIORESPIRATORY FITNESS AND VASCULAR HEALTH IN FIRST YEAR STUDENTS ATTENDING A DEIS POST-PRIMARY SCHOOL

INTRODUCTION

Cardiovascular disease (CVD), the primary cause of death in Ireland, refers to diseases of the heart and blood vessels. Atherosclerotic CVD (ASCVD), the most common form of CVD,[356] develops in response to the progressive accumulation of fibro-fatty plaque in the walls of large and medium-sized muscular arteries.[110] The extent of the plaque accumulation depends on the duration of exposure to established risk factors such as smoking, overweight/obesity, insulin resistance, hypertension, hyperlipidaemia and physical inactivity.[5,110] Although the clinical manifestation of ASCVD typically occurs in middle-aged and older adults, fatty streaks, - the hallmark of early ASCVD - are commonly present in the aorta of almost all individuals aged 15–19-years,[4] and clinically significant ASCVD is increasingly being identified in younger populations than previously recognised.[357] Rising prevalence of modifiable cardiometabolic risk (CMR) factors such as obesity and hypertension together with increased exposure to energy-dense, ultra-processed foods are contributors, further supports the rationale for early, school-based lifestyle interventions.[357]

Increased arterial stiffness is an important pathophysiological process reflecting degenerative changes in the large conduit arteries.[358] Pulse wave velocity (PWV) is a widely used non-invasive measure of arterial mechanical and elastic properties, with higher PWV values indicating increased vascular stiffness and reduced arterial compliance. Importantly, PWV is recognised as a surrogate endpoint for CVD and is predictive of both CVD and

cardiovascular events.[359] Short-term exercise interventions in adolescents may improve endothelial function within four weeks;[360] however, changes in arterial stiffness may require a longer intervention durations,[341] particularly when baseline PWV values are within the normal range.[148,152]

Cardiorespiratory fitness (CRF), also termed CV fitness or aerobic fitness, reflects the capacity of the cardiovascular and respiratory systems to deliver oxygen to skeletal muscle mitochondria for energy metabolism required to perform and sustain physical activity.[38] CRF is inversely associated with CVD risk in children and adolescents.[19,125,126] Low CRF may mediate CVD risk indirectly through its effects on established modifiable risk factors, including hypertension, hyperlipidaemia, body weight, and insulin resistance, and directly through its influence on cardiac and vascular structure and function.[361] Conversely, higher CRF levels are associated with a greater number of ideal cardiovascular health components among European adolescents.[20]

The metabolic syndrome (MetS) describes a constellation of metabolic derangements, ranging from dyslipidaemia (hypertriglyceridaemia and low high density lipopoprotein cholesterol (HDL-C)), central adiposity, insulin resistance, and hypertension.[185] MetS is associated with a two- to three-fold increased risk of myocardial infarction or stroke and a five-fold increased risk of developing type two diabetes mellitus (T2DM).[362] The prevalence of MetS in children and adolescents is increasing alarmingly, largely due to the growing obesity epidemic within this population.[363] Early lifestyle intervention and risk-factor modification may assist in preventing or delaying the progression of CVD and T2DM associated with MetS.[364] These measures are also easily obtained within school settings. Importantly, central adiposity is associated with vascular phenotype in youth, with evidence

demonstrating positive associations between elevated waist circumference and carotid intima media thickness (cIMT) in paediatric populations.[166,365] Evaluating changes in body composition alongside waist and hip circumferences, and derived ratios, therefore provides a meaningful approach to determining whether a school-based exercise intervention influences adiposity-related risk pathways during early adolescence. However, changes in body composition and waist-based anthropometric measures may be less likely to emerge during short intervention periods. Existing evidence suggests that four weeks may be insufficient to elicit measurable changes,[360] whereas improvements have been reported following a 12-week intervention in obese adolescent females.[55]

Low levels of CRF are also associated with elevated clustered MetS risk factors.[302] For example, the Health and Physical Activity Promotion in Youth study conducted in the UK identified an inverse association between CRF and clustered CMR in youth[123] Participants in the low-fit group demonstrated significantly higher clustered risk compared with those in the high-fit group, independent of age, sex, ethnicity, and SES.[123] Furthermore, paediatric metabolic abnormalities have been proposed to predict adult MetS.[13]

Socioeconomic status (SES) is strongly linked with health inequalities and is a reliable predictor of inequalities in youth health outcomes.[26] Children from lower SES backgrounds are at greater risk of poor health due to earlier exposure to chronic disease risk factors, including sedentary behaviour, low participation in exercise, and poor nutrition.[26] Delivering Equality in Schools (DEIS) is an Irish government initiative designed to support schools serving children from socioeconomically disadvantaged communities at greatest risk of educational disadvantage. As of 2022, 28% of Irish schools were classified as DEIS.[272] Positive associations between low CRF and elevated clustered CVD risk factors have also been reported among

South African primary school children from disadvantaged communities.[366] Similarly, students attending DEIS schools demonstrate lower PA levels than those attending non-DEIS schools.[30] Williams et al. (2018)[277] reported that only 34% of 13-year-old Irish children from the lowest SES group participated in paid organised sport or exercise, compared with 56% of children from higher social class groups.

Greater emphasis is needed on sustainable primordial and primary prevention strategies to reduce CVD risk among youth from lower SES communities. The Lifestyle Intervention for Everyone (LIFE) was a novel, inclusive, four-week school-based exercise programme designed for delivery during the academic term. The aim of the present study was to evaluate the effects of participation in LIFE on 20mSRT performance, MetS, vascular health, body composition, and BP in children attending a DEIS school.

Aims

1. To evaluate the effect of LIFE on 20mSRT performance in male and female first-year students attending a DEIS post-primary school.
2. To evaluate the effect of LIFE on grip strength in male and female first-year students attending a DEIS post-primary school.
3. To evaluate the effect of LIFE on body composition, waist and hip circumferences in male and female first-year students attending a DEIS post-primary school.
4. To evaluate the effect of LIFE on arterial stiffness and blood pressure in male and female first-year students attending a DEIS post-primary school.
5. To assess the proportion of year males and females presenting with the MetS metabolic syndrome.

Hypothesis

1. Compared to the control group, participation in LIFE will result in a significant improvement in 20mSRT performance.
2. Compared to the control group, participation in LIFE will result in a significant improvement in grip strength.
3. Compared to the control group, participation in LIFE will result in no change in body composition, waist and hip circumferences.
4. Compared to the control group, participation in LIFE will result in no change in measures of arterial stiffness or blood pressure.
5. A low proportion of male and female students will present with MetS

METHODS

Study Overview

A summary letter outlining the research project was sent to the principal of an inner-city (Dublin) DEIS post-primary school. Participants and their guardians were fully informed of the experimental procedures and provided with a plain language statement, written assent forms, and informed consent forms, all of which were completed prior to participation.

The study protocol was conducted in accordance with the ethical standards set out in the 1961 Declaration of Helsinki (as revised in 2000) and was approved by the Research Ethics Committee of Dublin City University (DCU/REC/2018/164); the full protocol is provided in Appendix M.

The intervention was originally planned to last six weeks; however, it was reduced to four weeks to accommodate school timetable constraints and to ensure completion of baseline and post-intervention assessments within a single school term. This adjustment also allowed delivery of the exercise programme to the control group following post-testing, minimised disruption to teaching time, and improved the feasibility of sustained implementation by school staff.

Study Design

An a priori power calculation indicated that 52 participants per group (104 in total) were required to detect a between-group difference of 1 metabolic equivalent in estimated $\dot{V}O_2max$. To account for potential attrition and incomplete data, recruitment exceeded this minimum threshold, with all eligible first-year students invited to participate. A total of 102 participants consented to take part in the study.

The study employed a randomised controlled design, with participants randomly assigned to either an intervention group or an age-, sex-, and CRF-matched control group. Assessments were conducted over three separate days at baseline (within a two-week period) and over two separate days post-intervention. Each testing session was separated by a minimum of 24 hours.

On the first assessment day, body composition was measured, along with height, weight, grip strength, waist circumference, and hip circumference. The 20 m shuttle run test (20mSRT) was also completed to estimate CRF. Blood pressure (BP) and PWV were assessed on the second assessment day; while fasting blood samples were collected on the third day.

Measurements

Height

As previously described in the methods section of Chapter V.

Weight

As previously described in the methods section of Chapter V.

Waist circumference

As previously described in the methods section of Chapter V.

Hip circumference

As previously described in the methods section of Chapter V.

Waist-to-hip ratio

As previously described in the methods section of Chapter V.

Waist-to-height ratio

As previously described in the methods section of Chapter V.

Body composition

As previously described in the methods section of Chapter V.

Body Mass Index (BMI)

As previously described in the methods section of Chapter V.

20m Shuttle Run Test (20mSRT)

As previously described in the methods section of Chapter V.

Est $\dot{V}O_2$max

As previously described in the methods section of Chapter III.

Blood Pressure

As previously described in the methods section of Chapter V.

Upper Body Muscle Strength

As previously described in the methods section of Chapter V.

Pulse Wave Velocity

As previously described in the methods section of Chapter V.

Carotid Intima-Media Thickness

As previously described in the methods section of Chapter V.

Phlebotomy

Participants attended school following a 12-hour overnight fast. Blood samples were obtained via standard venepuncture from a prominent forearm vein into serum and sodium fluoride/potassium oxalate vacutainers (Becton Dickinson and Company) by the PhD candidate. Sodium fluoride/potassium oxalate tubes were immediately placed on ice, while serum tubes were allowed to clot for 30 min at room temperature before being stored on ice. Serum vacutainers were allowed to stand for 30 min at room temperature before being stored on ice.

Samples were centrifuged at 3000 rev·min^{-1} (1600 g) for 10 minutes at 4°C, after which 1.5 mL aliquots of plasma and serum were separated and stored at −80°C until analysis. Serum concentrations of total cholesterol (TC), high-density lipoprotein cholesterol (HDL-C), and triglycerides (TG), along with plasma levels of high sensitivity C-reactive protein (hs-CRP) and glucose, were measured in duplicate using spectrophotometric analysis (Randox RX Daytona clinical chemistry analyser, Randox Laboratories, UK). Low-density lipoprotein cholesterol (LDL-C) was calculated using the Friedewald formula: LDL-C = TC − (HDL-C + (TG/5))[367]

Metabolic Syndrome

MetS classification was based on the age-specific International Diabetes Federation guidelines (2005), defined as the presence of central adiposity in combination with two or more of the following clinical features: elevated TG, low HDL-C, elevated BP, and increased plasma glucose concentration (Table 6.1).

Table 6.1: International Diabetes Federation MetS classification for 10–16 year-olds

Parameter	Value
Waist circumference (cm)	≥ 90th percentile or adult cut-off if lower
Triglycerides ($mg \cdot dL^{-1}$)	≥ 150
High-density lipoprotein-cholesterol ($mg \cdot dL^{-1}$)	< 40
Blood pressure (mm Hg)	Systolic ≥ 130 or Diastolic ≥ 80
Glucose ($mg \cdot dL^{-1}$)	≥ 100 or known T2DM

T2DM, type 2 diabetes

Experimental intervention

"Non-traditional games" were defined as modified, high-participation movement activities that were not based on formal competitive sport rules and were deliberately structured to maximise active participation time by minimising queuing and elimination. These activities promoted intermittent running and multi-directional movement while supporting inclusive engagement across a mixed-ability class.[246] Games-based formats were selected because evidence suggests that game-based PE and games-centred pedagogical approaches can enhance enjoyment, motivation, and satisfaction of basic psychological needs among children and adolescents, thereby supporting sustained engagement in higher-intensity PA during school-based programmes.[247,249,250,368]

The "Marathon Challenge" incorporated a group-based distance target to operationalise key behaviour-change techniques, including goal setting, self-monitoring, and feedback, with distances recorded during each session to provide immediate feedback on progress.[240] The threshold of >42.2 km was selected to approximate the standard marathon distance (42.195 km), thereby providing a prominent and easily communicated benchmark for the class-based challenge, consistent with established race standards. Marathon-distance challenges have also been implemented within school- and community-based youth running initiatives to promote participation and sustained engagement.[369] The "Marathon Challenge"

required participants to accumulate distance across a range of cardiovascular exercise modalities (treadmill, rowing ergometer, cross-trainer, and cycle ergometer) during a 25-minute session. Following completion of a self-selected distance on each apparatus, the distance achieved was recorded by the instructor, after which participants took a short rest period before transitioning to another piece of equipment. The total distance accumulated by each group was summed, with the collective aim of exceeding 42.2 km per session.

The intervention group participated in three exercise sessions per week for four weeks. Sessions were delivered during class time by qualified exercise specialists and comprised a series of structured activities, including non-traditional games, exercise challenges, and resistance-based exercises. Exercise intensity was monitored during weeks 1 and 3 using heart rate telemetry (Polar Team2, Polar, Finland). Participants in the control group did not participate in the intervention sessions during the study period; however, they were offered the same exercise programme following completion of post-intervention testing.

The intervention group was divided into two subgroups at the start of each session. On Mondays and Fridays, sessions were organised into two 25-minute blocks comprising non-traditional games and high-intensity circuit training. On Wednesdays, sessions were similarly divided into two 25-minute blocks consisting of a “Marathon Challenge” and high-intensity circuits, with the order alternated across weeks. Adherence was monitored and recorded with 81% of participants attending all sessions, and the remaining 19% of participants attending 83% (10 out of 12) exercise sessions.

Heart rate monitoring

Each participant was fitted with a POLAR Team2 Pro telemetry system (Polar Electro Oy, Kempele, Finland), consisting of a chest strap with integrated electrodes and a Polar Pro sensor. The electrode contact area of the strap was moistened prior to application and positioned around the chest at the mid-axillary level. The strap was adjusted to ensure a secure and comfortable fit, and the Polar Pro sensor was attached to the front of the strap (Figure 6.1).

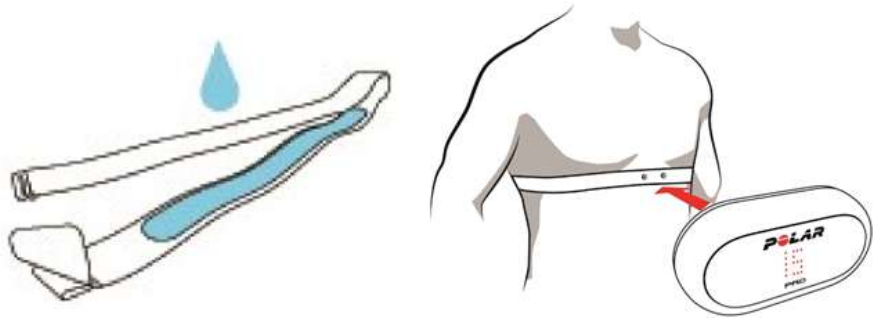


Figure 6.1: *Polar Team Pro 2 strap and sensor*

Statistical Analysis

Participant characteristics are presented as means ± standard deviations (SD). Baseline group differences were assessed using independent samples t-tests. A two-way repeated measures analysis of variance (ANOVA) was used to examine group (control/intervention) × time (baseline/post-intervention) effects for all continuous outcome variables, with sex included as a covariate. Where Mauchly's test indicated a violation of the assumption of sphericity, the Greenhouse–Geisser correction was applied. Significant main effects and/or interactions were further explored using pairwise comparisons with Bonferroni-adjusted post hoc tests.

Effect sizes were calculated using partial eta squared (η^2) and interpreted as small (> 0.01), medium (> 0.06), and large (> 0.14). Statistical analyses were performed using SPSS for Windows (Version 28.0; SPSS Inc., IL, USA). Statistical significance was set at $p < 0.05$.

Bivariate associations between selected health-related fitness, anthropometric, and biomarker variables and vascular outcomes (PWV and mean cIMT) were examined using Pearson product–moment correlations (r), with statistical significance defined as $p < 0.05$ (two-tailed).

RESULTS

Baseline Characteristics

A total of 102 students (82% of the first-year cohort), evenly distributed between males and females, participated in the study. Three participants from the intervention group and five from the control group withdrew during the study due to lack of interest, illness, and inability to attend school early in the morning.

There were no significant differences in baseline anthropometric, body composition, or grip strength measures between males in the control and intervention groups, nor between females in the control and intervention groups, as summarised in Table 6.2.

Table 6.2: Baseline anthropometric, body composition and grip strength values

	Male		Female	
	Control N=24	**Intervention N=22**	**Control N=23**	**Intervention N=25**
Age (y)	13.0±0.5	13.0±0.5	12.9±0.5	13.0±.0.4
Height (cm)	159.5±9.6	161.7±7.8	157.5±7.7	156.4±6.7
Weight (kg)	53.7±14.4	52.0±11.6	51.7±12.2	50.8±14.6
BMI (kg/m²)	20.7±4.2	19.7±3.5	20.6±4.0	20.4±5.0
BMI (percentile)	61.2±29.0	53.2±31.3	58.7±29.3	56.0±30.7
Body fat (%)	17.9±7.1	18.9±9.4	25.6±8.9	25.4±8.2
Waist (cm)	70.0±9.8	69.1±10.7	70.5±15.0	67.4±10.5
Hip (cm)	85.6±8.5	85.1±10.7	88.6±12.2	86.9±12.2
W:H	0.82±0.06	0.81±0.05	0.79±0.07	0.78±0.05
W:Ht	0.44±0.07	0.43±0.06	0.45±0.08	0.43±0.06
Grip strength (kg)	24.8±7.3	24.7±6.0	20.9±3.4	23.2±6.1

Values presented are means ± SD; BMI, body mass index; W:H, waist to hip ratio; W:HT, waist to height ratio

Selected blood biomarkers and cIMT values, stratified by sex and group, are summarised in Table 6.3. At baseline, there were no significant differences in glucose, hs-CRP, circulating lipid concentrations, or cIMT values between males in the control and intervention groups, between females in the control and intervention groups, or between males and females within either the control or intervention groups.

Table 6.3: Baseline glucose, hs-CRP, lipids and mean cIMT values

	Male		**Female**	
	Control N=20	**Intervention N=21**	**Control N=20**	**Intervention N=21**
Total cholesterol (mg/dL)	165.6±26.0	154.6±21.0	167.4±31.9	162.5±25.8
d-HDL-c (mg/dL)	57.8±12.4	56.6±15.5	59.0±12.3	59.3±10.0
LDL-c (mg/dL)	89.5±17.8	86.2±18.0	91.4±26.3	91.4±188
Triglycerides (mg/dL)	78.3±35.5	66.3±18.8	71.4±33.0	71.0±19.6
Glucose (mg/dL)	98.8±5.9	96.6±6.2	94.6±7.8	94.3±6.6
hs-CRP (mg/L)	1.18±1.6	0.98±1.5	0.53±0.6	0.41±0.3
cIMT (mm)	0.453±0.02	0.441±0.03	0.441±0.04	0.434±0.034

Values presented are means ± SD; d-HDL-c, direct high-density lipoprotein cholesterol; LDL-c, low-density lipoprotein cholesterol, hs-CRP, high-sensitivity C-reactive protein; cIMT, carotid intima media thickness

Post-training

There was no significant time × group interaction for any of the variables examined following the four-week intervention. Similarly, no significant main effects of time were observed, $F(9, 14) = 1.643$, $p = 0.195$, or sex, $F(9, 14) = 1.597$, $p = 0.209$. Neither 20mSRT performance nor maximum heart rate (HRmax) differed between baseline and post-intervention assessments, as summarised in Table 6.4. Inter-individual changes in 20mSRT performance from baseline to post-testing, stratified by sex and group, are presented in Figure 6.2.

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Table 6.4: Mean 20mSRT results at baseline and post-training

	Male		Female	
	Baseline	**Post-training**	**Baseline**	**Post-training**
20mSRT				
Control	38.6±19.3	41.2±22.4	29.7±14.1	27.3±15.9
Intervention	38.8±20.1	42.3±20.1	30.9±13.4	35.4±14.6
HR_{max}				
Control	203.0±8.4	206.3±5.8	201.1±8.1	203.0±8.2
Intervention	203.8±6.1	203.0±8.5	206.1±5.8	204.3±8.5

Values presented are means ± SD; 20mSRT, 20-meter shuttle run test; HR_{max}; maximum heart rate.

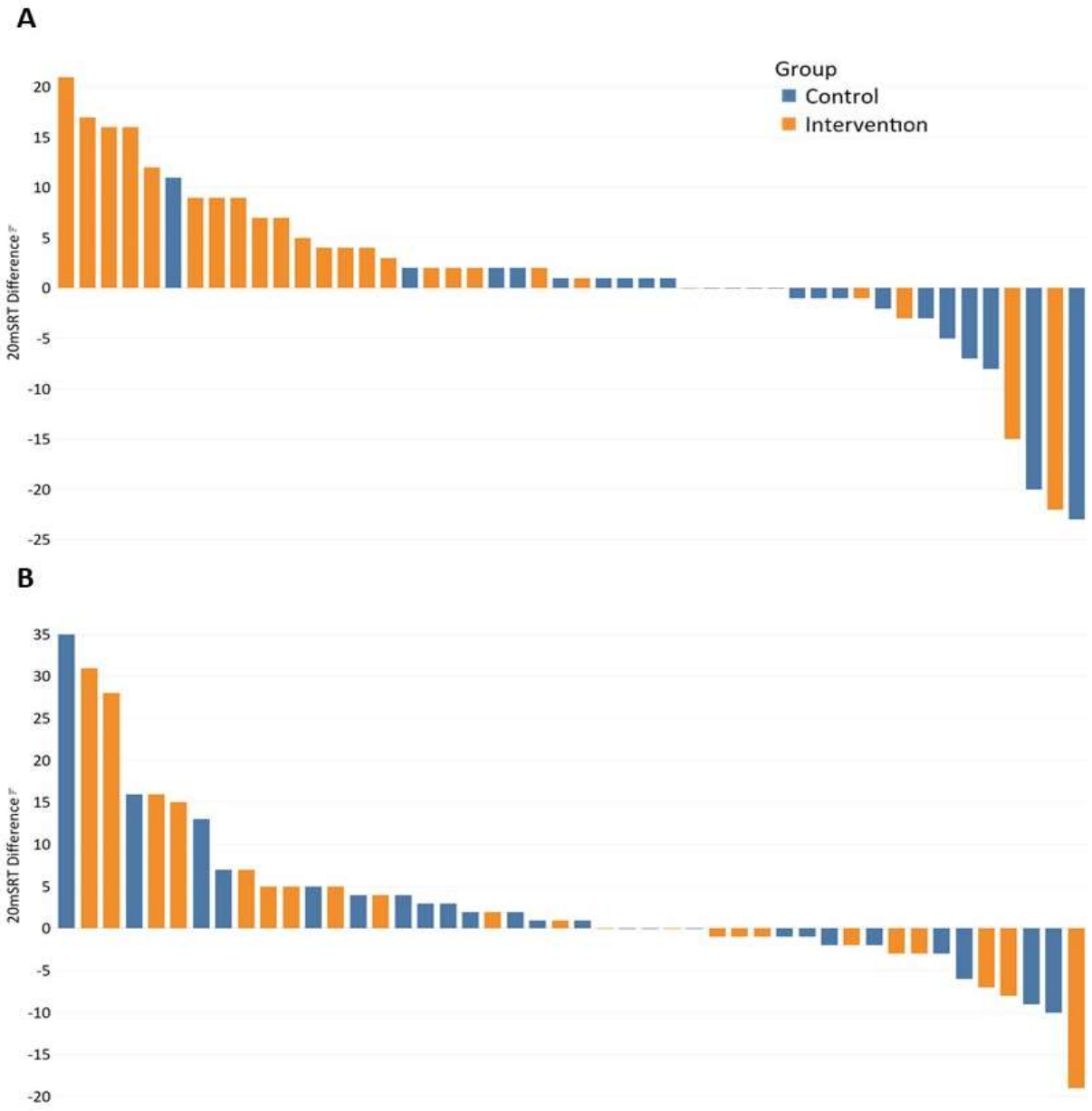


Figure 6.2: *Inter-individual changes in 20mSRT performance in between baseline and post-testing for females (A) and males (B) in both the control and intervention groups*

Blood Pressure and Arterial Stiffness

The 4-week intervention did not impact arterial stiffness and blood pressure measures as summarised in Table 6.5. Systolic and diastolic blood pressure, cfPWV and baPWV remained unchanged for both males and females in the control and intervention groups.

Table 6.5: Mean blood pressure and arterial stiffness at baseline and post-training

	Male		Female	
	Baseline	**Post-training**	**Baseline**	**Post-training**
Systolic BP (mmHg)				
Control	124.4±9.1	119.1±8.0	120.0±10.4	122.7±8.3
Intervention	116.6±12.3	120.1±10.7	122.7±8.3	119.4±10.6
Diastolic BP (mmHg)				
Control	57.9±8.9	55.1±5.6	59.2±6.0	52.2±6.5
Intervention	55.5±9.5	50.4±5.2	56.6±7.0	54.9±7.5
cfPWV ($m \cdot s^{-1}$)				
Control	6.6±0.6	6.7±0.5	6.4±0.8	6.4±0.8
Intervention	6.7±0.6	6.7±0.7	6.7±0.6	6.5±0.4
baPWV ($m \cdot s^{-1}$)				
Control	10.4±0.9	10.2±0.9	9.7±1.7	10.0±1.6
Intervention	10.0±1.0	10.3±0.9	9.9±1.0	9.7±0.9

Values presented are means ± SD; BP, blood pressure; cfPWV, carotid-femoral pulse wave velocity; baPWV, brachial-ankle pulse wave velocity.

Sufficient data were available for 73 of the 102 participants to assess the presence of MetS, as summarised in Table 6.6. Of these participants, three males and one female (5.5%) met the criteria for MetS, characterised by central adiposity (≥90th percentile) in combination with two or more additional MetS risk factors. Central adiposity accompanied by one MetS risk factor was observed in three males and three females, while four males and two females presented with central adiposity alone.

Table 6.6: Number of participants with complete MetS risk factor assessments

Sex	Central Adiposity	Total	No Risk Factors	1 Risk Factor	2 Risk Factors
Male	No	27	13	11	3
	Yes	10	4	3	3
Female	No	30	22	6	2
	Yes	6	2	3	1

Baseline Correlations

Table 6.7 presents Pearson product–moment correlation coefficients (r) between selected health-related fitness components and vascular measures. A significant inverse association was observed between 20mSRT performance (number of shuttles completed) and a range of anthropometric variables, with the strongest correlation reported for body fat % ($r = -0.589$, $p < 0.001$). Systolic blood pressure demonstrated a moderate positive correlation with body weight ($r = 0.529$, $p < 0.001$).

Weak positive correlations were observed between mean cIMT and hs-CRP, BMI, waist-to-height ratio, and waist-to-hip ratio ($r = 0.342$, 0.239, 0.272, and 0.268, respectively; all $p < 0.001$). In addition, HDL-C was weakly negatively correlated with BMI ($r = -0.25$, $p < 0.001$).

Table 6.7: Significant Pearson (r) correlations between blood biomarkers and selected health and vascular measures

	HDL-C	hs-CRP	20mSRT Shuttles	Weight	BMI	Waist to Height	Waist to Hip
Mean cIMT		0.342			0.239	0.272	0.268
Systolic BP				0.529			
BMI	-0.250		-0.450				
Body Fat %			-0.589				
Waist to Height			-0.334				

HDL-C, High-density lipoprotein cholesterol; hs-CRP, high sensitivity C reactive protein; 20mSRT, 20-meter shuttle run test; BMI, body mass index; cIMT, carotid-intima media thickness.

DISCUSSION

The LIFE intervention was developed as a novel, inclusive, school-based programme designed to balance physiological training principles with pedagogical feasibility within a DEIS post-primary setting. By incorporating games-based activities and behaviour change techniques (BCTs), the programme sought to address previously identified low CRF and elevated cardiometabolic risk within this cohort.

However, the findings indicate that the four-week intervention did not produce statistically significant changes in CRF, arterial stiffness, or BP. These outcomes necessitate critical reflection on whether a need-supportive pedagogical climate, while essential for fostering engagement and adherence, is sufficient in isolation to elicit meaningful physiological adaptations within a relatively short intervention period. [228,229] By prioritising overall enjoyment through the use of game-based PA, the intervention aimed to create a positive and engaging environment[246]; however, this emphasis may have limited the physiological stimulus required to induce measurable adaptations.

Despite the absence of statistically significant effects, a non-significant improvement in 20mSRT performance was observed, with increases of 9% in males and 15% in females. Exercise training adaptations are influenced by four primary principles: frequency, intensity, time, and type.[370] Evidence suggests that short-term, school-based exercise interventions capable of eliciting significant improvements in CRF are typically characterised by higher exercise intensities.[371] Martin-Smith et al. (2019)[56] reported significant improvements in 20mSRT performance following a four-week, school-based sprint interval training programme. Similarly, Lee et al. (2017)[372] observed a 10% increase in $\dot{V}O_2$max among obese adolescents following a four-week, low-volume high-intensity training (HIT) intervention

consisting of ten 60-sec cycling bouts performed three times per week. In contrast, the LIFE intervention adopted a more holistic and autonomy-supportive approach, which may have resulted in lower self-regulated exercise intensity, thereby attenuating improvements in CRF.

The reduction of the LIFE intervention from the ethically approved six-week duration to four weeks represents a significant from the study's original design, which aimed to mirror the six-week protocol utilised in Study 2. This modification was necessitated by practical constraints within the school calendar, specifically the requirement to complete baseline testing, the intervention period, and post-testing within a continuous timeframe that avoided mid-term breaks and the potential for a "washout" effect, particularly within a short-duration intervention. While this decision enhanced feasibility and standardisation of delivery within the post-primary setting, it likely had important implications for physiological adaptation.

Evidence from Hartwig et al. (2021)[54] indicates that school-based interventions frequently produce variable or modest outcomes, partly because effectiveness depends on both programme content and the fidelity of exercise prescription over time. Meta-analytic evidence further suggests that larger improvements in CRF are associated with clearly defined dose characteristics and explicit intensity control, both of which require a sufficient "time" component within the Frequency, Intensity Time, Type framework to manifest. Consequently, the reduction of the intervention to four weeks narrowed the physiological window for adaptation, potentially falling below the threshold necessary to observe significant changes in CRF and vascular outcomes. Longer interventions provide further context, for example, a 12-week, female-only programme reported by Petrušič et al. (2024)[373] demonstrated significant improvements in CRF among 13-year-old participants who engaged in two additional weekly sessions alongside their regular physical education classes,

compared to those undertaking physical education alone. These findings underscore the importance of sustained engagement when seeking to elicit meaningful fitness adaptations in adolescents, particularly those with lower baseline CRF.

Physiological data derived from weekly monitoring indicated that the average exercise intensity across sessions was approximately 66% HRmax. While this falls within the recognised range for moderate-intensity PA,[34] it may represent a suboptimal stimulus for eliciting significant improvements in CRF within a condensed four-week intervention period. Martin-Smith et al. (2019)[56] suggests that larger improvements in CRF are more consistently associated with vigorous-intensity activity exceeding 77% HRmax, rather than the accumulation of time spent at moderate intensity. Consequently, the self-selected, moderate intensity observed within the LIFE programme likely prioritised enjoyment and psychological well-being over the physiological threshold required to meaningfully enhance 20mSRT performance or improve vascular outcomes.

Allowing participants to self-regulate exercise intensity is well established as a strategy to promote autonomy and is associated with enhanced affective responses, pleasure, and overall well-being,[374,375] while also demonstrating effectiveness in improving both physiological and psychological outcomes.[376,377] However, this emphasis on a need-supportive motivational climate may have introduced what can be conceptualised as a "stimulus–enjoyment" paradox. While need-supportive practices are associated with more adaptive forms of motivation,[242] performance-oriented environments - although potentially more effective in eliciting higher exercise intensities,[56] may undermine perceptions of competence and relatedness, thereby increasing the risk of amotivation, particularly among adolescents from lower SES backgrounds (243).[242]

Within the context of the present study, the prioritisation of a holistic, autonomy-supportive approach may have resulted in exercise intensities that were insufficient to drive meaningful physiological adaptation. This highlights a critical challenge in the design and implementation of school-based interventions: achieving consistent exposure to vigorous-intensity activity requires deliberate structuring, progressive overload, and pedagogical support, rather than assuming that sufficient intensity will emerge organically from games-based formats - particularly within a short-duration intervention.[374]

The small increase in 20mSRT performance observed among males in the control group may have contributed to the absence of a statistically significant between-group effect. As external physical activity levels were not monitored in either group, habitual activity, extracurricular sport participation, or informal peer-led PA outside of school may have independently influenced CRF. This interpretation is consistent with Social Cognitive Theory, which posits that adolescent behaviour is shaped by the reciprocal interaction between personal factors and environmental opportunity structures.[233] Furthermore, given that the 20mSRT is a volitional field-based test, post-intervention differences in motivation, pacing strategy, or effort may also have contributed to the observed improvements in control males.

The four-week LIFE intervention did not produce any observable effect on arterial stiffness. The fact that baseline PWV values were within normal ranges for 12-13-year-olds, combined with the short intervention duration, likely explains this finding. Previous studies demonstrating favourable effects of exercise on arterial stiffness have typically employed longer intervention periods, particularly in populations with elevated baseline vascular risk.[341] Similarly, no changes were observed in BP following the intervention. Kranen et al. (2023)[360] reported that four weeks of high-intensity interval training was sufficient to improve flow-

mediated dilation, but not microvascular function, body composition, or circulating biomarkers, suggesting that short-duration interventions may differentially affect vascular outcomes. Accordingly, the absence of change in vascular measures in the present study is not unexpected, given the short intervention period and the fact that vascular indices were within normal physiological ranges at baseline in this young cohort.

The observed positive correlation between hs-CRP and cIMT is consistent with previous research linking systemic inflammation to early atherosclerotic development.[378] Although participants presented with vascular measures generally within age-appropriate ranges, the presence of a moderate association between inflammatory and structural vascular markers is noteworthy. This may indicate that elevated systemic inflammation during adolescence precedes the development of subclinical ASCVD. This finding should be interpreted within the broader longitudinal risk profile of the cohort. A large-scale longitudinal study of late adolescents demonstrated that elevated baseline hs-CRP predicted increased cIMT and PWV at seven-year follow-up.[350] The observation of similar associations in first-year students attending a DEIS school is particularly concerning given the socio-ecological context, where exposure to behavioural and environmental cardiovascular risk factors-including poor diet and physical inactivity-is more prevalent in lower socioeconomic groups.[350] Taken together, these findings suggest that elevated inflammatory burden in this population may represent an early indicator of the cardiovascular inequalities that may emerge later in life.

In summary, Study 4 demonstrated that a four-week intervention delivered three times per week did not elicit statistically significant improvements in CRF, vascular health, or BP among first-year students in a DEIS post-primary setting. While the programme was

feasible and inclusive in its design, the combination of short duration and moderate self-regulated exercise intensity was likely insufficient to induce the physiological adaptations required to improve 20mSRT performance. Nevertheless, the observed associations between CRF, adiposity, inflammation, and vascular markers reinforce the potential clinical relevance of early intervention in socioeconomically disadvantaged adolescents. Overall, Study 4 highlights the ongoing challenge of balancing pedagogical feasibility and engagement with the exercise dose required to elicit meaningful health outcomes and supports the need for longer and more structured interventions within DEIS school settings.

CHAPTER VII

STUDY 5

COMPARISON OF MEASURED AND PREDICTED MAXIMAL HEART RATE AND SUBMAXIMAL HEART RATE RESPONSES AMONG IRISH FIRST-YEAR POST-PRIMARY STUDENTS DURING THE 20M SHUTTLE RUN TEST

INTRODUCTION

A major limitation of the 20m shuttle run test (20mSRT) is the absence of a fully objective, quantifiable criterion to confirm that each participant achieved maximal effort. Consequently, performance may be influenced by factors unrelated to physiological fitness, including low self-efficacy, anxiety, peer pressure, injury, pre-existing health conditions (e.g., exercise-induced asthma), and motivational differences.[379]

Historically, attainment of a proportion of age-predicted maximal heart rate (PHRM) has been used as an objective criterion for verifying maximal or near-maximal effort during incremental exercise testing. Common thresholds include a maximum heart rate (HRmax) >185 b·min^{-1} (384), >95% PHRM,[24] or or values exceeding 95% of age-predicted HRmax derived from the Fox equation (220 − age).[68,82,380] While the Fox equation remains widely used in exercise science and applied settings, it has notable limitations, particularly its tendency to overestimate or underestimate HRmax across different age groups, including children and adolescents.[60,61]

Alternative prediction models have therefore been proposed. In youth populations, the equation 208 − (0.7 × age), developed by Tanaka et al. (2021)[61] has demonstrated reduced bias and narrower error margins compared with the Fox equation, making it a more appropriate alternative.[63] Additional models incorporating variables such as resting heart

rate, body mass index (BMI), metabolic equivalents (MET), and body composition have further improved prediction accuracy.[61,64,71,75] Collectively, these findings suggest that HRmax in paediatric populations typically clusters around ~200 b·min^{-1}, while also highlighting that reliance on a single prediction equation may lead to misclassification of maximal effort in some individuals. Accordingly, the use of a ≥95% PHRM criterion across multiple validated youth-specific equations may provide a more robust estimate of maximal or near-maximal effort during the 20mSRT. Based on expected physiological responses in this age group, it is anticipated that a substantial proportion of participants, potentially ≥90%, would meet this threshold.

Although the 20mSRT is a central outcome measure within this thesis and is widely used as a field-based estimate of cardiorespiratory fitness (CRF), informal feedback from teachers and students who opted out of participation suggests that the test itself may act as a barrier to engagement in school-based fitness assessment. This is consistent with survey evidence indicating that while 90% of PE teachers support the inclusion of fitness testing in the curriculum, 60% also believe that associated anxiety may negatively impact students' psychological well-being.[381]

Ideally, both laboratory- and field-based assessments of CRF should involve a gradual progression from low to maximal intensity over approximately 8-12 minutes. In contrast, the 20mSRT may impose relatively rapid physiological strain for youth with low baseline fitness, as reflected in early elevations in heart rate (HR) and rate of perceived exertion (RPE). Elevated perceived exertion at the outset of the test may negatively influence motivation and willingness to continue, particularly among less physically competent individuals. Furthermore, the socially evaluative nature of the 20mSRT may exacerbate anxiety, especially

in adolescents with low perceived physical competence or body image concerns.[382] Although submaximal HR has value as an indicator of relative effort levels, its utility as a prognostic marker of 20mSRT performance in adolescents remains unclear.

From a physiological perspective, HR responses during incremental exercise reflect the integrated function of multiple systems, including autonomic regulation, baroreflex activity, venous return, age, and training status,[383] the slope of this response is influenced by training adaptations and autonomic control. Endurance training reduces HR at a given submaximal workload.[384] Although HR increases in an approximately linear manner with rising workload[385] primarily through activation of the sympathetic and inhibition of the parasympathetic nervous system.[87] Accordingly, at the same running speed during the 20mSRT, higher-fit individuals would be expected to demonstrate lower HR responses than their lower-fit peers.

In contrast, HRmax is relatively stable following training interventions but declines progressively with age.[87] The predictable relationship between HR and workload during incremental exercise has therefore been widely used to estimate aerobic capacity using submaximal responses.[386] In this context, early-stage HR responses during the 20mSRT may offer a practical and scalable approach to estimating overall performance.[387]

To date, relatively few studies have examined HR responses during field-based 20mSRT assessments in school-aged populations. The datasets collected in Studies 3 and 4 provide a unique opportunity to: (i) evaluate attainment of %PHRM using both the Fox equation and youth-specific prediction models; (ii) quantify physiological strain via HR responses across CRF quartiles during the initial stages of the test; and (iii) examine the prognostic utility of submaximal HR responses in predicting overall 20mSRT performance.

Aims

1. To determine HR_{max} values attained during the 20mSRT in a cohort of first-year post-primary school students
2. To determine the proportion of first-year post-primary school students who achieve a HR >95% PHRM during the 20mSRT based on six commonly used prediction equations
3. To examine the relation between directly measured HR_{max} achieved during the 20mSRT and 6 commonly used adolescent PHRM equations
4. To compare the physiological strain (indexed using HR) between 20mSRT performance quartiles during the first two stages of the test
5. To evaluate the prognostic ability of submaximal HR responses during the 20mSRT in predicting overall test performance

Hypothesis

1. Mean HR_{max} values achieved during the 20mSRT will exceed 195 bpm
2. Based on six equations, ≥ 90% of participants will achieve a HR ≥ 95% PHRM
3. Submaximal HR responses will be lower in higher- fit individuals compared with lower-fit individuals
4. Submaximal HR parameters will not serve as a prognostic indicator of 20mSRT performance

METHODS

Study Overview

As previously described in the methods section of Chapter V.

Heart Rate

As previously described in the methods section of Chapter V.

Participant HR was continuously monitored, rom 5 min prior to the commencement of the 20mSRT and until 3 min post-test. The exact start time of each 20mSRT was recorded for every participant. HR data was subsequently downloaded to a portable PC and analysed using dedicated software (POLAR Team^2 Pro) and Microsoft Excel (Microsoft Corporation, USA). Individual participant files were inspected and exported at 1-sec intervals to ensure high temporal resolution. The recorded start time of each 20mSRT was then aligned with the corresponding time-stamped HR data within each participant file to ensure accurate synchronisation of physiological responses with test performance.

Maximum Heart Rate

HR_{max} was defined as the highest HR value recorded during the 20mSRT, calculated as the peak 10-second average HR.

Predicted Maximal Heart Rate

Six different equations were used to calculate PHRM (Table 7.1).

Table 7.1: PHRM equations

Author	Equation
Fox[388]	220 - A
Tanaka[61]	208 - 0.7 x A
Nikolaidis[64]	223 - 1.44 x A
Gelbart (1)[75]	186 + 0.25 x RHR - 0.13 x BM
Gelbart (2)[75]	164 + 0.27 x RHR - 0.155 x BM + 1.1 x METs + 0.258 x BF
Mahon[71]	158 + 0.44 x RHR + 0.68 x Age

A, age; RHR, resting heart rate; BM, body mass (kg); METs, metabolic equivalents; BF, body fat %

20mSRT

As previously described in the methods section of Chapter III.

Statistical Analysis

Descriptive statistics (mean ± SD) were calculated for all variables. Data were screened for outliers using boxplots, and normality was assessed through visual inspection of histograms and quantile–quantile (Q–Q) plots.

PART A: Maximal Heart Rate

An independent samples t-test was used to compare HRmax and total shuttles completed between male and female students. The relations between measured HRmax, total shuttles, BMI, and body fat percentage (BF%) were assessed using Pearson's product–moment correlation coefficient (r), stratified by gender. The magnitude of correlation coefficients was interpreted as very weak ($r < 0.1$), weak ($0.1 \leq r < 0.3$), moderate ($0.3 \leq r < 0.5$), large ($0.5 \leq r < 0.7$), very large ($0.7 \leq r < 0.9$), nearly perfect ($0.9 \leq r < 1$), and perfect ($r = 1$).[389]

The accuracy and variability of the PHRM equations were assessed using Bland–Altman analysis overall and stratified by gender and fitness quartile. Linear regression analyses were conducted to determine the presence of proportional bias in predicted versus measured values.

PART B: Submaximal Responses

Total shuttle quartiles were calculated to categorise participants into sex-specific groups: bottom 25%, below average, above average, and top 25%. A mixed multivariate analysis of covariance (MANCOVA) was conducted to examine main effects and interactions involving two between-subjects factors (sex and 20mSRT quartile) and five within-subjects variables (resting HR, heart rate recovery [HRR], HRmax, HR at level 1, and HR at level 2 of the 20mSRT), while controlling for BF% as a continuous covariate.

A second mixed MANCOVA was performed to examine %HRmax and %HRR, assessing main effects and interactions across quartile categories at each stage of the 20mSRT. This model included two between-subjects factors (sex and fitness quartile) and two within-subjects factors (level 1 and level 2 of the 20mSRT), with BF% included as a covariate. Where significant main effects or interactions were identified, Bonferroni-adjusted post hoc analyses were applied to control for multiple comparisons.

Regression

A simple linear regression was conducted using HR at level 2 (HR@L2) as the independent variable to examine its ability to explain variance in 20mSRT performance, defined as total shuttles completed. A backward stepwise multiple regression was then performed, incorporating anthropometric variables and HR@L2 as predictors, to evaluate their combined ability to explain performance in the 20mSRT.

Multicollinearity among independent variables was assessed using tolerance values and variance inflation factors (VIF). The dataset was randomly split (50:50) to enable cross-validation, and predictive accuracy was evaluated using the root mean squared error. All statistical analyses were conducted using SPSS for Windows (version 28.0; IBM Corp., Armonk, NY, USA). Statistical significance was set at $p < 0.05$.

RESULTS

PART A: PHRM

Due to technical issues with the Polar Team Pro 2 heart rate telemetry system, measured HRmax values were available for 428 of the 540 participants. Accordingly, the PHRM analysis was conducted on 79% of the total cohort (n = 428), with a mean age of 13.0 ± 0.4 years.

Participant anthropometric and 20mSRT characteristics are presented in Table 7.2. With the exception of BF%, no significant differences were observed in anthropometric variables between male and female participants. However, male students completed a significantly greater number of shuttle runs compared with female students.

Table 7.2: Participants' anthropometric characteristics and total number of shuttles performed during the 20mSRT

		Sex	
	Combined	**Female**	**Male**
N	428	188	240
Age (y)	13.0±0.4	13.0±0.4	13.0±0.4
Height (cm)	159.±8.0	158.0±6.9	160.2±8.7
Weight (kg)	51.3±12.4	51.2±11.8	51.3±13.0
BMI ($kg \cdot m^{-2}$)	20.0±3.9	20.3±3.9	19.8±3.8
BMI percentile	56.4±29.7	58.0±28.9	55.3±30.3
Body fat (%)	19.7±8.3	24.4±7.2	16.0±7.3*
Waist (cm)	68.8±10.0	68.6±9.3	68.9±10.5
Hip (cm)	87.8±10.4	89.2±9.9	85.6±10.6
Waist-to-hip	0.79±0.06	0.77±0.05	0.80±0.05
Waist-to-height	0.43±0.06	0.43±0.07	0.43±0.06
20mSRT (n)	51.1±23.1	41.2±17.8	58.7±23.9*

Values presented are means ± SD; *p<0.001 v female. BMI: Body Mass Index; 20mSRT, 20 metre shuttle run test.

Heart Rate

The distribution, mean, median, and interquartile range (IQR) of measured HRmax in male and female participants are presented in Figure 7.1. The mean HRmax attained during

the 20mSRT was 202.4 ± 8.2 b·min^{-1} (range: 82–214 b·min^{-1}). There was no significant difference in measured HRmax between male (202.5 ± 6.7 b·min^{-1}) and female (202.7 ± 6.6 b·min^{-1}) first-year students (p = 0.67).

A significant positive relation was observed between measured HRmax, and total shuttle runs completed during the 20mSRT in both males (r = 0.148, p < 0.05) and females (r = 0.214, p < 0.001). In females only, weak but significant inverse correlations were observed between HRmax and both BF% (r = −0.165, p < 0.05) and BMI (r = −0.152, p < 0.05), whereas no significant associations were found in males.

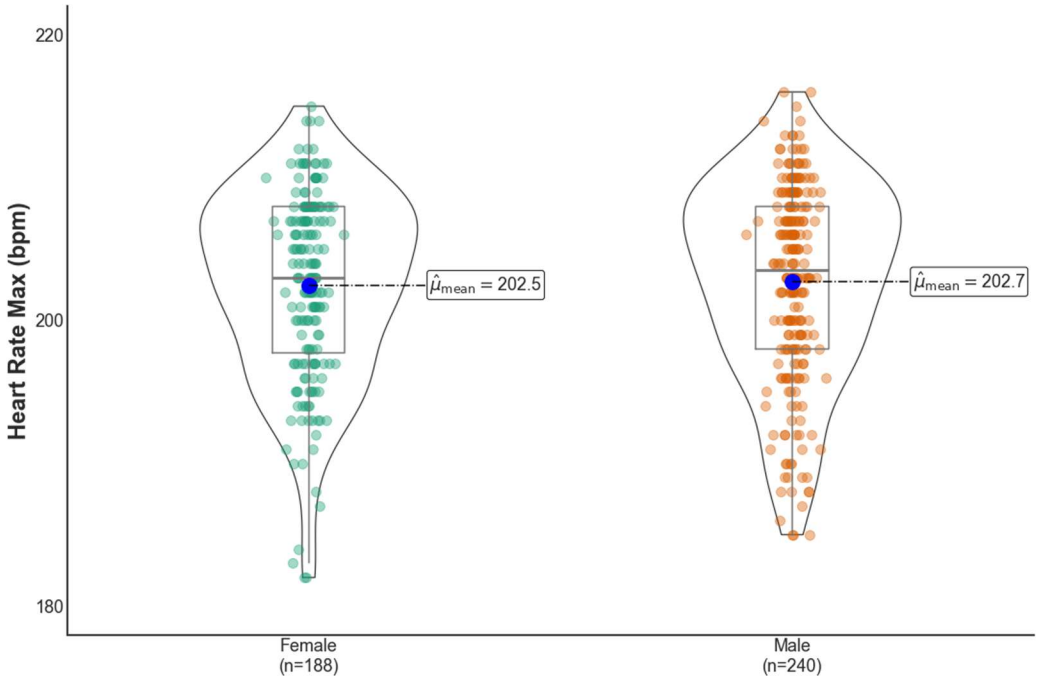


Figure 7.1: *Distribution, mean, median and IQR for HR_{max} among male and female participants*

PHRM Equations

Boxplots illustrating the range, IQR, and outliers for HRmax values in the entire cohort (n = 428), both measured during the 20mSRT and predicted using six different equations, are presented in Figure 7.2.

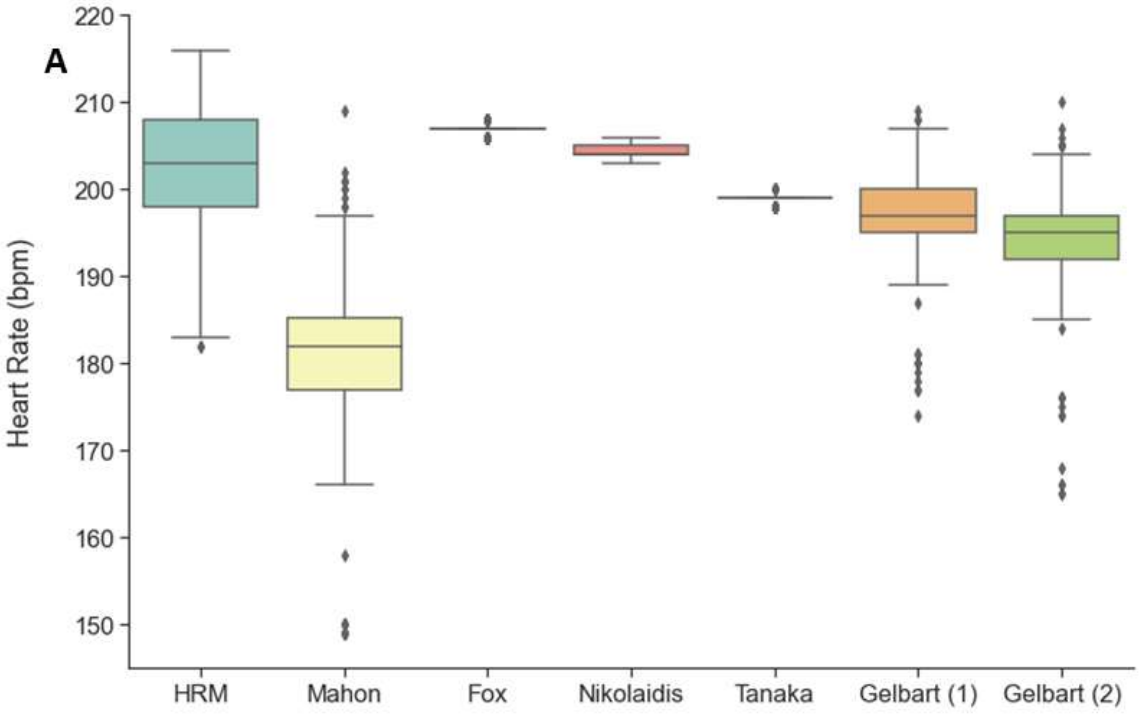


Figure 7.2: *Box plot, IQR range and outliers of measured HR_{max} and 6 PHRM equations for all male and female participants*

Table 7.3 summarises the percentage of participants achieving a HR ≥95% of PHRM based on each of the six equations, alongside the mean difference between measured HRmax and PHRM. The Pearson correlation coefficients describing the relationship between measured HRmax and PHRM for each equation, as well as the standard error of the estimate (SEE), are also presented.

Although statistically significant, the correlations between measured HRmax during the 20mSRT and HRmax estimated using the Gelbart 1 ($r = 0.13$, $p < 0.05$) and Gelbart 2 ($r = 0.16$, $p = 0.05$) equations were weak. No significant relations were observed between measured HRmax and PHRM derived from the Fox, Tanaka, Nikolaidis, or Mahon equations.

Table 7.3: Agreement between measured and age-predicted HR_{max} and the percentage of students attaining a HR_{max} ≥95% of the PHRM in Irish first-year post-primary students during the 20mSRT

	PHRM (b·min^{-1})	≥95% PHRM (%)	Difference (b·min^{-1})	Pearson Correlation Coefficient (r)	SEE of PHRM (b·min^{-1})
Fox	207.0±0.5	88	4.4±6.8	0.059	9.6
Tanaka	198.9±0.3	96	-3.7±6.8	0.033	8.1
Nikolaidis	204.3±0.7	89	1.7±6.8	0.054	4.5
Gelbart (1)	197.1±4.9	98	-5.5±7.7	0.13*	8.0
Gelbart (2)	195.0±5.7	99	-8.0±8.0	0.16*	11.0
Mahon	181.1±9.1	100	-21.5±10.4	0.092	24.7

Values presented are means ± SD. PHRM, predicted heart rate maximum; SEE, standard error of the estimate. * $p<0.05$

The difference between measured HRmax and PHRM derived from each of the six equations is illustrated using Bland-Altman plots for the entire cohort (Figure 7.3). Although mean PHRM values were broadly comparable to measured HRmax, there was considerable variability in prediction accuracy, as evidenced by the dispersion and proportional bias observed in the regression slopes.

At lower measured HRmax values, the Fox, Tanaka, and Nikolaidis equations tended to overestimate HRmax, whereas the Gelbart (1 and 2) and Mahon equations demonstrated a more balanced pattern of over- and underestimation across the range of values. Overall, the SEE for PHRM varied substantially between equations, ranging from 4.5 b·min^{-1} (Nikolaidis) to 24.7 b·min^{-1} (Mahon) (Table 7.3).

Regression models examining the difference between measured HRmax and PHRM derived from the Fox (β = −0.989, t = −138.322, p < 0.001), Tanaka (β = −0.996, t = −226.263, p < 0.001), Nikolaidis (β = −0.980, t = −102.328, p < 0.001), Gelbart 1 (β = −0.372, t = −8.261, p < 0.001), Gelbart 2 (β = −0.217, t = −4.592, p < 0.001), and Mahon (β = 0.239, t = 5.075, p < 0.001) equations were all statistically significant, indicating the presence of systematic magnitude bias in all PHRM-derived estimates of measured HRmax.

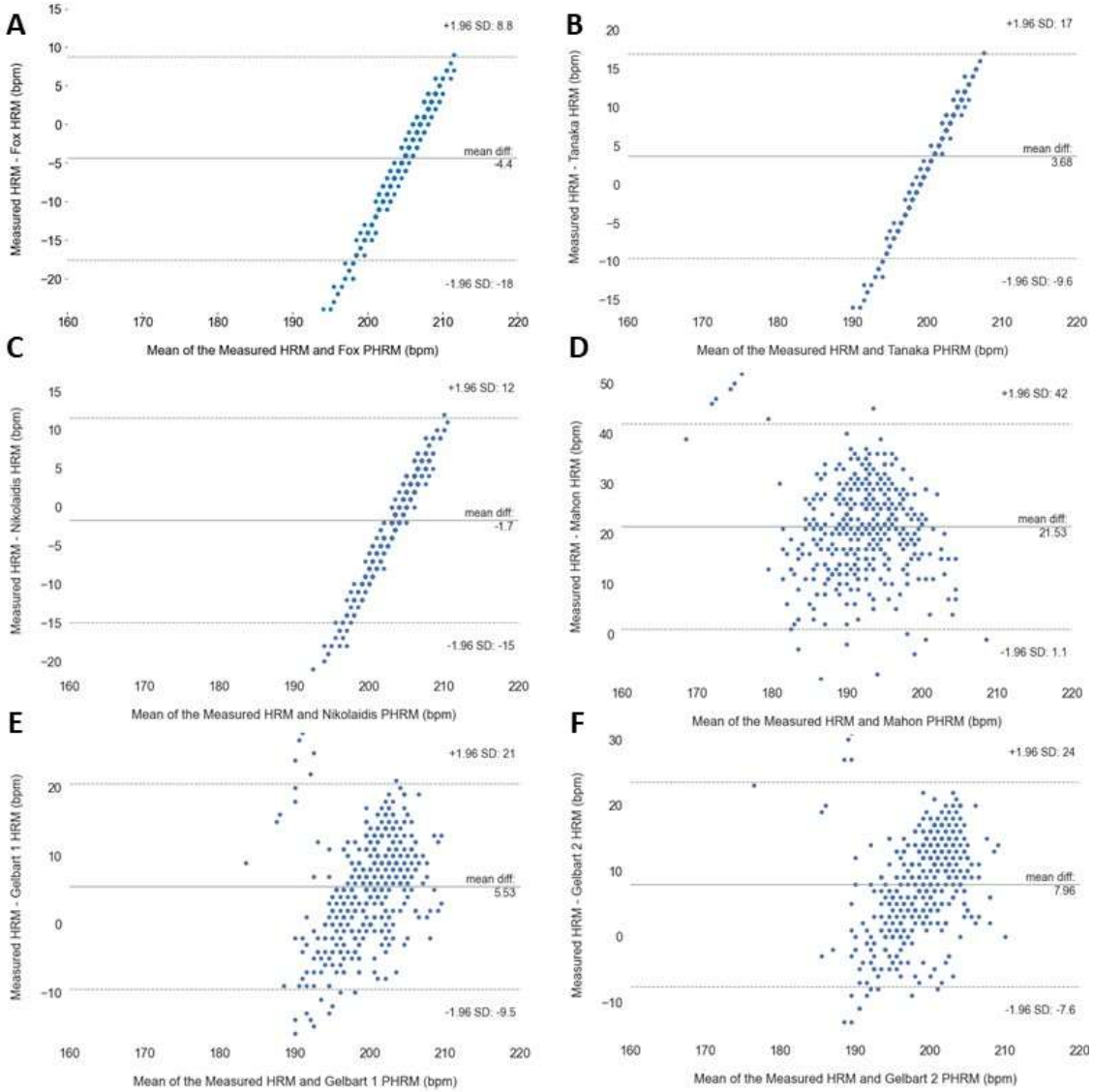


Figure 7.3A-F*: Bland-Altman plots depicting limits of agreement between measured HRmax values and PHRM based on each of the six equations; Fox (7.3A), Tanaka (7.3B), Nikolaidis (7.3C), Mahon (7.3D), Gelbart 1 (7.3E), Gelbart 2(7.3F).*

Part B: Submaximal HR Responses

Suitable data files for submaximal heart rate analysis were available for 330 participants. Selected anthropometric characteristics for the entire cohort are summarised in Table 7.4. With the exception of BF%, no significant differences were observed in anthropometric variables between male and female participants.

Table 7.4: Participants anthropometric characteristics for submaximal analysis

		Sex	
	Combined	**Female**	**Male**
N	330	136	194
Age (y)	13.0±0.4	12.9±0.4	13.0±0.4
Height (cm)	158.9±8.0	158.0±7.0	160.0±8.5
Weight (kg)	50.5±11.8	49.9±10.7	50.9±12.6
BMI ($kg \cdot m^{-2}$)	19.8±3.5	19.9±3.3	19.8±3.6
BMI percentile	55.7±29.6	56.5±29.0	55.2±30.0
Body fat %	19.0±7.8	23.7±6.6	15.7±6.8*
Waist (cm)	68.5±9.4	69.0±7.8	67.8±10.4
Hip (cm)	86.7±10.2	88.6±10.9	85.3±9.0
Waist-to-hip	0.79±0.06	0.77±0.05	0.80±0.05
Waist-to-height	0.43±0.06	0.43±0.07	0.43±0.06

Values presented are means ± SD; * p<0.001 v female. BMI: Body Mass Index

To account for beat-to-beat variability and potential signal noise from the heart rate sensor, HR data were averaged over the final 10 s of each stage and compared between male and female participants. The results are summarised in Table 7.5. Females exhibited significantly higher resting HR (RHR), HR, %HRmax, and %HRR than males at both level 1 and level 2 of the 20mSRT ($p < 0.001$).

Table 7.5: RHR, Average HR, %HR_{max} and HRR during levels 1, 2 and 3 of the 20mSRT

Heart Rate Response	Female	Male	P Value	T test statistic
	N=136	N=194		
Resting Heart Rate ($b \cdot min^{-1}$)	75.5±12.2	70.0±12.1	<0.001	-4.086
Heart Rate ($b \cdot min^{-1}$)				
Level 1	173.8±11.4	166.3±13.1	<0.001	-5.486
Level 2	189.6±9.6	180.9±12.6	<0.001	-7.061
Heart Rate Maximum (%)				
Level 1	85.3±5.4	81.5±5.8	<0.001	-6.125
Level 2	93.1±4.3	88.7±5.5	<0.001	-8.093
Heart Rate Reserve (%)				
Level 1	76.9±8.2	72.0±8.6	<0.001	-5.140
Level 2	89.2±6.3	82.9±8.2	<0.001	-7.680

Values presented are means ± SD; RHR, resting heart rate; HR, heart rate; 20mSRT 20m shuttle run test

20mSRT - Quartiles

On average, male students completed 19.1 more shuttle runs than female students (61.0 ± 17.0 vs 41.9 ± 23.2, $p < 0.001$). Quartile ranges for total shuttle runs completed during the 20mSRT were calculated separately for males and females and are summarised in Table 7.6.

Table 7.6: Total number of 20mSRT shuttles associated with each quartile

	Male	Female
Bottom 25 %	<45	<29
Below Average	45-57	29-35
Above Average	58-76	36-53
Top 25 %	>76	>53

Figure 7.4A and Figure 7.4B summarises the count for 20mSRT level achieved across quartiles for male and female students.

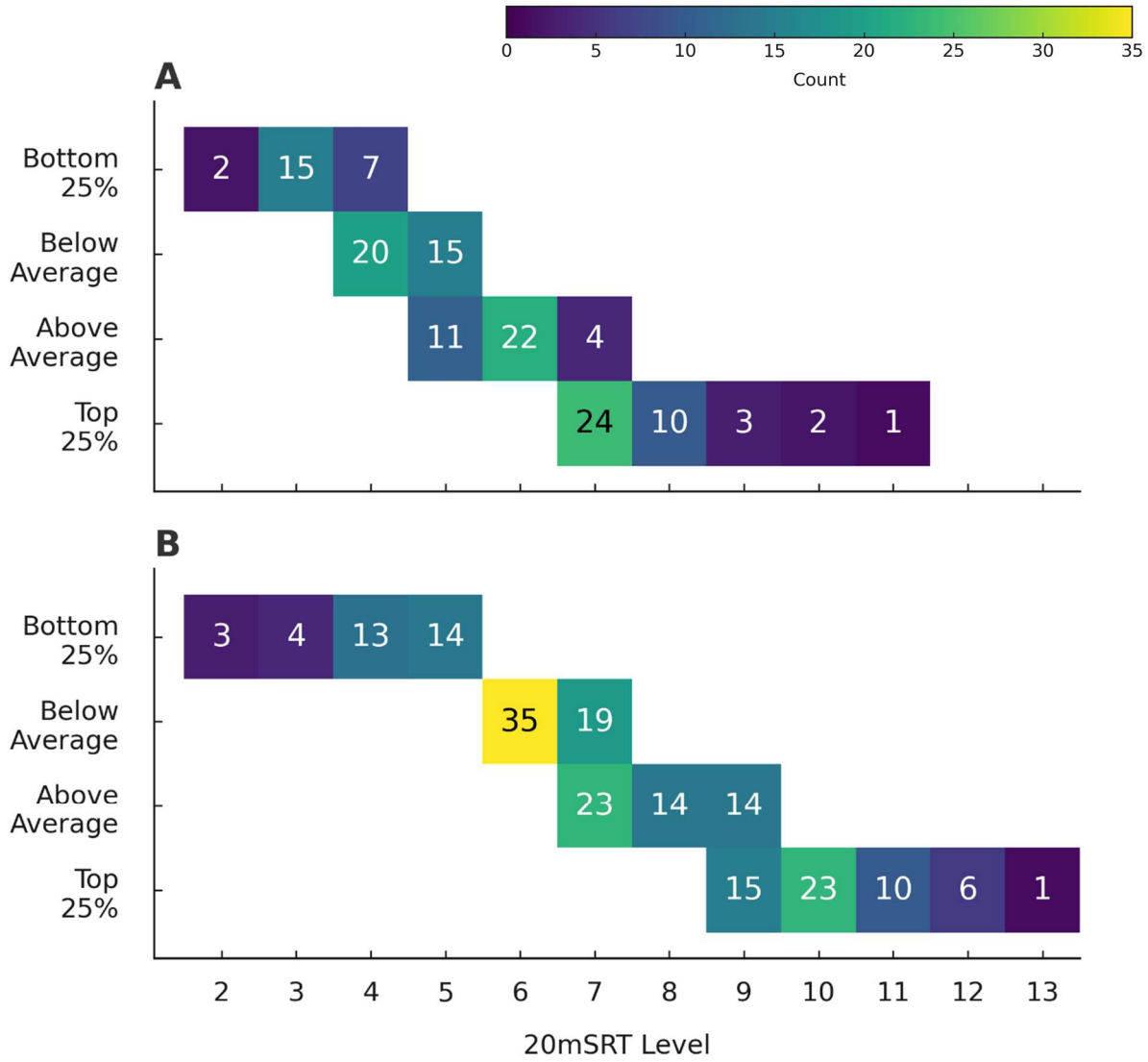


***Figure 7.4A-B**: The count of the number female (A) and male (B) participants and their final level achieved in the 20mSRT for each 20mSRT quartile.*

20mSRT - HR response

The mean RHR, HRmax, and HRR, stratified by fitness quartile, along with mean HR, %HRmax, and %HRR at levels 1 and 2 of the 20mSRT, are summarised in Table 7.7. Absolute HR responses across selected timepoints for females and males before, during, and after the 20mSRT, stratified by fitness quartile, are illustrated in Figures 7.5A-B.

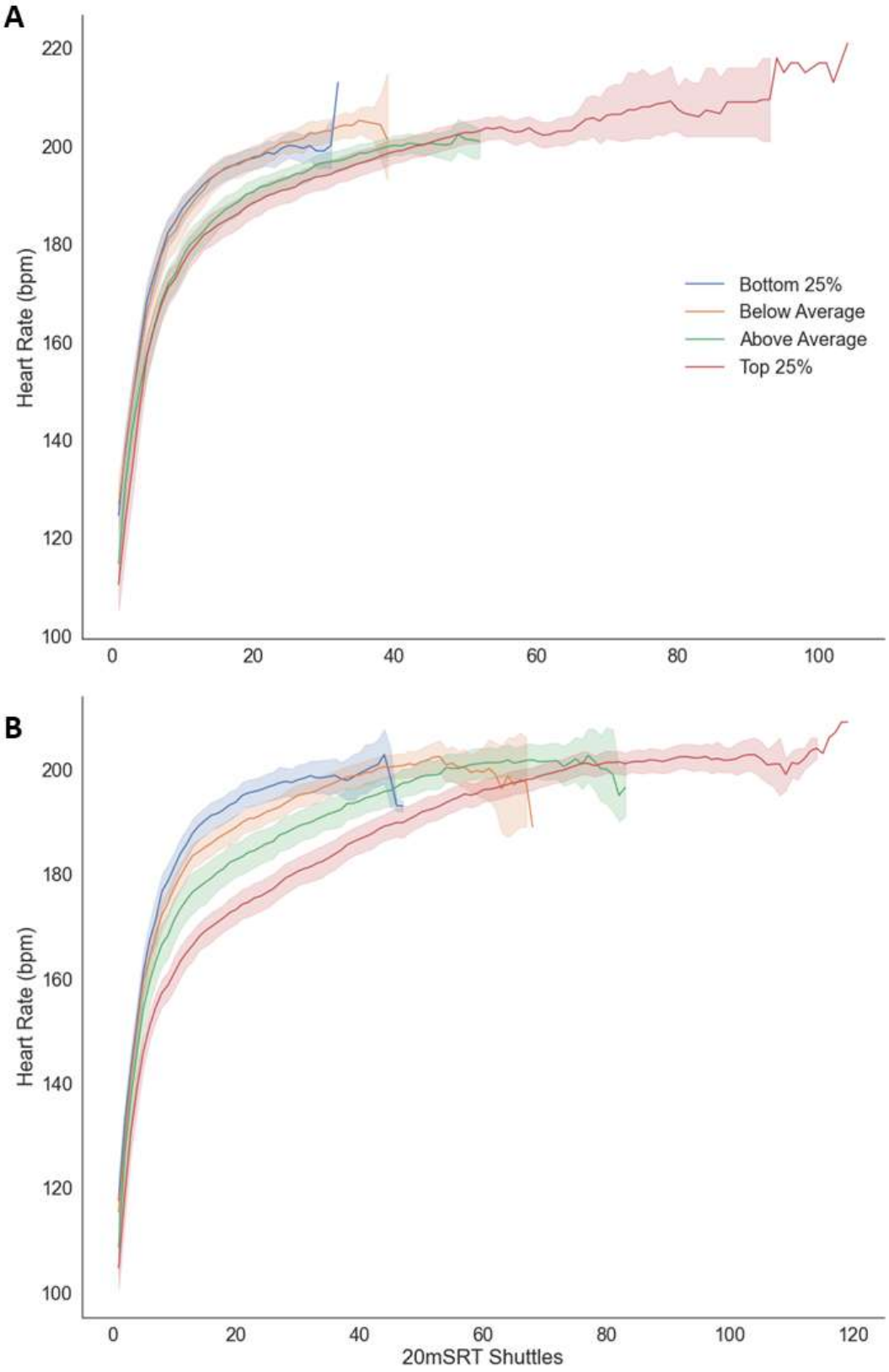


Figure 7.5A-B: *Mean HR at each shuttle for female (A) and male (B) participants in the 20mSRT categorised by fitness quartile*

A statistically significant sex × quartile interaction was observed for RHR, $F(3,305) = 3.778$, $p = 0.011$, partial $\eta^2 = 0.036$, and HR at level 2 (HR@L2), $F(3,305) = 3.173$, $p = 0.025$, partial $\eta^2 = 0.003$. No significant interaction effects were observed for HRmax, HRR, or HR at level 1 (HR@L1). A significant main effect of sex was observed for HRR, $F(1,305) = 13.189$, $p < 0.001$, partial $\eta^2 = 0.045$, and HR@L1, $F(1,305) = 33.598$, $p < 0.001$, partial $\eta^2 = 0.099$, while controlling for BF% (18.5%). No significant sex effect was observed for HRmax. A significant main effect of 20mSRT quartile was also observed for HRR, $F(3,305) = 20.318$, $p < 0.001$, partial $\eta^2 = 0.167$, HRmax, $F(3,305) = 3.933$, $p = 0.009$, partial $\eta^2 = 0.037$, and HR@L1, $F(3,305) = 32.545$, $p < 0.001$, partial $\eta^2 = 0.242$.

Resting Heart Rate

RHR was significantly lower ($p < 0.05$) in females classified in the “above average” and “top 25%” quartiles compared with those in the “bottom 25%”. No significant differences in RHR were observed across quartiles in males.

HR_{max}

HRmax was significantly lower ($p < 0.05$) in females in the “bottom 25%” compared with those in the “top 25%” quartile. No significant differences in HRmax were observed across quartiles in males.

Absolute Heart rate

For females, mean HR during the final 10 s of levels 1 and 2 was significantly lower in the “top 25%” compared with the “below average” and “bottom 25%” groups ($p < 0.001$). Females in the “above average” group also demonstrated significantly lower HR than the

"bottom 25%" at both levels ($p < 0.05$) and lower HR than the "below average" group at level 2 ($p < 0.05$).

For males, mean HR during the final 10 s of levels 1 and 2 was significantly lower in the "top 25%" compared with the "bottom 25%" and "below average" groups ($p < 0.001$). The "top 25%" group also demonstrated significantly lower HR than the "above average" group at level 1 ($p < 0.05$) and level 2 ($p < 0.001$).

%HR_{max} (20mSRT)

Among females, %HRmax during levels 1 and 2 was significantly lower in the "top 25%" compared with the "above average" ($p < 0.001$), "below average" ($p < 0.001$), and "bottom 25%" ($p < 0.05$) groups. The "above average" group demonstrated significantly lower %HRmax than the "bottom 25%" at level 1 ($p < 0.05$) and lower values than both the "below average" and "bottom 25%" at level 2 ($p < 0.001$).

Among males, %HRmax was significantly lower in the "top 25%" compared with all other quartiles at both levels ($p < 0.001$). The "above average" group also demonstrated lower %HRmax than the "below average" ($p < 0.05$) and "bottom 25%" ($p < 0.001$) at level 1, and lower values than both groups at level 2 ($p < 0.001$).

Relative HRR

For females, %HRR during level 2 was significantly lower in the "top 25%" compared with the "above average", "below average", and "bottom 25%" groups ($p < 0.001$). The "above average" group also demonstrated lower %HRR than the "below average" ($p < 0.05$) and "bottom 25%" ($p < 0.001$).

For males, %HRR was significantly lower in the “top 25%” compared with all other quartiles at both levels ($p < 0.001$). The “above average” group also showed significantly lower %HRR compared with the “below average” ($p < 0.05$) and “bottom 25%” ($p < 0.001$) at level 1, with larger differences observed at level 2 ($p < 0.001$).

Table 7.7: Absolute and relative HR characteristics categorised by 20mSRT quartile for female and male participants

	Female				Male			
	Bottom 25%	**Below Average**	**Above Average**	**Top 25%**	**Bottom 25%**	**Below Average**	**Above Average**	**Top 25%**
	N=40	N=30	N=35	N=32	N=45	N=54	N=45	N=49
RHR ($b \cdot min^{-1}$)	76.5312.2	81.0±13.0	70.9±9.7[e]	72.6±12.4[e]	73.0±10.4	67.9±10.1	68.6±12.0	69.7±13.1
HR_{max} ($b \cdot min^{-1}$)	201.6±6.2	205.2±6.4	203.8±7.0	206.5±7.3[d]	201.9±6.3	204.7±7.1	204.4±7.7	205.2±6.0
HR reserve	123.4±11.5	124.2±14.2	132.3±12.2[d]	133.9±13.5[d,e]	127.9±12.5	136.8±11.7[d]	135.8±13.0[d]	135.5±13.2[d]
HR ($b \cdot min^{-1}$)								
Level 1	180.0±10.3	177.2±11.1	172.2±10.5[d]	165.8±11.1[a,b]	174.8±11.1	170.7±10.7	164.0±14.2[a,e]	156.4±10.0[a,b,f]
Level 2	194.5±7.5	194.5±7.4	186.7±8.1[d,e]	182.1±10.1[a,b]	190.5±8.3	186.0±9.6	178.0±10.9[a,b]	170.1±10.2[a,b,c]
%HR maximum								
Level 1	89.5±4.6	83.4±5.0[d]	84.5±3.7[a]	80.3±4.4[a,b,d]	86.6±4.6	83.4±3.7[d]	80.2±5.9[a,e]	76.2±4.2[a,b,c]
Level 2	96.8±2.7	94.8±2.4[d]	91.6±2.6[a,b]	88.2±3.6[a,b,c]	94.3±2.8	90.9±2.8[a]	87.0±4.1[a,b]	83.0±4.1[a,b,c]
%HR reserve								
Level 1	82.9±4.6	77.3±8.1[d]	75.8±6.8[a,e]	69.7±5.4[a,b,f]	78.8±7.0	75.0±5.4[d]	70.2±8.2[a,e]	63.9±6.4[a,b,c]
Level 2	94.8±4.3	91.2±4.3[d]	87.0±4.3[a,b]	81.8±4.6[a,b,c]	91.1±4.3	86.3±4.2[a]	80.5±5.6[a,b]	82.9±4.1[a,b,c]

Values presented are means ± SD; [a] $p<0.001$ v Bottom 25%, [b] $p<0.001$ v Below Average, [c] $p<0.001$ v Above Average, [d] $p<0.05$ v Bottom 25%, [e] $p<0.05$ v Below Average, [f] $p<0.05$ v Above Average

Predicting 20mSRT Performance

HR@L2 was inversely associated with 20mSRT performance, accounting for 48% of the variance in total shuttles completed ($R^2 = 0.48$, $p < 0.001$), indicating that higher heart rate responses at level 2 were associated with lower aerobic capacity.

Tables 7.8 and 7.9 summarise the multiple linear regression analyses examining physiological and anthropometric predictors of total shuttles completed during the 20mSRT. The dataset was randomly split (50:50), with half used for model training and half for validation testing. A backward stepwise regression approach was applied, initially including all measured anthropometric and heart rate variables. Non-significant predictors were sequentially removed, and variables exhibiting multicollinearity (VIF > 5) were excluded from the final model.

The final model retained four significant predictors: BF%, HR@L2, hip circumference, and grip strength, collectively explaining 61% of the variance in 20mSRT performance, $F(13, 142) = 60.861$, $p < 0.001$. Regression coefficients (Table 7.8) indicated that BF% ($B = -0.605$, $p = 0.013$), HR@L2 ($B = -1.057$, $p < 0.001$), hip circumference ($B = -0.651$, $p = 0.006$), and grip strength ($B = 0.660$, $p = 0.006$) all contributed significantly to the model.

The resulting predictive equation was:

Total shuttles = 306.429 − (0.605 × BF% × 100) − (1.057 × HR@L2) − (0.651 × hip circumference) + (0.660 × grip strength)

Table 7.8: Regression model summary

	Adjusted *R* squared	**Standard Error of the Estimate**	***F***	**p**
Training Set	.607	13.9	60.861	p<.001
Test Set	.583	15.3		

Table 7.9: Regression model variables

	Model Characteristics					Collinearity statistics	
Variable	***B***	**SE(B)**	β	***t***	**p**	**Tolerance**	**VIF**
Total shuttles (constant)	306.4	25.544		11.99	.001		
Heart Rate – Level 2	-0.605	0.115	-0.528	-9.22	<0.001	0.774	1.291
Body Fat %	-1.057	0.242	-0.197	-2.50	.013	0.410	2.436
Hip Circumference	-0.651	0.206	-0.246	-3.16	0.002	0.417	2.399
Grip	0.660	0.236	0.160	2.80	0.006	0.778	1.291

The regression model was validated using an independent test set, with an explained variance of 58.3%, representing a 3.4% reduction compared with the training dataset. This modest decrease in R^2, alongside a slight increase in the SEE from 13.9 to 15.3, may indicate a small degree of overfitting in the training model.

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DISCUSSION

Historically, attainment of a proportion of age-adjusted HRmax has been used as an objective criterion to confirm maximal or near-maximal effort during incremental exercise testing. The most widely used prediction model in exercise science is the Fox equation (HRmax = 220 − age).[388] However, evidence from a systematic review of youth-specific prediction equations indicates that the Tanaka equation (208 − 0.7 × age) provides a more appropriate alternative, demonstrating reduced bias and lower prediction error compared with the Fox equation.[63]

HR was not routinely recorded by teachers during the SFC. However, in the present thesis, a subsample of 188 female and 230 male first-year students wore HR monitors during the 20mSRT. Subsequent analyses in Study 5 indicated that mean HRmax attained during the test was within ±4 beats of values predicted using the Fox equation. Using the Tanaka equation, approximately 96% of participants achieved ≥95% PHRM during the 20mSRT. Collectively, these findings suggest that the majority of first-year students likely achieved near-maximal effort, supporting the validity of the 20mSRT as a maximal field-based test in this cohort.

Higher RHR and submaximal HR responses observed in females were consistent with established physiological sex differences, as females typically demonstrate higher resting HR and lower stroke volume during exercise compared with males. [390,391] Accordingly, the higher HR, %HRmax, and %HRR observed among females at levels 1 and 2 of the 20mSRT likely reflect both these physiological differences and their lower mean shuttle-run performance in the present sample.[264,392]

A key limitation of the 20mSRT is that, despite being a progressive test to volitional exhaustion, it provides no objective mechanism to confirm whether maximal effort has been achieved by all participants.[24,44] Consequently, performance reflects not only CRF but also motivation, pacing strategies, tolerance of discomfort, and understanding of the test protocol.[379] In school-based group settings, additional contextual factors such as social facilitation or inhibition may further influence performance.[393,394] These effects may vary according to confidence, body image, peer dynamics, and perceived competence, potentially introducing measurement error and bias around performance cut-points.[44,394]

The 20mSRT was a central component of this thesis. While widely used and well established as a field-based assessment of CRF, informal feedback from teachers and students who declined participation in Studies 3 and 4 suggested that the test itself may represent a barrier to engagement. The test is typically conducted in a socially evaluative environment and requires maximal effort, which may elicit anxiety, discomfort, and reduced self-esteem, particularly among students with low perceived competence or body image concerns[382] Survey evidence supports this concern, with the majority of PE teachers reporting that fitness testing should be included in the curriculum, however, 60% of the respondents also noted that the anxiety associated with fitness testing may negatively influence students' psychological well-being.[381]

The 20mSRT protocol may also impose excessive physiological strain for youth with low baseline CRF. Ideally, assessments of aerobic fitness should involve a gradual increase from low intensity to maximal effort over approximately 8-12 minutes. In contrast, analyses from this thesis indicated that by the end of level 1, participants in the lowest fitness quartile were already exercising at approximately 87-90% of HRmax, compared with ≤80% in the

highest quartile. By level 2, HR responses in the lowest quartile approached maximal values, indicating substantial early physiological strain. It is therefore likely that these students also experienced high perceived exertion early in the test, which may negatively impact motivation and inclination to engage in future testing.

At present, there are no universally accepted recommendations for modified field-based protocols for assessing CRF in youth. Some studies have proposed adaptations to the 20mSRT, including reductions in initial running speed (e.g., 4.0 $km \cdot h^{-1}$),[395] shorter shuttle distances[396] or modified protocols using the Léger prediction equation to estimate $\dot{V}O_2max$.[23] Such approaches may help reduce early physiological strain and improve accessibility for low-fit individuals, while retaining the capacity to assess higher-fit participants.

Submaximal testing methods offer a pragmatic alternative, typically associated with lower discomfort and improved feasibility in primary school settings.[387] The linear relation between HR and $\dot{V}O_2$ during graded exercise provides the physiological basis for predicting aerobic capacity from submaximal responses. HR data were available for approximately 60% of participants up to level 2 of the 20mSRT. HR at level 2 alone explained 48% of the variance in total shuttle performance, with lower HR responses associated with higher aerobic capacity. This finding is consistent with previous literature demonstrating strong associations between submaximal HR responses and $\dot{V}O_2max$ in youth populations.[397,398]

The addition of BF%, hip circumference, and grip strength to HR at level 2 increased explained variance to approximately 60%. Higher adiposity (BF% and hip circumference) was associated with poorer performance, reflecting known negative effects of excess adiposity on aerobic efficiency and movement economy.[399,400] In contrast, grip strength contributed

positively to performance, consistent with evidence linking muscular strength with overall health and aerobic fitness in children and adolescents.[401]

Cross-validation of the predictive model demonstrated similar performance between training and test datasets, indicating good generalisability and only minimal overfitting. This approach is consistent with prior research using split-sample validation to predict aerobic capacity in youth.[33,397,402] Collectively, these findings support the utility of early-stage submaximal HR responses as scalable predictors of aerobic performance in school-based settings.

Kasai et al. (2024)[387] previously proposed a submaximal adaptation of the 20mSRT using RPE to guide test termination. Their findings demonstrated that terminating the test at RPE 7 provided a valid and reliable estimate of $\dot{V}O_2$peak in children and adolescents, with extrapolated values not significantly different from laboratory-based measures.[387] However, this work was limited by a small sample size and controlled laboratory conditions. Future research should explore the feasibility of integrating HR and RPE-guided submaximal protocols in authentic school environments, potentially incorporating slower initial running speeds and more gradual stage progression to reduce early physiological strain.

Overall, the present findings demonstrate marked differences in physiological responses across fitness quartiles, with lower-fit participants exhibiting substantially higher HR at equivalent running velocities. These results highlight that the current 20mSRT protocol may not adequately accommodate individual differences in fitness, potentially limiting both physiological validity and psychological acceptability in school-based settings. Collectively,

Study 5 supports the potential value of adapting the 20mSRT to better balance measurement validity, participant experience, and inclusivity in adolescent populations.

Overall Summary

Cardiorespiratory fitness (CRF) is an integrative measure of an individual's capacity to transport oxygen from the atmosphere to the mitochondria, reflecting the coordinated function of the cardiovascular, respiratory, haematological, and muscular systems.[38] In youth, higher levels of CRF are consistently associated with reduced cardiometabolic risk,[401] improved cognitive function,[403] and lower adiposity, independent of PA levels.[404] Longitudinal evidence further indicates that CRF tracks from childhood into adulthood and is a significant predictor of non-communicable diseases, including CVD and T2DM.[338] Despite these well-established benefits, population-level data indicate a global decline in youth CRF over recent decades, raising significant public health concerns.[43] Accordingly, the assessment and promotion of CRF during childhood and adolescence represents both a scientific priority and a societal imperativev.[38]

The present thesis examined CRF and vascular health among Irish first-year post-primary students, with particular emphasis on socioeconomic status (SES) disparities and the effectiveness of school-based interventions. Schools represent a critical setting for health promotion, given their sustained engagement with adolescents throughout key developmental years.

Across five interconnected studies, consistent evidence demonstrated that students attending DEIS Schools -an indicator of lower SES - exhibited significantly lower CRF compared with peers in non-DEIS and fee-paying schools. Studies 1 and 3 identified clear SES gradients in 20mSRT performance and vascular health, with lower CRF and higher PWV observed in DEIS students, particularly males. These findings highlight early emergence of health inequalities in cardiovascular risk profiles during adolescence.

Study 2 demonstrated that a national six-week school-based PA intervention produced an overall 11% improvement in 20mSRT performance across participating schools, with the greatest gains observed in students with the lowest baseline CRF. This suggests that school-based interventions can be particularly effective for the least fit adolescents.

However, Study 4 showed that a shorter four-week, games-based intervention delivered within a DEIS school setting produced only modest and non-significant improvements in CRF, vascular health, body composition, and blood pressure. This contrast highlights the importance of intervention dose, including duration, intensity, and exercise prescription, in eliciting meaningful physiological adaptations.

Study 5 further extended these findings by demonstrating the limitations of current maximal field-based testing approaches and highlighting the potential value of submaximal physiological indicators for improving CRF assessment and interpretability in school settings. Collectively, these findings emphasise that while school-based interventions can positively influence CRF - particularly among lower-fit students -programme design and testing protocols require refinement to optimise both engagement and physiological impact.

Overall, the thesis demonstrates that CRF disparities are already evident in early adolescence and are socially patterned by SES. While short-term school-based interventions can produce meaningful improvements in some contexts, more sustained, structured, and context-sensitive approaches are required to maximise health outcomes. These findings have important implications for public health policy and suggest that targeted, school-based strategies are essential for reducing long-term cardiovascular risk and health inequalities.

Limitations

Study 1 and 2

- A key limitation was the absence of individual-level date of birth and anthropometric data. Without precise age (in months) and relevant covariates (e.g., body size or maturation proxies), it was not possible to apply GAMLSS modelling to generate age-adjusted centile curves that account for non-linear growth trajectories and distributional skewness. Consequently, derived estimates may be less precise across the adolescent age range and may not fully reflect developmental heterogeneity.
- There was no formal standardisation or audit of 20mSRT administration across schools. Teacher adherence to protocol could not be verified, and inter- or intra-rater reliability was not assessed. Although written guidance was provided, the absence of formal training or competency checks may have introduced variability in test administration, including differences in encouragement, pacing fidelity, and environmental conditions, thereby increasing measurement error.
- RPE, which are often used alongside physiological markers to support confirmation of maximal effort, were not collected. This decision was made to minimise burden on teachers and preserve feasibility within timetabled PE lessons. However, the absence of RPE limits the ability to triangulate maximal effort, meaning that psychological factors influencing test termination could not be systematically assessed.
- The cross-sectional design of parts of the analysis also limits causal inference regarding determinants of CRF.
- Furthermore, in the intervention component, individual-level linkage between baseline and follow-up 20mSRT data was not possible. As a result, paired within-subject analyses

could not be conducted, and baseline and post-intervention samples were treated as independent groups. Although class-level balancing was used to reduce bias, unmeasured individual differences and selection effects may still have influenced outcomes, reducing statistical power and limiting inference to group-level change.

- Finally, the machine learning models did not include post-hoc interpretability analyses (e.g., feature importance, SHAP values), limiting insight into the relative contribution of individual- versus school-level predictors and restricting translation into targeted policy recommendations.

Study 3 and 5

- A key limitation was the absence of maturity status assessment. Given that biological maturation significantly influences CRF, body composition, and performance during adolescence, observed sex and group differences may be partially confounded by inter-individual variation in maturation timing. As a result, some of the observed associations may reflect developmental stage rather than behavioural or physiological differences alone.
- In addition, assessments were conducted during timetabled PE classes at varying times of day. This introduced potential diurnal and post-prandial variability in performance, which may have increased measurement noise and attenuated between-group differences. However, this also enhances ecological validity by reflecting real-world school conditions.

Study 4

- The primary limitation of Study 4 was the relatively short intervention duration. The protocol was originally designed as a six-week programme (as per the ethics application) but was reduced to four weeks due to school-term logistical constraints, including the time required to complete baseline testing, deliver the intervention, conduct post-testing, and subsequently offer the programme to the control group within the same term. Consequently, the opportunity to bring about measurable adaptations in outcomes that typically require longer exposure (e.g., CRF, adiposity and vascular indices) may have been limited, and modest or null effects should be interpreted within the context of a real-world implementation window.

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APPENDICES

Appendix A – Risk Assessment

Laboratory Assessments - SCHOOL-BASED ASSESSMENT

Prepared by: Kevin O'Brien

Date: (dd/mm/yyyy) 04/02/2021

Review date:

School/Unit/Faculty name: School of Health and Human Performance (SHHP)

Groups affected: Staff, postgraduate researchers, research participants, INTRA students x2

Hazards	Is the Hazard present? Y/N	What is the risk?	Controls - Controls in place to reduce risks	Is the control in place? Y/N	Likelihood	Severity	Risk Rating (L x S)	L/M/H	Control measure(s) to be put in place	By whom	By date
3. cIMT Measurement The researcher must place an ultrasound probe on the artery in the participants neck and identify the bulb of the carotid artery, and take a measurement.	Y	The risk is the virus being transmitted between researcher and participant as it is not possible to maintain physical distancing while preparing for & administering the test	Participants will be directed to look to the opposite side during the measurement	Y	2	4	8	M			
4. Arterial Stiffness Measurement The researcher must place an 4 blood pressure cuffs on the arm, leg and neck of the participant.	Y	The risk is the virus being transmitted between researcher and participant as it is not possible to maintain physical distancing while preparing the participant for the test, however it is possible during the test.	The participant will be asked to look in the opposite direction during the set up for this measurment.	Y	2	4	8	M			
5. Grip Strength The participants are required to squeeze a handheld unit to ascertain maximal grip strength.	Y	The risk is the virus being transmitted from the unit to the researcher / next participant	Participants will be instructed to reset the unit themselves between measurements & researchers will sanitise it before the next participant	Y	2	4	8	M			

Appendix B – The Data Scientist's Toolbox



JOHNS HOPKINS UNIVERSITY

COURSE CERTIFICATE

Apr 13, 2021

Kevin O'Brien

has successfully completed

The Data Scientist's Toolbox

an online non-credit course authorized by Johns Hopkins University and offered through Coursera

Jeff Leek, PhD; Roger Peng, PhD; Brian Caffo, PhD
Department of Biostatistics
Johns Hopkins Bloomberg School of Public Health

EDUCATION FOR EVERYONE · coursera · COURSE CERTIFICATE

Verify at:
coursera.org/verify/7NC9UB8TLBF4

Coursera has confirmed the identity of this individual and their participation in the course.

This certificate does not affirm that this learner was enrolled as a student at Johns Hopkins University. It does not confer a JHU grade, course credit or degree; establish a relationship between this learner and JHU; enroll or register this learner at JHU or in any course offered by JHU; or entitle this learner to access or use resources beyond the online courses provided by Coursera.

Appendix C – Managing Big Data with MySQL



Duke
UNIVERSITY

COURSE
CERTIFICATE

Apr 22, 2020

Kevin O'Brien

has successfully completed

Managing Big Data with MySQL

an online non-credit course authorized by Duke University and offered through Coursera

EDUCATION FOR EVERYONE
coursera
COURSE CERTIFICATE

Daniel Egger
Executive in Residence and Director,
Center for Quantitative Modeling
Pratt School of Engineering

Jana Schaich Borg
Assistant Research Professor
Social Science Research Institute

Verify at:
coursera.org/verify/3KQRK24NWAX6

Coursera has confirmed the identity of this individual and their participation in the course.

Appendix D – Foundations: Data, Data, Everywhere



Google

COURSE CERTIFICATE

Apr 7, 2021

Kevin O'Brien

has successfully completed

Foundations: Data, Data, Everywhere

an online non-credit course authorized by Google and offered through Coursera

Google

EDUCATION FOR EVERYONE · coursera · COURSE CERTIFICATE

Verify at:
coursera.org/verify/X2L4KCN4LY42

Coursera has confirmed the identity of this individual and their participation in the course.

Appendix E - UCD Professional Academy – Specialist Certificate



Appendix F: DCUREC/2018/208

Dublin City University
RESEARCH ETHICS
COMMITTEE

APPLICATION FOR APPROVAL OF A PROJECT INVOLVING
HUMAN PARTICIPANTS

Application No. *(office use only)* DCUREC/2018/**208**

Please read the following information carefully before completing your application. Failure to adhere to these guidelines will make your submission ineligible for review.

- **Applications must be e-mailed to the DCU Research Ethics Committee at rec@dcu.ie** –no hardcopy required.
- **Student applicants must cc their supervisor on that e-mail** – this applies to all masters by research and PhD students. The form should be checked, approved and signed by the supervisor in advance of submission to REC. ***NB – Taught Masters and Undergraduate students apply for ethical review via their local review panels, not via REC.***
- **The application should consist of one electronic file only,** with an electronic signature from the PI. The completed application must incorporate all supplementary documentation, especially that being given to the proposed participants. It must be proofread and spellchecked before submission to the REC.
- **All sections of the application form must be answered as instructed and within the word limits given.**

Applications which do not adhere to all of these requirements will not be accepted for review and will be returned directly to the applicant.

Applications must be completed on the form; answers in the form of attachments will not be accepted, except where indicated. No hardcopy applications will be accepted. **Research must not commence until written approval has been received from the Research Ethics Committee.**

Note: If your research requires approval from the Biosafety Committee (BSC), or review by the School of Nursing and Human Sciences Ethics Advisory Committee (SNHSEAC), this must be in place prior to REC submission. Please attach the responses from these committees to this submission as directed below.

PROJECT TITLE	A retrospective evaluation of the changes in cardiorespiratory fitness levels in response to a 6-week exercise intervention among post-primary school students between 2013 -2018
PRINCIPAL INVESTIGATOR(S) *The named Principal Investigator is the person with primary responsibility for the research project. In the case of Taught Masters projects the supervisor is the Principal Investigator.*	Dr Sarah Kelly, Dr Bróna Furlong and Prof Niall M. Moyna
START AND END DATE	01.10.18 to 31.12.19
	Full review

Please confirm that all supplementary information is included in your application (in electronic copy). If questionnaire or interview questions are submitted in draft form, please indicate this by putting (draft) after YES. A copy of the final documentation must be submitted for final approval when available.

	My application has been collated as one electronic file which includes the following documentation:	INCLUDED (mark as YES)	NOT APPLICABLE (mark as N/A)
	Bibliography		N/A
	Recruitment advertisement		N/A
	Plain language statement/Information Statement		N/A
	Informed Consent form		N/A
	Personal Data Security Schedule		N/A
	Evidence of external approvals related to the research		N/A
	Questionnaire/Survey		N/A
	Interview/Focus Group Questions		N/A
	Debriefing material		N/A
	Other (e.g. BSC approval, SNHSEAC review letter)		N/A

Please note:

1. Any amendments to the original approved proposal must receive prior REC approval.
2. As a condition of approval investigators are required to document and report immediately to the Secretary of the Research Ethics Committee any adverse events, any issues which might negatively impact on the conduct of the research and/or any complaint from a participant relating to their participation in the study

1. ADMINISTRATIVE DETAILS

PROJECT TYPE: (mark Y to as many as apply)	Research Project	Y	Funded Consultancy	…
			Clinical Trial	…
	Student Research Project (please indicate level, e.g. PhD/MSc Research)	…	Other - Please Describe:	…
	PhD / Other Doctorate	Y		
	MSc Research	…		

1.1 INVESTIGATOR CONTACT DETAILS

PRINCIPAL INVESTIGATOR(S): *Doctoral researchers and Research Masters or their supervisors may be listed as Principal Investigators, depending on the conventions of the discipline and on the individual case. It should be made clear, in subsequent sections of this application, who is carrying out the research procedures.*

NAME	*SCHOOL/UNIT*	*EMAIL*
Dr. Sarah Kelly	Health and Human Performance	sarah.kelly@dcu.ie
Dr. Bróna Furlong	Health and Human Performance	brona.furlong@dcu.ie
Prof. Niall Moyna	Health and Human Performance	niall.moyna@dcu.ie

OTHER INVESTIGATORS:

NAME	*SCHOOL/UNIT*	*EMAIL*
Dr. Andrew McCarron	School of Computing	Andrew.mccarron@dcu.ie
Dr Mark Roantree	School of Computing	Mark.roantree@dcu.ie
Kevin O'Brien	Health and Human Performance	Kevin.obrien7@mail.dcu.ie

1.2 WILL THE RESEARCH BE UNDERTAKEN ON-SITE AT DUBLIN CITY UNIVERSITY?

YES or NO
Yes

1.3 IS THIS PROTOCOL BEING SUBMITTED TO ANOTHER ETHICS COMMITTEE, OR HAS IT BEEN PREVIOUSLY SUBMITTED TO AN ETHICS COMMITTEE?

YES or NO
NO

DECLARATION BY PRINCIPAL INVESTIGATOR(S)

The information contained herein is, to the best of my knowledge and belief, accurate. I have read the University's current research ethics guidelines, and accept responsibility for the conduct of the procedures set out in the attached application in accordance with the form guidelines, the REC guidelines (https://www.dcu.ie/researchsupport/researchethics.shtml), the University's policy on Conflict of Interest, Code of Good Research Practice and any other condition laid down by the Dublin City University Research Ethics Committee. I have attempted to identify all risks related to the research that may arise in conducting this research and acknowledge my obligations and the rights of the participants.

If there exists any affiliation or financial interest for researcher(s) in this research or its outcomes or any other circumstances which might represent a perceived, potential or actual conflict of interest this should be declared in accordance with Dublin City University policy on Conflicts of Interest.

I and my co-investigators or supporting staff have the appropriate qualifications, experience and facilities to conduct the research set out in the attached application and to deal with any emergencies and contingencies related to the research that may arise.

Electronic Signature(s):

Principal investigator(s):
Print Name(s) here: *Sarah Kelly* *Bróna Furlong* *Niall Moyna*

Date: 3-10-18

2. PROJECT OUTLINE

2.1 LAY DESCRIPTION *(Approx. 300 words)*

Please outline, in terms that any non-expert would understand, what your research project is about, including what participants will be required to do. Please explain any technical terms or discipline-specific phrases.

This study will retrospectively examine changes in cardiorespiratory fitness levels from data collected during the Irish Life Health Schools Fitness Challenge, between 2012 and 2018. It will also develop standardised test scores in boys and girls between the age of 12 and 18. Prof Niall Moyna and Dr Sarah Kelly from the School of Health and Human Performance established the Schools Fitness Challenge in 2012. To date 172,000 tests have been completed.

2.2 AIMS OF AND JUSTIFICATION FOR THE RESEARCH *(Approx. 400 words)*

State the aims and significance of the project. Where relevant, state the specific hypothesis to be tested. Please provide a brief description of background research, a justification as to why this research project should proceed in that context and an explanation of any expected benefits to the community. NB – all references cited should be listed in an attached bibliography.

Cardiovascular disease (CVD) is the leading cause of death in Ireland. Cardiorespiratory fitness (CRF) represents the capacity of the heart and lungs to transport oxygen around the body and is a powerful marker of cardiovascular health. Children and adolescents with higher levels of CRF have a more favourable cardiovascular profile and a reduced risk of myocardial infarction, stroke, and mortality later in adulthood. Levels of CRF tend to track from childhood to adolescence, as well as from adolescence to adulthood.

The 20-m shuttle run test (20 m SRT) is the most widely used test to estimate CRF in children and youth. It is low cost, easy to administer and can be used to test large groups of children simultaneously. To date, the 20 m SRT has been used to measure CRF in children and youth in more than 50 countries across six continents. A major barrier to the adoption of CRF testing to evaluate cardiovascular health in adolescents is the absence of evidence-based age and sex specific clinical cut points.

The aim of this study is to retrospectively examine the temporal changes in cardiorespiratory fitness levels among Irish youth (12 – 18 years) and to develop age- and sex-specific standardised fitness norms.

2.3 DESCRIBE THE METHODOLOGY BEING USED TO ACHIEVE YOUR STATED AIMS

Provide an outline of the proposed method and state who is doing which task – include details of data collection techniques, the tasks participants will be asked to do, the estimated time commitment involved, and how data will be analysed. If the project includes any procedure which is beyond already established and accepted techniques please include a description of it. There should be enough detail provided to facilitate ethical review, but applicants are encouraged to keep it as succinct as possible.

Cardiorespiratory changes will be analysed year by year based on school children's age and gender. Dr Mark Roantree (data controller) manages the database and is responsible for the safe storage of the anonymised data. Dr Andrew McCarron will oversee the statistical analysis of the project. Data will be analysed in R programming language. An outlier detection algorithm will be ran on the data. Descriptive statistics will be calculated for all

- PARTICIPANT PROFILE

Provide the number, age range and source of participants. Please provide a justification of your proposed sample size. Please provide a justification for selecting a specific gender, age, or any other group if this is done in your project.

No participants are being recruited for this study. Between 2012 and 2018 teachers submitted 172,000 anonymous 20-MST results including age and gender. This study will examine already captured data on fitness levels made available to Irish Life Health and DCU. No subject identifying information will be available the researcher. Any information at an individual level cannot be identified.

2.4(a) PARTICIPANT VULNERABILITY

Are some or all of participants vulnerable in any way? (e.g by virtue of the group they belong to, people who have undergone traumatic or adverse emotional events, people with diminished cognitive ability, power relations between researchers and participants etc.)? If they are, state what this vulnerability (or vulnerabilities) is and justify why this research is being done with such participants.

N//A

2.4(b) CHILD PARTICIPANTS (anyone under 18 years old)

*If your participants include children, you **must** confirm that you are in compliance with the research specific guidelines as detailed in "Keeping Children Safe - Policies and Procedures supporting Child Protection at DCU" - available at: https://www4.dcu.ie/sites/default/files/policy/157%20-%20child_protection_handbook_rev1%282%29%281%29.pdf*

Please indicate your compliance with the following guidelines:	Mark here
We confirm that we have read and agree to act in accordance with the DCU Child Protection policy and procedures	**YES**
We confirm that we have put in place safeguards for the children participating in the research	**YES**
We confirm that we have supports in place for children who may disclose current or historical abuse (whether or not this is the focus of the research)	**YES**

2.1 EXPLAIN HOW PARTICIPANTS ARE TO BE RECRUITED

Please provide specific details as to how you will be recruiting participants. How will people be informed that you are doing this research? How will they be approached and asked if they are willing to participate? If you are mailing or phoning people, please explain how you have obtained their names and contact details. If a recruitment advertisement is to be used, please ensure you attach a copy to this application.

There are no participants being recruited.

2.2 PLEASE EXPLAIN WHEN, HOW, WHERE, AND TO WHOM RESULTS WILL BE DISSEMINATED, INCLUDING WHETHER PARTICIPANTS WILL BE PROVIDED WITH ANY INFORMATION AS TO THE FINDINGS OR OUTCOMES OF THE PROJECT?

The results will be published in peer reviewed publications and conference presentations. The identity of the individual schools/classes will remain anonymous. Information, as a group, will only be presented.

2.1 ARE OTHER APPROVALS REQUIRED TO GAIN ACCESS TO ANOTHER LOCATION, ORGANISATION ETC.?

YES or NO
NO

2.2 HAS A SIMILAR PROPOSAL BEEN PREVIOUSLY APPROVED BY THE DCU REC?

YES or NO
NO

3.1 JUSTIFICATION OF STATED LEVEL OF RISK TO RESEARCH PARTICIPANTS

You must provide a justification for the stated level of risk, as indicated on the cover page of your application. Note that the level of risk may be influenced by the vulnerability of the research group, the methods employed and the nature of the research itself. For further information on risk levels, please refer to the Levels of Review information on the website: https://www.dcu.ie/researchsupport/researchethics.shtml

There are no participants being recruited for this study.

3.2 DOES THE RESEARCH INVOLVE:

	YES or NO
• use of a questionnaire? (attach copy)?	
• interviews (attach interview questions)?	NO
• observation of participants without their knowledge?	NO
• participant observation (provide details in section 2)?	NO
• audio- or video-taping interviewees or events?	NO
• access to personal and/or confidential data (including student, patient or client data) without the participant's specific consent?	NO
• administration of any stimuli, tasks, investigations or procedures which may be experienced by participants as physically or mentally painful, stressful or unpleasant during or after the research process?	NO
• performance of any acts which might diminish the self-esteem of participants or cause them to experience embarrassment, regret or depression?	NO
• investigation of participants involved in illegal activities?	NO
• procedures that involve deception of participants?	NO
• administration of any substance or agent?	NO
• use of non-treatment of placebo control conditions?	NO
• collection of body tissues or fluid samples?	NO
• collection and/or testing of DNA samples?	NO
• participation in a clinical trial?	NO
• administration of ionising radiation to participants?	NO

3.3 POTENTIAL RISKS TO PARTICIPANTS AND RISK MANAGEMENT PROCEDURES

Identify, as far as possible, all potential risks to participants (physical, psychological, social, legal, economic, etc.), associated with the proposed research. Please explain what risk management procedures will be put in place to minimise these risks.

N/A

3.4 ARE THERE LIKELY TO BE ANY BENEFITS (DIRECT OR INDIRECT) TO PARTICIPANTS FROM THIS RESEARCH?

YES or NO
NO

3.5 ARE THERE ANY SPECIFIC RISKS TO RESEARCHERS?

3.1 DEALING WITH ADVERSE/UNEXPECTED OUTCOMES

Please describe what measures/protocols you have put in place in the event that there are any unexpected outcomes or adverse effects to participants arising from involvement in the project.

N/A

3.2 HOW WILL THE CONDUCT OF THE PROJECT BE MONITORED?

Please explain how the principal investigator will monitor the conduct of the project (especially where several people are involved in recruiting or interviewing, administering procedures, etc.) to ensure that it conforms with the procedures set out in this application. In the case of student projects please give details of how the supervisor(s) will monitor the conduct of the project.

The principal investigators will be involved in all aspects of data analysis and interpretation. The data controller Dr Mark Roantree will manage data storage.

3.3 SUPPORT FOR PARTICIPANTS

Depending on risks to participants you may need to consider having additional support for participants during/after the study. Consider whether your project would require additional support, e.g., external counselling available to participants. Please advise what support will be available.

NO

3.4 DO YOU PROPOSE TO OFFER PAYMENTS OR INCENTIVES TO PARTICIPANTS?

YES or NO
N/A

3.5 DO ANY OF THE RESEARCHERS ON THIS PROJECT HAVE A PERSONAL, PHILOSOPHICAL, FINANCIAL OR COMMERCIAL INTEREST IN ITS OUTCOME THAT MIGHT INFLUENCE THE INTEGRITY OF THE RESEARCH, OR BIAS THE CONDUCT OR REPORTING OF THE RESEARCH, OR UNDULY DELAY OR OTHERWISE AFFECT THEIR PUBLICATION?

YES or NO
NO

supporting staff have in carrying out the research and in dealing with any emergencies, unexpected outcomes, or contingencies that may arise. ***State specifically who will be carrying out the research procedures***

- Dr. Sarah Kelly is an exercise physiologist and has extensive experience in cardiovascular research including the assessment of vascular health and function through ultrasonography and exercise testing
- Prof. Niall Moyna is an exercise physiologist and has extensive experience in cardiovascular research, phlebotomy and exercise testing
- Dr. Bróna Furlong is an exercise physiologist and has extensive experience in cardiovascular research including the assessment of vascular health and function through ultrasonography and exercise testing
- Dr Andrew McCarron is a statistician in the School of Computing.
- Dr Mark Roantree is a data controller in the School of Computing.
- Kevin O'Brien, BSc. Sport Science and Health, is a PhD student in the school of Health and Human Performance. Kevin has extensive experience assessing athletes, school children and adults in laboratory and field-based tests. Kevin has experience analysing large excel databases from previous employment in Institute of Technology Carlow, and his time working as a conditioning coach with Tennis Ireland. Kevin was awarded the "Outstanding Researcher of the Year" in 2005 for his undergraduate thesis.

5. CONFIDENTIALITY/ANONYMITY

5.1 WILL THE IDENTITY OF THE PARTICIPANTS BE PROTECTED?

YES or NO
YES

IF YOU ANSWERED YES TO 5.1, PLEASE ANSWER THE FOLLOWING QUESTIONS:

5.2 HOW WILL THE ANONYMITY OF THE PARTICIPANTS BE RESPECTED?

Please bear in mind that where the sample size is very small, it may be impossible to guarantee anonymity/confidentiality of participant identity. Participants involved in such projects need to be advised of this limitation in the Plain Language Statement/Information Sheet. If you intend to fully anonymize the data, please provide details

Teachers submitted individual results as a group, therefore no individual data is possible to access. Each class submitted is given an ID Code and that code along with the schools roll number is stored on a password protected computer in the School of Computing, accessed to solely by Dr Mark Roantree.

5.3 LEGAL LIMITATIONS TO DATA CONFIDENTIALITY

Participants need to be made aware that confidentiality of information provided cannot always be guaranteed by researchers and can only be protected within the limitations of the law - i.e., it is possible for data to be subject to subpoena, freedom of information claim or mandated reporting by some professions. This information should be included in your Plain Language Statement and Informed Consent Form. Depending on the research proposal and academic discipline, you may need to state additional specific limitations.

State how and where participants will be informed of these limitations

Personal data is data relating to a living individual (i.e. the 'Data Subject') who is, or can be, identified either from the data itself or from the data in conjunction with other information that is in, or is likely to come into, the possession of the 'Data Controller' (i.e. DCU and its constituent units e.g. research teams etc.). ***Further information on personal data is available from the DCU Data Protection Unit at https://www.dcu.ie/ocoo/dp/guides.shtml***

6.1 IS PERSONAL DATA BEING PROCESSED AS PART OF THIS PROJECT?

YES or NO
NO

If YES, Please indicate your compliance with the following guidelines:	Mark here
We confirm that we have read and agree to act in accordance with DCU Data Protection Unit guidance and procedures regarding personal data	YES
We confirm that we have put in place a Personal Data Security Schedule (PDSS) for the project and have attached it to this application	YES

Please see the GDPR and the Research Ethics Process section of the REC main webpage for guidance

IF YOU ANSWERED YES TO 6.1, PLEASE ANSWER THE FOLLOWING QUESTIONS:

6.2 WHAT KIND OF PERSONAL DATA IS BEING PROCESSED?

Note special categories of personal data include health data, genetic data and/or data relating to ethnicity/race of participants, their sex lives and/or sexual orientation

No personal data is being processed

6.3 WILL ANONYMISATION/PSEUDONYMISATION OF THE PERSONAL DATA BE UNDERTAKEN?

YES or NO
YES

For the purpose of this section, "Data" includes that in a raw or processed state (e.g. interview audiotape, transcript or analysis). "Samples" include body fluids or tissue samples.

7.1 HOW AND WHERE WILL THE DATA/SAMPLES BE STORED?

Note that the REC recommends that all data be stored on campus – please justify any off-site storage.

Data for this study will kept indefinitely. These will serve as normative cardiorespiratory fitness data for Irish adolescents.

7.2 WHO WILL HAVE ACCESS TO DATA/SAMPLES?

If people other than the main researchers have access, please name who they are and explain for what purpose.

The principal investigators and the data controller (Dr Mark Roantree).

7.3 HOW LONG IS THE DATA TO BE HELD/RETAINED FOR?

Note that with very few exceptions ***personal data*** *may not be retained indefinitely. It is up to the unit or research team to establish an upper retention limit for each category of personal data under its control.*

No personal identifiable data will be collected or stored.

7.4 IF DATA/SAMPLES ARE TO BE DISPOSED OF, PLEASE EXPLAIN HOW, WHEN AND BY WHOM THIS WILL BE DONE?

Note that simply deleting files is not sufficiently secure. The additional steps to be taken to maintain data security should be given. ***Personal data*** *must be disposed of in a safe and secure manner at the end of its retention period. If the data is stored in a: a) paper based format then shredding or disposal via a secure bin is recommended; or b) if it is stored in an electronic based format then deletion of the record or full anonymization of the data is recommended.If data/samples are NOT being disposed of, please justify this decision.*

N/A

8.1 HOW IS THIS WORK BEING FUNDED?

School of Health and Human Performance

8.2 PROJECT GRANT NUMBER *(If relevant and/or known – otherwise mark as N/A)*

N/A

8.3 DOES THE PROJECT REQUIRE APPROVAL BEFORE CONSIDERATION FOR FUNDING BY A GRANTING BODY?

YES or NO
NO

8.4.1 HOW WILL PARTICIPANTS BE INFORMED OF THE SOURCE OF THE FUNDING? *(e.g. included in the Plain Language Statement)*

N/A

8.5 DO THE FUNDERS OF THIS PROJECT HAVE A PERSONAL, FINANCIAL OR COMMERCIAL INTEREST IN ITS OUTCOME THAT MIGHT COMPROMISE THE INDEPENDENCE AND INTEGRITY OF THE RESEARCH, OR BIAS THE CONDUCT OR REPORTING OF THE RESEARCH, OR UNDULY DELAY OR OTHERWISE AFFECT THEIR PUBLICATION?

YES or NO
NO

Appendix G: Female and male 20mSRT performance categorized by year

Female 20mSRT Year by Year Comparisons

Year 1	Year 2	Mean Diff	Std. Error	p	95% Confidence Interval for Difference Lower Bound	Upper Bound
2012	2013	-0.199	0.446	1.000	-1.556	1.157
	2014	-2.491*	0.447	0.000	-3.849	-1.133
	2015	-2.061*	0.462	0.000	-3.464	-0.658
	2016	-4.281*	0.444	0.000	-5.631	-2.931
	2017	-5.447*	0.419	0.000	-6.719	-4.175
	2018	-6.512*	0.445	0.000	-7.865	-5.159
2013	2014	-2.292*	0.443	0.000	-3.636	-0.947
	2015	-1.862*	0.458	0.001	-3.252	-0.471
	2016	-4.081*	0.440	0.000	-5.418	-2.744
	2017	-5.247*	0.414	0.000	-6.505	-3.990
	2018	-6.313*	0.441	0.000	-7.653	-4.973
2014	2015	0.430	0.458	1.000	-0.962	1.822
	2016	-1.790*	0.440	0.001	-3.128	-0.452
	2017	-2.956*	0.414	0.000	-4.215	-1.697
	2018	-4.021*	0.441	0.000	-5.362	-2.680
2015	2016	-2.220*	0.456	0.000	-3.604	-0.835
	2017	-3.386*	0.431	0.000	-4.694	-2.078
	2018	-4.451*	0.457	0.000	-5.838	-3.064
2016	2017	-1.166	0.412	0.097	-2.417	0.085
	2018	-2.232*	0.439	0.000	-3.565	-0.898
2017	2018	-1.066	0.413	0.207	-2.320	0.188

Male 20mSRT Year by Year Comparisons

Year 1	Year 2	Mean Diff	Std. Error	p	95% Confidence Interval for Difference Lower Bound	95% Confidence Interval for Difference Upper Bound
2012	2013	1.333	0.463	0.085	-0.075	2.741
	2014	1.092	0.460	0.367	-0.304	2.489
	2015	-0.223	0.482	1.000	-1.687	1.241
	2016	-1.318	0.468	0.102	-2.739	0.104
	2017	-1.970*	0.460	0.000	-3.367	-0.572
	2018	0.157	0.481	1.000	-1.304	1.619
2013	2014	-0.240	0.427	1.000	-1.539	1.058
	2015	-1.556*	0.451	0.012	-2.927	-0.186
	2016	-2.650*	0.436	0.000	-3.975	-1.325
	2017	-3.302*	0.428	0.000	-4.602	-2.003
	2018	-1.176	0.450	0.189	-2.543	0.192
2014	2015	-1.316	0.447	0.069	-2.674	0.043
	2016	-2.410*	0.432	0.000	-3.723	-1.097
	2017	-3.062*	0.424	0.000	-4.349	-1.775
	2018	-0.935	0.446	0.759	-2.291	0.421
2015	2016	-1.094	0.456	0.344	-2.479	0.290
	2017	-1.746*	0.448	0.002	-3.106	-0.386
	2018	0.380	0.469	1.000	-1.045	1.806
2016	2017	-0.652	0.433	1.000	-1.966	0.662
	2018	1.475*	0.455	0.025	0.093	2.856
2017	2018	2.127*	0.447	0.000	0.770	3.484

Appendix H: DCUREC/2018/209

Dublin City University
RESEARCH ETHICS COMMITTEE

APPLICATION FOR APPROVAL OF A PROJECT INVOLVING **HUMAN PARTICIPANTS**

Application No. *(office use only)* DCUREC/2018/209

Please read the following information carefully before completing your application. Failure to adhere to these guidelines will make your submission ineligible for review.

- **Applications must be e-mailed to the DCU Research Ethics Committee at rec@dcu.ie** –no hardcopy required**.**
- **Student applicants must cc their supervisor on that e-mail** – this applies to all masters by research and PhD students. The form should be checked, approved and signed by the supervisor in advance of submission to REC. ***NB – Taught Masters and Undergraduate students apply for ethical review via their local review panels, not via REC.***
- **The application should consist of one electronic file only,** with an electronic signature from the PI. The completed application must incorporate all supplementary documentation, especially that being given to the proposed participants. It must be proofread and spellchecked before submission to the REC**.**
- **All sections of the application form must be answered as instructed and within the word limits given.**

Applications which do not adhere to all of these requirements will not be accepted for review and will be returned directly to the applicant.

Applications must be completed on the form; answers in the form of attachments will not be accepted, except where indicated. No hardcopy applications will be accepted. **Research must not commence until written approval has been received from the Research Ethics Committee.**

Note: If your research requires approval from the Biosafety Committee (BSC), or review by the School of Nursing and Human Sciences Ethics Advisory Committee (SNHSEAC), this must be in place prior to REC submission. Please attach the responses from these committees to this submission as directed below.

PROJECT TITLE	**Cardiorespiratory Fitness Levels Associated with Increased Cardiovascular Disease Risk and Asymptomatic Cardiovascular Disease in Irish Adolescents**
PRINCIPAL INVESTIGATOR(S)	Dr Sarah Kelly, Dr Brona Furlong, Prof Niall Moyna
START AND END DATE	01.11.18 to 31.12.22
LEVEL OF RISK	Full review

Please confirm that <u>all</u> supplementary information is included in your application (in electronic copy). If questionnaire or interview questions are submitted in draft form, please indicate this by putting (draft) after YES. A copy of the final documentation must be submitted for final approval when available.

My application has been collated as one electronic file which includes the following documentation:	**INCLUDED (mark as YES)**	**NOT APPLICABLE (mark as N/A)**
Bibliography	YES	
Recruitment Advertisement	YES	
Plain language statement/Information Statement	YES	
Informed Consent Form	YES	
Personal Data Security Statement	YES	
Evidence of external approvals related to the research		N/A
Questionnaire/Survey		N/A
Interview/Focus Group Questions		N/A
Debriefing material		N/A
Other (BSc approval, SNHSEAC review letter)		N/A

Please note:

1. Any amendments to the original approved proposal must receive prior REC approval.

2. As a condition of approval investigators are required to document and report immediately to the Secretary of the Research Ethics Committee any adverse events, any issues which might negatively impact on the conduct of the research and/or any complaint from a participant relating to their participation in the study.

Dublin City University
RESEARCH ETHICS COMMITTEE

APPLICATION FOR APPROVAL OF A PROJECT INVOLVING **HUMAN PARTICIPANTS**

Application No. *(office use only)* DCUREC/2018/209

Please read the following information carefully before completing your application. Failure to adhere to these guidelines will make your submission ineligible for review.

- **Applications must be e-mailed to the DCU Research Ethics Committee at rec@dcu.ie** –no hardcopy required**.**

- **Student applicants must cc their supervisor on that e-mail** – this applies to all masters by research and PhD students. The form should be checked, approved and signed by the supervisor in advance of submission to REC. ***NB – Taught Masters and Undergraduate students apply for ethical review via their local review panels, not via REC.***

- **The application should consist of one electronic file only,** with an electronic signature from the PI. The completed application must incorporate all supplementary documentation, especially that being given to the proposed participants. It must be proofread and spellchecked before submission to the REC**.**

- **All sections of the application form must be answered as instructed and within the word limits given.**

Applications which do not adhere to all of these requirements will not be accepted for review and will be returned directly to the applicant.

Applications must be completed on the form; answers in the form of attachments will not be accepted, except where indicated. No hardcopy applications will be accepted. **Research must not commence until written approval has been received from the Research Ethics Committee.**

Note: If your research requires approval from the Biosafety Committee (BSC), or review by the School of Nursing and Human Sciences Ethics Advisory Committee (SNHSEAC), this must be in place prior to REC submission. Please attach the responses from these committees to this submission as directed below.

PROJECT TITLE	**Cardiorespiratory Fitness Levels Associated with Increased Cardiovascular Disease Risk and Asymptomatic Cardiovascular Disease in Irish Adolescents**
PRINCIPAL INVESTIGATOR(S)	Dr. Sarah Kelly, Dr. Bróna Furlong and Prof Niall M. Moyna
START AND END DATE	01.11.18 to 31.12.22
LEVEL OF RISK	Full review

1. ADMINISTRATIVE DETAILS

PROJECT TYPE: (mark Y to as many as apply)	Research Project	Y	Funded Consultancy	
			Clinical Trial	
	Student Research Project (please indicate level, e.g.	Y	Other - Please Describe:	
	PhD/MSc Research)			
	PhD / Other Doctorate	Y		
	MSc Research			

1.1 INVESTIGATOR CONTACT DETAILS

PRINCIPAL INVESTIGATOR(S):

NAME	*School/Unit*	*Email*
Dr. Sarah Kelly	Health and Human Performance	sarah.kelly@dcu.ie
Dr Brona Furlong	Health and Human Performance	brona.furlong@dcu.ie
Prof Niall Moyna	Health and Human Performance	niall.moyna@dcu.ie

OTHER INVESTIGATORS:

NAME	*SCHOOL/UNIT*	*EMAIL*
Dr Andrew McCArron	School of Computing	Andrew.mccarron@dcu.ie
Clare McDermott	Health and Human Perofrmance	Clare.mcdermott26@dcu.ie
Aidan Brady	Health and Human Performance	Aidan.brady39@mail.dcu.ie
Eoin Durkan	Health and Human Performance	Eoin.durkan@dcu.ie
Kevin O'Brien	Health and Human Performance	Kevin.obrien7@mail.dcu.ie

1.2 WILL THE RESEARCH BE UNDERTAKEN ON-SITE AT DUBLIN CITY UNIVERSITY? YES or NO

No

Data will be collected in primary and post-primary schools.

1.3 IS THIS PROTOCOL BEING SUBMITTED TO ANOTHER ETHICS COMMITTEE, OR HAS IT BEEN PREVIOUSLY SUBMITTED TO AN ETHICS COMMITTEE?

YES or NO No

N/A

DECLARATION BY PRINCIPAL INVESTIGATOR(S)

The information contained herein is, to the best of my knowledge and belief, accurate. I have read the University's current research ethics guidelines, and accept responsibility for the conduct of the procedures set out in the attached application in accordance with the form guidelines, the REC guidelines (https://www.dcu.ie/researchsupport/researchethics.shtml), the University's policy on Conflict of Interest, Code of Good Research Practice and any other condition laid down by the Dublin City University Research Ethics Committee. I have attempted to identify all risks related to the research that may arise in conducting this research and acknowledge my obligations and the rights of the participants.

If there exists any affiliation or financial interest for researcher(s) in this research or its outcomes or any other circumstances which might represent a perceived, potential or actual conflict of interest this should be declared in accordance with Dublin City University policy on Conflicts of Interest.

I and my co-investigators or supporting staff have the appropriate qualifications, experience and facilities to conduct the research set out in the attached application and to deal with any emergencies and contingencies related to the research that may arise.

Electronic Signature(s):

Principal investigator(s):

Print Name(s) here:	Sarah Kelly	Bróna Furlong	Niall Moyna *1.10.18*
Date:	*1.10.18*	*1.10.18*	

2. PROJECT OUTLINE

2.1 LAY DESCRIPTION

Cardiovascular disease (CVD) is the leading cause of disease in Ireland.1 Accumulation of fatty plaques in blood vessels (atherosclerosis) is the major cause of CVD, and begins early in life due to exposure to established risk factors as high blood pressure, cigarette smoking, poor diet and physical inactivity.2 There is normally a lag time of two to three decades between initial exposure to risk factors in childhood and adolescence and clinical manifestation such a heart attacks and stroke in middle and late adulthood.3 Individual CVD risk factors can be combined to derive a single risk score to predict the risk of developing atherosclerosis.4 Although a CVD risk factor score is useful in predicting cardiovascular events, direct measurement of plaque in blood vessels by non-invasive imaging techniques such as ultrasound, provides a powerful approach to determine the extensiveness and severity of asymptomatic disease in teenagers.

Children and adolescents with higher levels of cardiorespiratory fitness (CRF) have a more favourable cardiovascular risk profile and a reduced risk of myocardial infarction, stroke, and mortality later in adulthood.3 The 20-m shuttle run test (20 m SRT) is the most widely used test to estimate CRF in adolescents. The purpose of this research study is to identify a minimum CRF level that is required to significantly reduce cardiovascular disease risk and the build-up of fatty plaque in blood vessels of 10-18 year old boys and girls. Broader adoption of cardiorespiratory fitness standards for use in schools as part of surveillance and/or screening systems will greatly assist teachers to identify students with CVD risk or subclinical CVD who might benefit from intervention programs.

2.2 AIMS OF AND JUSTIFICATION FOR THE RESEARCH

Cardiovascular disease (CVD) is the leading cause of death in Ireland.1 Although the clinical manifestations of CVD usually occur in middle-age and in older individuals, there is evidence indicating that CVD risk factors have their origin in childhood and adolescence. Moreover, adverse CVD risk factors in early life have been found to track into adulthood.3 Clustering of CVD risk factors is a better measure of cardiovascular health in children and adolescents than single CVD risk factors.4 A composite CVD risk score could, to some extent, compensate for day-to-day fluctuations in the single CVD risk factors. Furthermore, measurement of sub-clinical atherosclerosis by non-invasive imaging techniques such as echo-Doppler studies of the carotid arteries provides a powerful approach to determine the extensiveness and severity of asymptomatic disease. 5

Cardiorespiratory fitness (CRF) represents the capacity of the heart and lungs to transport oxygen around the body and is a powerful marker of cardiovascular health. Children and adolescents with higher levels of CRF have a more favourable cardiovascular profile and a reduced risk of myocardial infarction, stroke, and mortality later in adulthood.3 Levels of CRF tend to track from childhood to adolescence, as well as from adolescence to adulthood.3

The 20-m shuttle run test (20 m SRT) is the most widely used test to estimate CRF in children and youth. It is low cost, easy to administer and can be used to test large groups of children simultaneously. To date, the 20 m SRT has been used to measure CRF in children and youth in more than 50 countries across six continents.6 A major barrier to the adoption of CRF testing to evaluate cardiovascular health in adolescents is the absence of evidence-based age and sex specific clinical cut points. The aim of this study is to determine the CRF value associated with high CVD risk profile and asymptomatic CVD in children and adolescents.

2.3 DESCRIBE THE METHODOLOGY BEING USED TO ACHIEVE YOUR STATED AIM

STUDY OVERVIEW Experimental Design

Study Overview: A number of schools in the greater Dublin area will be recruited to participate in this study. On an assigned morning participants will arrive to school following an 8-hour fast. Within 2 hours of arriving to school, participants will have a blood sample drawn, blood pressure, handgrip strength, arterial stiffness, waist and hip circumference and carotid intima media thickness measured. Participants will be provided with breakfast following completion of the tests. Participants' aerobic endurance will be assessed by the researchers on another day during a PE class.

Participant Recruitment: A letter (Appendix 1) providing a brief summary of the research project will be sent to school principals. Upon expression of interest, plain language statements, informed consent and assent forms will be sent to the schools. A systematic, one-stage cluster (school) sampling method will be used to obtain a representative sample of the target population. Clusters will be based on school type, class/year group, geographical location, sex and school classification. All students in the relevant class/year group will be invited to participate in the study. Due to the voluntary nature of the study, sample weighting will be applied, if necessary, to correct for uneven distribution.

ASSESSMENT PROTOCOLS

Cardiorespiratory Fitness: A 20m shuttle run test (SRT) will be used to estimate cardiorespiratory fitness. Participants will run back and forth between two lines 20 m apart, keeping in time with a series of audio signals (bleeps). The initial speed will be 8.0 km/hr and will increase by 0.14 m/sec every min. The test will be terminated if a participant stops voluntarily, or is unable to maintain the set pace. Heart rate will be continuously monitored using a receiver attached to a strap (Polar)worn around the chest.

Carotid Intima-Media Thickness: Thickness of the carotid intima-media will be assessed using MultiHertz linear-array transducer (Siemens, Acuson P500) and Siemens portable ultrasound system (Acuson P500 FROSK). Ultrasound images of the carotid artery will be obtained with the participant resting in a supine position, with the head turned slightly to the contralateral side. The common coronary artery (CCA), including the carotid bulb, will be visualized, and 2 longitudinal B-mode images of the left and the right common carotid arteries will be recorded and electronically stored. Carotid Studio software by Quipu will be used to instantaneously measure IMT by real-time processing of B-mode ultrasound image sequences from longitudinal section of the artery. The method uses an edge detection algorithm and works in real-time with a frame rate equal to 25 frames/sec. The intima media thickness will be computed during the last 8 sec of the examination.

Arterial Stiffness: Pulse Wave Velocity is the velocity of the blood pressure wave as it travels a known distance between 2 anatomic sites within the arterial system; it is determined by the elasticity and other properties of the artery. Participants will rest in a supine position with shoes and socks/tights removed. A pillow will support the participant's head and shoulders and the bed adjusted so that the neck is not compressed onto the chin and the upper body is at an angle of approximately 30 degrees (Figure 1). Blood pressure sensor cuffs will be placed around their neck, upper thigh, upper arm, and ankle (Figure 1). A sensor clip will also be place on the big toe of right foot and on the middle finger of right hand (Figure 1) to assess arterial stiffness via pulse wave velocity and ankle brachial index (Vicorder 2 Electronics module). The blood pressure cuffs can be placed over thin clothing (e.g. t-shirt, blouse, trousers, jeans etc.). Following cuff placement, the distance between the sternoclavicular joint to the midpoint of the ankle blood pressure cuff will be measured using a Seca measuring tape. The participant will then be left to rest quietly for 5 min. Blood pressure will be recorded at the end of 5 min. The cuffs will inflate a small amount as the subject lies still and the Vicorder unit will measure changes in pressure between the upper and lower cuff.



Figure 1

Blood Pressure Measurement: Blood pressure will be measured using a sphygmomanometer and a stethoscope, following 5 min of seated rest.

Blood Sample: A blood sample will be drawn via a single venepuncture in the forearm to measure fasting glucose, blood lipids, insulin and other cardiometabolic biomarkers including high-sensitivity C-reactive protein.

Handgrip Strength: A handheld dynamometer (Takei - Hand Grip Dynamometer Digital) will be used to measure handgrip strength. While standing upright, with the dynamometer in their dominant hand between the heel of the hand and the second joint of the fingers and squeeze as hard as they can for 3 seconds. This will be repeated 3 times. Grip strength has been shown to be a useful test for assessing muscular strength in youths and performing the test with the arm extended is the most appropriate protocol to assess maximal grip strength in adolescents.

Anthropometrics: Height will be measured using a portable stadiometer (SECA) and electronic balance scales with bioelectrical impedance (Tanita Body Comp Analyser TBF300WA) for body composition analysis. Footwear and any heavy clothing will be removed prior to measurement. Measurements will be made to the nearest 0.1kg. BMI categories for overweight and obese will be based on age and sex-specific data. Waist and hip circumference will be measured using standard procedures by placing a measuring tape (SECA 201) around the body and taking a measurement to the nearest millimetre. The circumference of the waist will be measured at the narrowest point above the suprailia around the navel after a few relaxed breaths and the hip at the level of the greater trochanter. A ratio is taken of the two measurements. The measurements are carried out 3 times for repeatability. Waist circumference is positively correlated with percentage body fat and, as such, is considered a good anthropometric predictor for screening abdominal fat content in children and adolescents.

Statistical Analysis: A cluster of CVD risk factors by sex will be constructed. For this purpose, computed standardized normalized indices (z score¼[value mean]/standard deviation) will be computed. The CVD risk score will be calculated as the mean of the standardized scores. Participants with values > 1.0 SD in the continuous composite risk score variable will be defined as being at risk. The CRF cut-off point associated with CVD risk (CVD risk score >1.0 SD) will be determined using the receiver operating characteristic curve. The area under the curve (AUC) and 95% CI will be calculated. Binary logistic regression will be used to study the relation between the CRF cut-off point (high vs. low) and CVD risk (1 SD vs >1 SD). Vascular age will be determined by evaluating cIMT measurements against percentile charts for race and gender matched adult population (Stein et al., 2004).7

2.4 PARTICIPANT PROFILE

Five hundred boys and girls between the ages of 12-18 years will be recruited to participate in the study.

2.4(a) PARTICIPANT VULNERABILITY

Participants in this study will be boys and girls between 12-18 years of age. Aside from being classified as minors (<18 years), participants are not considered to be vulnerable in any way.

2.4(b) CHILD PARTICIPANTS (anyone under 18 years old)	**Mark here** Yes
We confirm that we have read and agree to act in accordance with the DCU Child Protection policy and procedures	Yes
We confirm that we have put in place safeguards for the children participating in the research	YES
We confirm that we have supports in place for children who may disclose current or historical abuse (whether or not this is the focus of the research)	Yes

2.5 EXPLAIN HOW PARTICIPANTS ARE TO BE RECRUITED

A letter (Appendix 1) providing a brief summary of the research project will be sent to principals of secondary schools. Upon expression of interest plain language statements, informed consent and assent forms will be sent to the schools.

2.6 PLEASE EXPLAIN WHEN, HOW, WHERE, AND TO WHOM RESULTS WILL BE DISSEMINATED, INCLUDING WHETHER PARTICIPANTS WILL BE PROVIDED WITH ANY INFORMATION AS TO THE FINDINGS OR OUTCOMES OF THE PROJECT?

The results will be published in peer-reviewed publications and conference presentations. The identity of the individual participants will remain anonymous. Information, as a group, will only be presented

2.7 ARE OTHER APPROVALS REQUIRED TO GAIN ACCESS TO ANOTHER LOCATION, ORGANISATION ETC.?

YES or NO

YES

The Principal in each school will be asked to consent to their school's involvement, as described in section 2.5

2.8 HAS A SIMILAR PROPOSAL BEEN PREVIOUSLY APPROVED BY THE DCU REC? YES or NO

YES

DCU REC/2018/047

DCU/REC/2017/202

3. RISK AND RISK MANAGEMENT

3.1 JUSTIFICATION OF STATED LEVEL OF RISK TO RESEARCH PARTICIPANTS

With the exception of arterial stiffness measurement, the current research project involves standardised protocols that have been previously approved by the REC for studies involving boys and girls between the ages of 12 and 18 years. The necessary training and appropriate supervision are in place.

3.2DOES THE RESEARCH INVOLVE:

Interviews (attach interview questions)?	NO
Observation of participants without their knowledge?	NO
Audio or video taping interviewees or events?	NO
Access to personal and/or confidential data (including student, patient or client data) without the participants specific consent?	NO
Administration of any stimuli, tasks, investigations or procedures which may be experienced by participants as physical or mentally painful, stressful or unpleasant during or after the research process?	NO
Performance of any acts which might diminish the self esteem of participants or cause them to experience embarrassment, regret or depression?	NO
Investigation of participants involved in illegal activities?	NO
Procedures that involve deception of participants?	NO
Administration of any substance or agent?	NO
User of non treatment or placebo control conditions?	NO
Collection of body tissues or fluid samples?	YES
Collection and/or testing of DNA samples?	NO
Participation in a clinical trial?	NO
Administration of ionising radiation to participants?	NO

3.3 POTENTIAL RISKS TO PARTICIPANTS AND RISK MANAGEMENT PROCEDURES

· Exercise testing carries with it a very small risk of abnormal heart rhythms, heart attack or death. In an asymptomatic, adolescent population this risk is minimal.

· Drawing blood may cause a slight pain and discomfort and can result in localized bruising where the needle is inserted. An individual trained in phlebotomy will draw the blood samples. A volume of approximately 10 mL of blood will be drawn. Blood samples are required to assess fasting glucose, blood lipids, insulin and other cardiometabolic biomarkers including high-sensitivity C-reactive protein.

3.4 ARE THERE LIKELY TO BE ANY BENEFITS (DIRECT OR INDIRECT) TO PARTICIPANTS FROM THIS RESEARCH?

YES

Study participants will receive a copy of their aerobic fitness result and the following blood results: glucose, total cholesterol, HDL-cholesterol, LDL-cholesterol and high-sensitivity C-reactive protein.

3.5 ARE THERE ANY SPECIFIC RISKS TO RESEARCHERS?

Examples include use of dangerous materials, asking certain types of questions, research being undertaken in certain locations, researchers working alone in isolated areas, etc.

NO

3.6 DEALING WITH ADVERSE/UNEXPECTED OUTCOMES

The research team involved in this study has the capabilities to deal with all aspects of this study and an emergency plan is in place for adverse events. All minor injuries will be addressed by referring the participant to each school's health service area. In the unlikely event of a serious adverse outcome, either an ambulance will be called or the participant will be brought to a local hospital. The school's own policies and procedures will be followed in all instances. Furthermore, a first aid kit and mobile phone will be on site at all times.

In the event of an unexpected outcome, it will be brought to the attention of Dr. Noel McCaffrey, medical director in the School of Health and Human performance. Based on Dr. McCaffrey's interpretation, if it is deemed results warrant follow up, a letter will be sent to parents with a request that they make an appointment to see the appropriate medical personnel.

3.7 HOW WILL THE CONDUCT OF THE PROJECT BE MONITORED?

The principal investigators will be involved in all aspects of the research, including participant recruitment and data collection. The research team will have weekly meetings to update on all aspects of the study. All researchers, including students, are familiar with the procedures and the Safety Statement prior to beginning data collection.

3.8 SUPPORT FOR PARTICIPANTS N/A

3.9 DO YOU PROPOSE TO OFFER PAYMENTS OR INCENTIVES TO PARTICIPANTS? YES or NO

No

3.10 DO ANY OF THE RESEARCHERS ON THIS PROJECT HAVE A PERSONAL, PHILOSOPHICAL, FINANCIAL OR COMMERCIAL INTEREST IN ITS OUTCOME THAT MIGHT INFLUENCE THE INTEGRITY OF THE RESEARCH, OR BIAS THE CONDUCT OR REPORTING OF THE RESEARCH, OR UNDULY DELAY OR OTHERWISE AFFECT THEIR PUBLICATION?

NO

4. INVESTIGATORS' QUALIFICATIONS, EXPERIENCE AND SKILLS *(Approx. **200 words**)*

· Dr. Sarah Kelly is an exercise physiologist and has extensive experience in cardiovascular research including the assessment of vascular health and function through ultrasonography and exercise testing

· Prof. Niall Moyna is an exercise physiologist and has extensive experience in cardiovascular research, phlebotomy and exercise testing

· Dr. Bróna Furlong is an exercise physiologist and has extensive experience in cardiovascular research including the assessment of vascular health and function through ultrasonography and exercise testing

· Dr Andrew McCarron is a statistician

· Clare McDermott, Aidan Brady, Eoin Durkan, and Nicola Hurley are PhD students in the School of Health and Human Performance. Each has extensive experience with the experimental procedures to be used in the study.

· Kevin O'Brien, BSc. Sport Science and Health, is a PhD student in the school of Health and Human Performance. Kevin has extensive experience assessing athletes, school children and adults in laboratory and field-based tests. Kevin has experience analysing large excel databases from previous employment in Institute of Technology Carlow, and his time working as a conditioning coach with Tennis Ireland. Kevin was awarded the "Outstanding Researcher of the Year" in 2005 for his undergraduate thesis.

5. CONFIDENTIALITY/ANONYMITY

5.1 WILL THE IDENTITY OF THE PARTICIPANTS BE PROTECTED?

Yes

IF YOU ANSWERED YES TO 5.1, PLEASE ANSWER THE FOLLOWING QUESTIONS:

5.2 HOW WILL THE ANONYMITY OF THE PARTICIPANTS BE RESPECTED?

All data will be anonymized by assigning an ID code to each participant. The participants name will not appear on research document or publication.

5.3 LEGAL LIMITATIONS TO DATA CONFIDENTIALITY

The following statement will be included in the plain language statement.

"Confidentiality of information provided can only be protected within the limitations of the law. It is possible for data to be subject to subpoena, freedom of information claim or mandated reporting by some professions".

6. PERSONAL DATA - COMPLIANCE WITH THE GENERAL DATA PROTECTION REGULATION

Personal data is data relating to a living individual (i.e. the 'Data Subject') who is, or can be, identified either from the data itself or from the data in conjunction with other information that is in, or is likely to come into, the possession of the 'Data Controller' (i.e. DCU and its constituent units e.g. research teams etc.). ***Further information available at https://www.dcu.ie/ocoo/dp/guides.shtml***

6.1 IS PERSONAL DATA BEING PROCESSED AS PART OF THIS PROJECT?

YES

If YES, Please indicate your compliance with the following guidelines:	**Mark here**
We confirm that we have read and agree to act in accordance with DCU guidance and procedures regarding personal data	YES

We confirm that we have put in place a Personal Data Security Schedule (PDSS) for the project and have attached it to this application

YES

IF YOU ANSWERED YES TO 6.1, PLEASE ANSWER THE FOLLOWING QUESTIONS:

6.2 WHAT KIND OF PERSONAL DATA IS BEING PROCESSED?

The following personal data will be collected as part of this research study:

- Name
- Date of birth/age
- Race
- Informed consent ·
- Anthropometric data (i.e. body composition, waist and hip circumference)
  Blood markers
- Smoking history
- Aerobic fitness results
- Carotid intima-media thickness measurement
- Arterial stiffness score
- Blood pressure · Heart rate

6.3 WILL ANONYMISATION/PSEUDONYMISATION OF THE PERSONAL DATA BE UNDERTAKEN? YES or NO

YES

7. DATA/SAMPLE STORAGE, SECURITY AND DISPOSAL

For the purpose of this section, "Data" includes that in a raw or processed state (e.g. interview audiotape, transcript or analysis). "Samples" include body fluids or tissue samples.

7.1 HOW AND WHERE WILL THE DATA/SAMPLES BE STORED?

Data collection forms will be stored in a secure, locked cabinet in the Vascular Health Research Unit in the School of Health and Human Performance at DCU. All personal data will be anonymised and electronic data will be saved in a password- protected computer in the School of Health and Human Performance at DCU. Blood samples will be stored in a -70°C freezer in the School of Health and Human Performance at DCU.

7.2 WHO WILL HAVE ACCESS TO DATA/SAMPLES?

The principal investigators and named collaborators listed on this ethics application will have access to the data.

7.3 HOW LONG IS THE DATA TO BE HELD/RETAINED FOR?

All personal data will be anonymised and saved in a password protected file on a computer at DCU. Data collection sheets and files containing identifiable data will be shredded and erased using a secure electronic shredder, respectively, following anonymisation.

7.4 IF DATA/SAMPLES ARE TO BE DISPOSED OF, PLEASE EXPLAIN HOW, WHEN AND BY WHOM THIS WILL BE DONE?

Blood samples will be placed in medical waste and hard copies of data collection sheets with personalised data will be shredded. Electronic data will be anonymized and stored for potential future use.

8. FUNDING OF THE RESEARCH

8.1 HOW IS THIS WORK BEING FUNDED?

This research study is being funded by the School of Health and Human Performance

8.2 PROJECT GRANT NUMBER *(If relevant and/or known – otherwise mark as N/A)* N/A

8.3 DOES THE PROJECT REQUIRE APPROVAL BEFORE CONSIDERATION FOR FUNDING BY A GRANTING BODY?

NO

8.4.1 HOW WILL PARTICIPANTS BE INFORMED OF THE SOURCE OF THE FUNDING? *(e.g. included in the Plain Language Statement)*

N/A

8.5 DO THE FUNDERS OF THIS PROJECT HAVE A PERSONAL, FINANCIAL OR COMMERCIAL INTEREST IN ITS OUTCOME THAT MIGHT COMPROMISE THE INDEPENDENCE AND INTEGRITY OF THE RESEARCH, OR BIAS THE CONDUCT OR REPORTING OF THE RESEARCH, OR UNDULY DELAY OR OTHERWISE AFFECT THEIR PUBLICATION?

NO

9. PLAIN LANGUAGE STATEMENT *(Attach to this document. Approx. 400 words)*

I. Introduction to the Research Study

Cardiovascular disease (CVD) is the leading cause of disease in Ireland. The build-up of fatty plaques in blood vessels (atherosclerosis) is the major cause of CVD, and begins early in life due to exposure to established risk factors as high blood pressure, cigarette smoking, poor diet and physical inactivity. There is normally a lag time of two to three decades between initial exposure to risk factors in childhood and adolescence and clinical manifestation such a heart attacks and stroke in middle and late adulthood. Individual CVD risk factors can be combined to derive a single risk score to predict the risk of developing atherosclerosis. Although a CVD risk factor score is useful in predicting cardiovascular events, direct measurement of plaque in blood vessels by non-invasive imaging techniques such as ultrasound, provides a powerful approach to determine the extensiveness and severity of asymptomatic disease in teenagers.

Children and adolescents with higher levels of cardiorespiratory fitness (CRF) have a more favourable cardiovascular risk profile and a reduced risk of myocardial infarction, stroke, and mortality later in adulthood. The 20-m shuttle run test (20 m SRT) is the most widely used test to estimate CRF in adolescents. A major barrier to the adoption of CRF testing to evaluate cardiovascular health in adolescents is the absence of an evidence-based age and sex specific minimum fitness level that is associated with CVD risk and sub-clinical atherosclerotic disease. The purpose of this research study is to identify a minimum fitness levels that is required to significantly reduce cardiovascular disease risk and the build-up of fatty plaque in blood vessels of 12-18 year old boys and girls. Broader adoption of cardiorespiratory fitness standards for use in schools as part of surveillance and/or screening systems will greatly assist teachers to identify students with CVD risk or subclinical CVD who might benefit from intervention programs.

II. What will happen if the person decides to participate in the research study?



Participation in the study involves arriving to school on one morning, having fasted from 10 pm the previous evening.

The study participants will have:

i) a blood sample drawn from a vein in their arm
ii) their height and weight measured
iii) their hip and waist circumference measured
iv) their blood pressure measured
v) breakfast offered to them
vi) 2 images taken of the carotid arteries in their neck with an ultrasound machine (picture)
vii) arterial stiffness measured
viii) their handgrip strength tested
ix) their aerobic fitness assessed during a PE class on a separate day

III. Arrangements to protect confidentiality of data

· Participant identity and other personal information will not be revealed, published or used in further studies

· Any personal information including name, will be kept in a locked filing cabinet but will be shredded after five years

- Participants will be assigned an ID number under which all personal information will be stored and saved in a password protected file on a computer at DCU
- Only named investigators on this research project will be allowed to view the data
- Electronic data will be stored on a password-protected computer in the School of Health and Human Performance at DCU
- Confidentiality of information provided can only be protected within the limitations of the law. It is possible for data to be subject to subpoena, freedom of information claim or mandated reporting by some professions.

IV. Potential risks from involvement in the Research Study

Exercise testing carries with it a very small risk of abnormal heart rhythms, heart attack or death. In an asymptomatic, adolescent population this risk is minimal.

During the process of taking a blood sample, a slight pain may be experienced when the needle is inserted. Some individuals may experience slight bruising afterwards in the area where the needle was inserted

VI. Benefits from involvement in the Research Study

Participants will receive a summary of their own results and a comparison to other individuals of the same gender and age.

VII. Involvement in the Research Study is voluntary

Involvement in the study is completely voluntary. Participants may withdraw from the Research Study at any point. There will be no penalty for withdrawing before all stages of the Research Study have been completed.

VIII. How will participants find out what happens with the project?

Information regarding any research publications or conference proceedings will be sent to the principals of the participating schools. The participants will receive copy of their blood results and blood pressure measurement.

IX. How will unexpected outcomes be dealt with?

In the event of an unexpected outcome, the abnormal result will be brought to the attention of Dr. Noel McCaffrey, medical director in the School of Health and Human performance. Based on Noel's interpretation, if it is deemed results warrant follow up, a letter will be sent to parents with a request that they make an appointment to see the appropriate medical personnel.

If participants have concerns about this study and wish to contact an independent person, please contact:

The Secretary, Dublin City University Research Ethics Committee, c/o Office of the Vice-President for Research, Dublin City University, Dublin 9. **Tel**: 01-7008000

9. INFORMED CONSENT FORM *(Include in this document. Approx. 300 words)*

DUBLIN CITY UNIVERSITY **Informed Consent Form**

I. Research Study Title

Cardiorespiratory Fitness Levels Associated with Increased Cardiovascular Disease Risk and Asymptomatic Cardiovascular Disease in Adolescents

Principle Investigators

Dr. Sarah Kelly, School of Health and Human Performance, DCU Dr. Bróna Furlong, School of Health and Human Performance Prof. Niall Moyna, School of Health and Human Performance

Email: sarah.kelly@dcu.ie; niall.moyna@dcu.ie, brona.furlong@dcu.ie

II. Purpose of the research

The purpose of this research study is to identify a minimum fitness level that is required to significantly reduce cardiovascular disease risk and the build-up of fatty plaque in blood vessels of 12-18 year old boys and girls

III. Participant Requirements

- On an assigned morning participants in this study will arrive to school after an 8 hour fast
- A single blood sample will be taken to measure risk factors for cardiovascular disease Following the blood sample, participants will be provided with a bowl of cereal and milk, and a glass of orange juice
- Participants will have their height and weight measured
- Participants will have their waist and hip circumference measured
- Participants will then lie with their head turned to one side and an ultrasound image of a blood vessel in their neck (the carotid artery) will be taken. They will then turn their heads to the opposite side, and a second ultrasound image another blood vessel in their neck will be taken.
- Participants will rest in a seated position for 5 min before having their blood pressure measured
- Participants will have the stiffness of their arteries measured through blood pressure cuffs placed around their arm, upper leg, ankle and neck (very small)
- Participants will have their grip strength measured
- During a PE class on a separate day, participants will complete a fitness test, that will involve running between two lines, 20 meters apart until they reach volitional fatigue
- Participants will wear a strap around their chest, to monitor their heart beat, during the fitness test

IV. Confirmation

of particular requirements as highlighted in the Plain Language Statement

Please complete the following (Circle Yes or No for each question)

I have read the Plain Language Statement (or had it read to me)	Yes	No
I understand the information provided	Yes	No
I have had an opportunity to ask questions and discuss this study	Yes	No
I have received satisfactory answers to all my questions	Yes	No

V. Confirmation that involvement in the Research Study is voluntary

Participants can withdraw from the research study at any point

VI. Advice as to arrangements to be made to protect confidentiality of data, including that confidentiality of information provided is subject to legal limitations

Participant's name and other personal information will not be revealed, published or used in further studies. Participants will be assigned an ID number under which all personal information will be stored in a secure locked cabinet and saved in a password protected file in a computer at DCU. The named investigators will have access to the data. Hard copies of data collection sheets will be shredded after 5 years by Prof. Sarah Kelly.

Confidentiality is insured, but you must be aware that confidentiality of information provided can only be protected within the limitations of the law. It is possible for data to be subject to subpoena, freedom of information claim or mandated reporting by some professions.

VII. How will unexpected outcomes be dealt with?

In the event of an unexpected outcome, the abnormal result will be brought to the attention of Dr. Noel McCaffrey, medical director in the School of Health and Human performance. Based on Noel's interpretation, if it is deemed results warrant follow up, a letter will be sent to parents with a request that they make an appointment to see the appropriate medical personnel.

I have read and understood the information in this form. My questions and concerns have been answered by the researchers, and I have a copy of this consent form. Therefore, I consent to allow my child take part in this research project

Participant's name: _____

Parent's Signature: _____

Name in Block Capitals: _____

Contact number: _____

Witness: _____

Date: _____

***DUBLIN CITY UNIVERSITY* Assent Form**

Research Study Title: Cardiorespiratory Fitness Levels Associated with Increased Cardiovascular Disease Risk and Asymptomatic Cardiovascular Disease in Adolescents

Principle Investigators

Dr. Sarah Kelly, School of Health and Human Performance, DCU Dr. Bróna Furlong, School of Health and Human Performance Prof. Niall Moyna, School of Health and Human Performance

Email: sarah.kelly@dcu.ie; niall.moyna@dcu.ie, brona.furlong@dcu.ie

1. I have been told that if I take part in this study I will arrive to school one day without eating breakfast and having only drank water

2. The researcher from Dublin City University will take a blood sample, using a needle, from a vein in my forearm. I know that taking a blood sample can cause a brief sharp "pinch-like" pain and can sometimes result in a bruise afterwards

3. I will sit for 5 minutes in a quiet room, before a blood pressure cuff is placed on my upper arm and my ankle. After 5 minutes a researcher from Dublin City University will measure my blood pressure and the stiffness of my arteries between my arm and ankle. I may feel an increase in pressure in the cuff as it measures the stiffness of my arteries

4. The researcher will place another blood pressure cuff on my upper thigh and a small cuff around my neck to measure the stiffness of my arteries between my heart and leg. The neck cuff is very small and does not inflate much. During the test, the cuffs will increase over 5 minutes. This test will take about 5 minutes

5. I will then lie on a bed and turn my head to the side. The researcher from Dublin City University will use an ultrasound machine to take a photograph of a blood vessel in my neck. I will turn my head to the opposite side and the researcher will take a photograph of the blood vessel on the other side of my neck. This test will take about 10 minutes

6. I will stand on a scales to have my weight assessed and stand against a height measure to see how tall I am

7. I will have my waist and hip measured

8. I will squeeze a handheld measure to see how strong my grip is

9. On a separate day, during my PE class, I will have my fitness assessed. This will involve running between 2 lines, 20 meters apart until I cannot run anymore

10. During my fitness test, I will wear an elasticated strap around my chest to count the number of times my heart beats

11. I know that I can choose not to take part in any of the tests 12. I know that at any point I can stop the tests

13. I know that the researchers from Dublin City University, my teachers or my parents/guardians will not be upset with me if I decide not to take part in this study, or if I wish to stop taking part in the study

SIGNED: _____ **DATE:** _____ **(Participant's name)**

SIGNED: _____ **DATE:** _____ **(Witness name)**

DCUREC/2018/209: Appendix 1 – Letter to schools

School of Health and Human Performance

Faculty of Science and Health

Dublin City University Dublin 9

Tel: +353 (0)1 700 5914

Email: ~~sarah.kelly@dcu.ie; niall.moyna@dcu.ie, bro~~na.furlong@dcu.ie

May 2018

Dear Principal:

The Vascular Health Research Unit at DCU is planning to undertake a research study to identify the minimum fitness level required to significantly reduce cardiovascular disease risk and subclinical atherosclerotic cardiovascular disease among 10-18 year old boys and girls.

Cardiovascular disease (CVD) is the leading cause of disease in Ireland. Accumulation of fatty plaques (atherosclerosis) in blood vessels is the major cause of CVD, and begins early in life due to exposure to established risk factors such as high blood pressure, cigarette smoking, poor diet and physical inactivity. There is normally a lag time of two to three decades between initial exposure to risk factors in childhood and adolescence, and clinical manifestation such a heart attacks and stroke in middle and late adulthood. Individual CVD risk factors can be combined to derive a single risk score to predict the risk of developing atherosclerosis. Although a CVD risk factor score is useful in predicting cardiovascular events, direct measurement of plaque in blood vessels by non-invasive imaging techniques such as ultrasound, provides a powerful approach to determine the extensiveness and severity of asymptomatic disease in teenagers.

Children and adolescents with higher levels of cardiorespiratory fitness (CRF) have a more favourable cardiovascular risk profile and a reduced risk of myocardial infarction, stroke, and mortality later in adulthood. The 20-m shuttle run test (20m SRT) is the most widely used test to estimate CRF in adolescents. A major barrier to the adoption of CRF testing to evaluate cardiovascular health in adolescents is the absence of an evidence-based age and sex-specific minimum fitness level that is associated with CVD risk and sub-clinical atherosclerotic disease. Broader adoption of cardiorespiratory fitness standards for use in schools as part of surveillance and/or screening systems will greatly assist teachers to identify students with CVD risk or subclinical CVD who might benefit from intervention programs.

The 2010 Children's Sport Participation and Physical Activity study (CSPPA Study) indicates that an alarming 81% of primary and 88% of post primary pupils do not meet the Department of Health and Children's physical activity recommendations. Furthermore, physically active Irish children were found to have a better health profile in terms of aerobic fitness, body composition and blood pressure than those who are inactive.

The aim of this study is to determine the CRF level associated with high CVD risk profile and asymptomatic CVD in children and adolescents.

If you are interested in your students participating in this proposed study or would like more information please feel free to contact Dr. Sarah Kelly, Dr. Bróna Furlong or Prof. Niall Moyna.

Thank you for taking the time to read this letter.

Best wishes,

_____

Dr. Sarah Kelly Dr Bróna Furlong Prof. Niall M. Moyna

DCUREC/2018/209: Appendix 2: Bibliography

1. Irish Heart Foundation Web site, available from https://irishheart.ie/heart-and-stroke-conditions-a-z/cardiovascular-disease/

2. Daniels, S.R. et al. (2013). *Reduction of Risk for Cardiovascular Disease in Children and Adolescents*. Circulation, Oct 11; 124(15); 1673-1686.

3. Ekelund, U. et al. (2007). *Independent associations of physical activity and cardiorespiratory fitness with metabolic risk factors in children: the European youth heart study*. Diabetologia, 50(9), 1832–40.

4. Ruiz, J. R. et al (2016) *Cardiorespiratory fitness cut points to avoid cardiovascular disease risk in children and adolescents; what level of fitness should raise a red flag? A systematic review and meta-analysis*. Br J Sports Med 50(23):1451-1458.

5. Kozakova M and Palombo C (2016). *Vascular Ultrasound and Cardiovascular Risk Assessment.* Journal of Vascular Medicine 3(1):1015

6. Tomkinson, G. R. et al (2017). *International normative 20 m shuttle run values from 1 145 026 children and youth representing 50 countries*. Br J Sports Med, 51(21):1545-1554.

7. Stein, J. H. et al (2004). Vascular age: integrating carotid intima-media thickness measurements with global coronary risk assessment. Clinical Cardiology, 27(7), 388–392.

Signature of Study PI:

Date: 1.10.18 1.10.18 1.10.18

Appendix I: Machine Learning Process

Data analysis

```
# import libraries required & data file
import pandas as pd
import seaborn as sns
data = pd.read_csv("full_class_w_annotation.csv")
data
```

[10281 rows x 124 columns]

```
# extracting year information from the competition ID
data['year'] = data.apply(lambda x: x['compkey'].split("_")[0][-4::], axis=1)
data
```

[10281 rows x 124 columns]

```
list(data.columns)
```

```
# only select phase 1 2018

#eighteen = data[data['year']=='2018'].copy()
phase_1 = data[data['phase']==1].copy()
```

```
phase_1
```

[6525 rows x 124 columns]

```
phase_1['completed_phase_2'].value_counts()
```

```
True     3450
False    3075
Name: completed_phase_2, dtype: int64
```

```
phase_1['comp_measure'] = phase_1.apply(lambda x: 1 if x['completed_phase_2'] else 0, axis=1)
phase_1['class_year'] = phase_1.apply(lambda x: str(x['class']).split(".")[0], axis=1)
phase_1.to_csv("phase_1_all.csv", index=False)
```

Measure selection

```
list(phase_1.columns)
```

```
['compkey',
 'rollnumber',
```

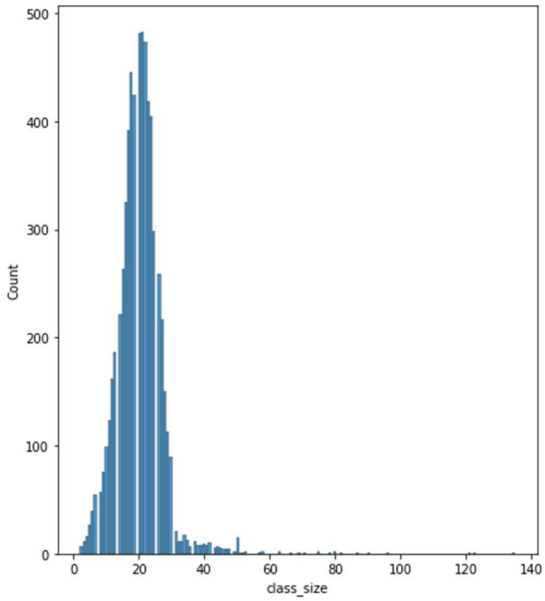
'class',
'class_size',
'totalshuttles_mean',
'totalshuttles_std',
'totalshuttles_min',
'totalshuttles_0.25',
'totalshuttles_0.5',
'totalshuttles_0.75',
'totalshuttles_max',
'distance_mean',
'distance_std',
'distance_min',
'distance_0.25',
'distance_0.5',
'distance_0.75',
'distance_max',
'finallevel_mean',
'finallevel_std',
'finallevel_min',
'finallevel_0.25',
'finallevel_0.5',
'finallevel_0.75',
'finallevel_max',
'finalshuttle_mean',
'finalshuttle_std',
'finalshuttle_min',
'finalshuttle_0.25',
'finalshuttle_0.5',
'finalshuttle_0.75',
'finalshuttle_max',
'finalspeed_mean',
'finalspeed_std',
'finalspeed_min',
'finalspeed_0.25',
'finalspeed_0.5',
'finalspeed_0.75',
'finalspeed_max',
'vo2max_mean',
'vo2max_std',
'vo2max_min',
'vo2max_0.25',
'vo2max_0.5',
'vo2max_0.75',
'vo2max_max',
'score_mean',
'score_std',

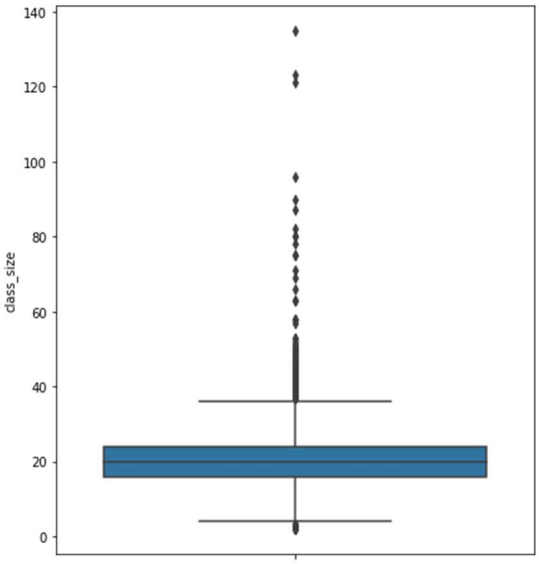
'score_min',
'score_0.25',
'score_0.5',
'score_0.75',
'score_max',
'hdp_data_mean',
'age',
'count_boys',
'count_girls',
'id',
'ed_name',
'nuts_4',
'nuts_3',
'nuts_2',
'nuts_1',
'year',
'hpabs',
'hprel',
'totpop',
'popdep_T',
'popdep_L',
'popdep_M',
'popdep_H',
'share_T',
'share_L',
'share_M',
'share_H',
'share',
'POPCHG',
'AGEDP',
'LONEPA',
'EDLOW',
'EDHIGH',
'HLPROF',
'LSKILL',
'UNEMPM',
'PEROOM',
'LARENT',
'PRRENT',
'OHOUSE',
'ed_no',
'isurban',
'classification',
'school_name',
'Address1',
'Address2',

'Address3',
'Address4',
'County',
'eircode',
'deis',
'gender',
'attendance',
'fees',
'ethos',
'status',
'females',
'males',
'GeoDirectory_identification',
'latititude',
'longitude',
'nace_code',
'nace_code_description',
'eircode_og',
'local_authority',
'island_location',
'gaeltacht_location',
'irish_classification',
'not_a_school',
'comp_id',
'phase',
'key',
'completed_phase_2',
'school_repeat',
'repeat_year',
'repeat_class',
'comp_measure',
'class_year']

```
analysis_atts = ['rollnumber' , 'class' , 'class_size' , 'totalshuttles_mean' , 'totalshuttles_std' ,
            'totalshuttles_min' , 'totalshuttles_0.25' , 'totalshuttles_0.5' , 'totalshuttles_0.75' ,
            'totalshuttles_max' , 'distance_mean' , 'distance_std' , 'distance_min' , 'distance_0.25' ,
            'distance_0.5' , 'distance_0.75' , 'distance_max' , 'finallevel_mean' , 'finallevel_std' , 'finall
evel_min' , 'finallevel_0.25' , 'finallevel_0.5' , 'finallevel_0.75' , 'finallevel_max' , 'finalshuttle_mean'
, 'finalshuttle_std' , 'finalshuttle_min' , 'finalshuttle_0.25' , 'finalshuttle_0.5' , 'finalshuttle_0.75' , 'fi
nalshuttle_max' , 'finalspeed_mean' , 'finalspeed_std' , 'finalspeed_min' , 'finalspeed_0.25' , 'finalsp
eed_0.5' , 'finalspeed_0.75' , 'finalspeed_max' , 'vo2max_mean' , 'vo2max_std' , 'vo2max_min' , 'v
o2max_0.25' , 'vo2max_0.5' , 'vo2max_0.75' , 'vo2max_max' , 'score_mean' , 'score_std' , 'score_m
in' , 'score_0.25' , 'score_0.5' , 'score_0.75' , 'score_max' ,  'age' , 'count_boys' , 'count_girls' , 'ed
_name' , 'nuts_4' , 'nuts_3' , 'nuts_2' , 'nuts_1' , 'year' , 'hpabs' , 'hprel' , 'totpop' , 'popdep_T' , 'p
opdep_L' , 'popdep_M' , 'popdep_H' , 'share_T' , 'share_L' , 'share_M' , 'share_H' , 'share' , 'POPC
HG' , 'AGEDP' , 'LONEPA' , 'EDLOW' , 'EDHIGH' , 'HLPROF' , 'LSKILL' , 'UNEMPM' , 'PEROOM' , 'LARE
```

NT' , 'PRRENT' , 'OHOUSE' , 'ed_no' , 'isurban' , 'classification' , 'school_name' , 'Address1' , 'Addre
ss2' , 'Address3' , 'Address4' , 'County' , 'eircode' , 'deis' , 'gender' , 'attendance' , 'fees' , 'ethos' ,
'status' , 'females' , 'males' , 'GeoDirectory_identification' , 'latititude' , 'longitude' , 'nace_code' , '





nace_code_description' , 'eircode_og' , 'local_authority' , 'island_location' , 'gaeltacht_location' , 'iri
sh_classification' , 'not_a_school' , 'completed_phase_2' , 'school_repeat' , 'repeat_year' , 'repeat
_class' , 'comp_measure' , 'class_year']

```
data = phase_1[analysis_atts].copy()
data
```

[6525 rows x 120 columns]

Preprocessing

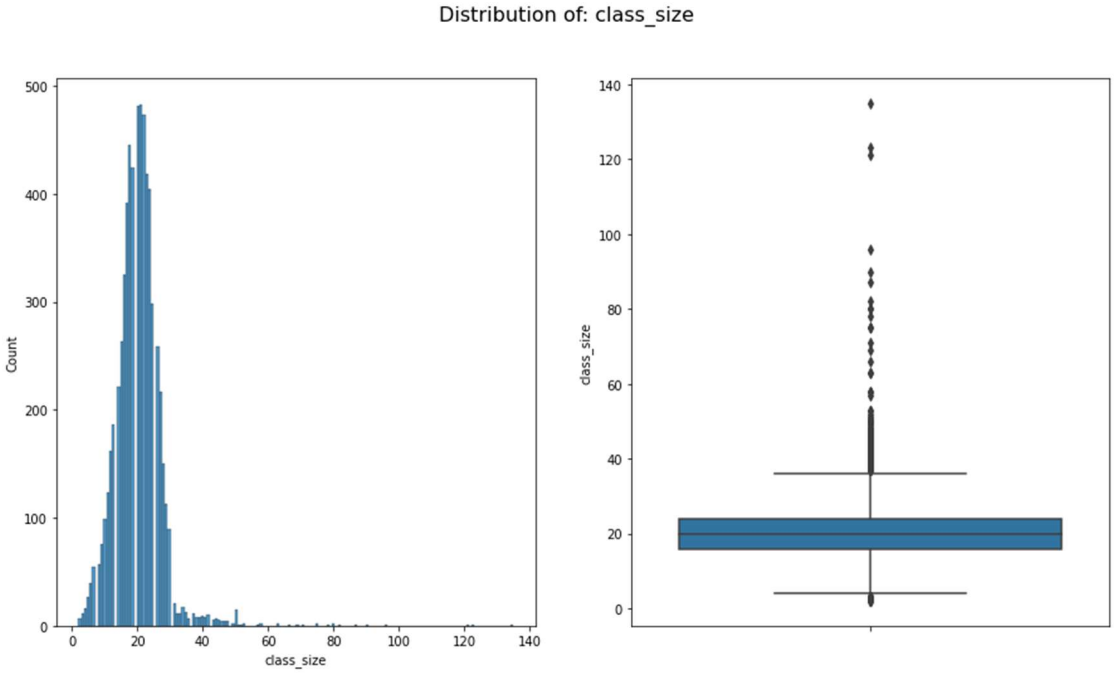
```
# distributions + boxplots to get the distribution of each variable type
%matplotlib inline
import matplotlib.pyplot as plt
numeric_features = []

fig, ax =plt.subplots(1,2, figsize=(15,8))
fig.suptitle('This is a somewhat long figure title', fontsize=16)
sns.histplot(x=phase_1["class_size"], ax=ax[0])
sns.boxplot(y="class_size", data=phase_1, ax=ax[1])
fig.show()
```

```
<ipython-input-10-04c700d45452>:10: UserWarning: Matplotlib is currently using module://ipykernel
.pylab.backend_inline, which is a non-GUI backend, so cannot show the figure.
  fig.show()
```

phase_1.dtypes

```
compkey              object
rollnumber           object
class               float64
class_size            int64
totalshuttles_mean    float64
```




```
                    ...
school_repeat         int64
repeat_year           int64
repeat_class          int64
comp_measure          int64
class_year           object
Length: 126, dtype: object
```

numeric_figs = ['class_size' ,'totalshuttles_mean' , 'totalshuttles_std' , 'totalshuttles_min' , 'totalshuttles_0.25' , 'totalshuttles_0.5' , 'totalshuttles_0.75' , 'totalshuttles_max' , 'distance_mean' , 'distance_std' , 'distance_min' , 'distance_0.25' , 'distance_0.5' , 'distance_0.75' , 'distance_max' , 'finallevel_mean' , 'finallevel_std' , 'finallevel_min' , 'finallevel_0.25' , 'finallevel_0.5' , 'finallevel_0.75' , 'finallevel_max' , 'finalshuttle_mean' , 'finalshuttle_std' , 'finalshuttle_min' , 'finalshuttle_0.25' , 'finalshuttle_0.5' , 'finalshuttle_0.75' , 'finalshuttle_max' , 'finalspeed_mean' , 'finalspeed_std' , 'finalspeed_min' , 'finalspeed_0.25' , 'finalspeed_0.5' , 'finalspeed_0.75' , 'finalspeed_max' , 'vo2max_mean' , 'vo2max_std' , 'vo2max_min' , 'vo2max_0.25' , 'vo2max_0.5' , 'vo2max_0.75' , 'vo2max_max' , 'score_mean' , 'score_std' , 'score_min' , 'score_0.25' , 'score_0.5' , 'score_0.75' , 'score_max' , 'age' , 'count_boys' , 'count_girls' , 'hpabs' , 'hprel' , 'totpop' , 'popdep_T' , 'popdep_L' , 'popdep_M' , 'popdep_H' , 'share_T' , 'share_L' , 'share_M' , 'share_H' , 'share' , 'POPCHG' , 'AGEDP' , 'LONEPA' , 'EDLOW' , 'EDHIGH' , 'HLPROF' , 'LSKILL' , 'UNEMPM' , 'PEROOM' , 'LARENT' , 'PRRENT' , 'OHOUSE' , 'females' , 'males' , 'school_repeat' , 'repeat_year' , 'repeat_class']

```
for m in numeric_figs:
   fig, ax =plt.subplots(1,2, figsize=(15,8))
   fig.suptitle('Distribution of: {}'.format(m), fontsize=16)
   sns.histplot(x=phase_1[m], ax=ax[0])
   sns.boxplot(y=m, data=phase_1, ax=ax[1])
   fig.savefig("./figures/distributions/{}.png".format(m))
```

<ipython-input-12-f14f4b25fde4>:4: RuntimeWarning: More than 20 figures have been opened. Figures created through the pyplot interface (`matplotlib.pyplot.figure`) are retained until explicitly closed and may consume too much memory. (To control this warning, see the rcParam `figure.max_open_warning`).
  fig, ax =plt.subplots(1,2, figsize=(15,8))

All dists have outliers, z-score normalization

```
for m in numeric_figs:
   phase_1["{}_zscore".format(m)] = (phase_1[m] - phase_1[m].mean())/phase_1[m].std(ddof=0)
phase_1
```

[6525 rows x 208 columns]

```
ncols = [x for x in analysis_atts if x not in numeric_figs]
ncols+=["{}_zscore".format(x) for x in numeric_figs]
aa = ncols[1::]
aal = phase_1[aa].copy()

categorical_vars = [x for x in aa if not x.endswith("_zscore") and x != "Latitude" and x != "Longitude" and x!="completed_phase_2"]
categorical_vars

for x in categorical_vars:
   one_hot = pd.get_dummies(aal[x], prefix="{}_".format(x))
   aal = aal.drop(x,axis = 1)
   aal = aal.join(one_hot)
aal

aal.to_csv("analysis_frame_all2.csv", index=False)
```

GBDT – Sampling Strategy: Under sample the majority

```
import pandas as pd

data = pd.read_csv("analysis_frame_all2.csv")
data
data = data.dropna()

data['completed_phase_2'].value_counts()
```

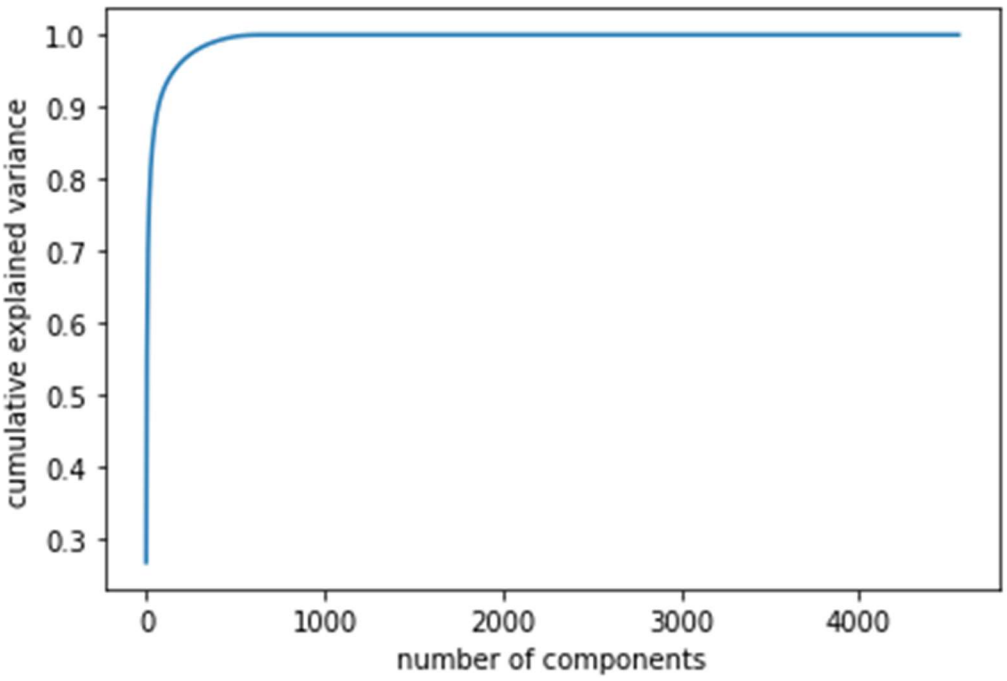
```
True    3445
False   3071
Name: completed_phase_2, dtype: int64
```

```
data.head()
```

[5 rows x 4562 columns]

```
from imblearn.under_sampling import RandomUnderSampler
# we will undersample the data
xcols = [x for x in list(data.columns) if x != 'completed_phase_2' and 'comp_measure' not in x]
undersample = RandomUnderSampler(sampling_strategy='majority')
X = data[xcols]
Y = data[['completed_phase_2']]
x_over, y_over = undersample.fit_resample(X, Y)
print((x_over.shape, y_over.shape))
```

```
((6142, 4559), (6142, 1))
```



PCA

```
from sklearn import decomposition, datasets
import numpy as np
```

```
import matplotlib.pyplot as plt
%matplotlib inline
pca = decomposition.PCA().fit(x_over)
plt.plot(np.cumsum(pca.explained_variance_ratio_))
```

```
plt.xlabel('number of components')
plt.ylabel('cumulative explained variance');
```

```
print(np.cumsum(pca.explained_variance_ratio_))
```

```
x_pca = decomposition.PCA(n_components=100).fit(x_over)
x_pca.singular_values_
components = x_pca.transform(x_over)
x_projected = x_pca.inverse_transform(components)
print(x_projected)
```

```
[[ 2.24375113e-01  1.06129552e+00 -3.98969638e-01 ...  6.85909177e-02
```

```
from sklearn.model_selection import train_test_split
x_train, x_test, y_train, y_test = train_test_split(x_projected,y_over, test_size=0.30) #x_projected, x_o
ver
print((x_train.shape, x_test.shape, y_train.shape, y_test.shape))
```

```
((4299, 4559), (1843, 4559), (4299, 1), (1843, 1))
```

GDBT

```
from sklearn.ensemble import GradientBoostingClassifier
from sklearn import metrics
from sklearn.metrics import classification_report, confusion_matrix
from sklearn.metrics import recall_score, precision_score,f1_score, accuracy_score
from tqdm import tqdm
f1 = []
precisions = []
recalls = []
accuracy = []
for i in tqdm(range(0,5)):
    clf = GradientBoostingClassifier(n_estimators=100, learning_rate=1.0).fit(x_train, y_train.values.rav
el())
    y_pred = clf.predict(x_test)
    f1.append(f1_score(y_test, y_pred))
```

```
    precisions.append(precision_score(y_test, y_pred))
    recalls.append(recall_score(y_test, y_pred))
accuracy.append(accuracy_score(y_test, y_pred))
print("F1 {}+- {}".format(np.mean(f1), np.std(f1)))
print("Precision {}+- {}".format(np.mean(precisions), np.std(precisions)))
print("Recall {}+- {}".format(np.mean(recalls), np.std(recalls)))
```

100%|██| 5/5 [1:02:37<00:00, 751.49s/it]

F1 0.7382080667175958+- 0.000318964765752628
Precision 0.726050543098252+- 0.001571383331193174
Recall 0.7507900677200903+- 0.002302040412457242
Accuracy 0.7440043407487792+- 0.0004060398683422727

GDBT – Sampling Strategy – SMOTE

```
import pandas as pd

data = pd.read_csv("analysis_frame_all2.csv")
data
data = data.dropna()

print(list(data.columns))

data.shape
```

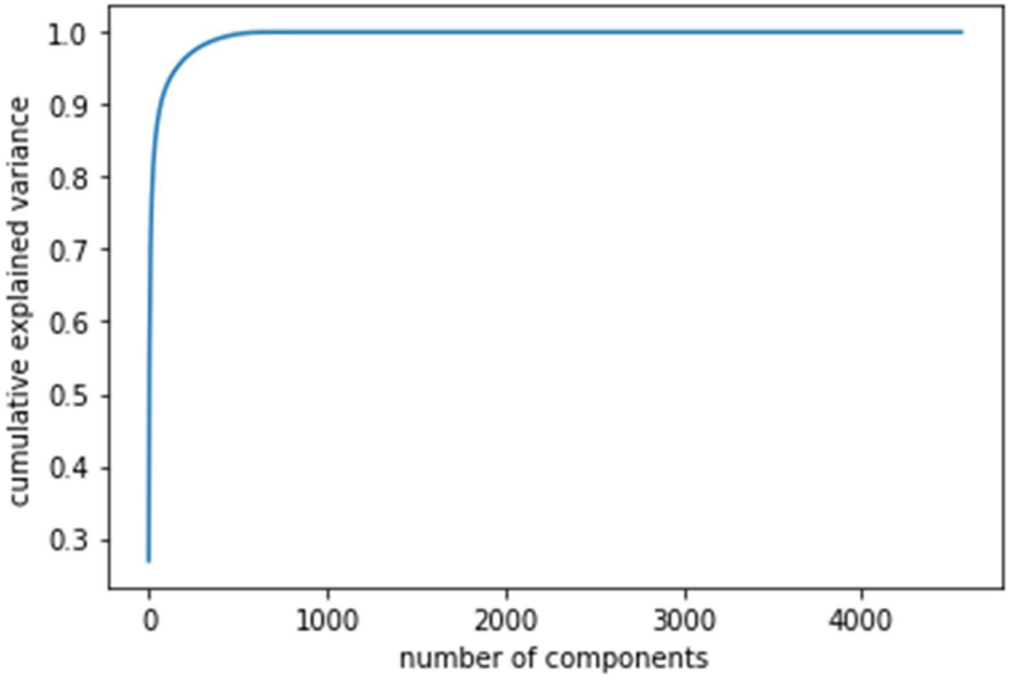
(6516, 4562)

```
data['completed_phase_2'].value_counts()
```

```
True     3445
False    3071
Name: completed_phase_2, dtype: int64
```

```
from imblearn.over_sampling import RandomOverSampler
from imblearn.over_sampling import SMOTE
# we will SMOTE the data
xcols = [x for x in list(data.columns) if x != 'completed_phase_2' and 'comp_measure' not in x]
undersample = SMOTE()
X = data[xcols]
Y = data[['completed_phase_2']]
x_over, y_over = undersample.fit_resample(X, Y)
print((x_over.shape, y_over.shape))
```

((6890, 4559), (6890, 1))



x_over

PCA

```
from sklearn import decomposition, datasets
import numpy as np
import matplotlib.pyplot as plt
%matplotlib inline
pca = decomposition.PCA().fit(x_over)
plt.plot(np.cumsum(pca.explained_variance_ratio_))
```

```
plt.xlabel('number of components')
plt.ylabel('cumulative explained variance');

print(np.cumsum(pca.explained_variance_ratio_))

x_pca = decomposition.PCA(n_components=100).fit(x_over)
x_pca.singular_values_
components = x_pca.transform(x_over)
x_projected = x_pca.inverse_transform(components)
print(x_projected)
```

```
from sklearn.model_selection import train_test_split
x_train, x_test, y_train, y_test = train_test_split(x_projected,y_over, test_size=0.30) #x_projected, x_o
ver
print((x_train.shape, x_test.shape, y_train.shape, y_test.shape))
```

((4823, 4559), (2067, 4559), (4823, 1), (2067, 1))

GDBT

```
from sklearn.ensemble import GradientBoostingClassifier
from sklearn import metrics
from sklearn.metrics import classification_report, confusion_matrix
from tqdm import tqdm
from sklearn.metrics import recall_score, precision_score,f1_score, accuracy_score
f1 = []
precisions = []
recalls = []
accuracy=[]
for i in tqdm(range(0,5)):
    clf = GradientBoostingClassifier(n_estimators=300, learning_rate=0.5, max_depth=5).fit(x_train, y_t
rain.values.ravel())
    y_pred = clf.predict(x_test)
    f1.append(f1_score(y_test, y_pred))
    precisions.append(precision_score(y_test, y_pred))
    recalls.append(recall_score(y_test, y_pred))
    accuracy.append(accuracy_score(y_test, y_pred))
print("F1 {}+- {}".format(np.mean(f1), np.std(f1)))
print("Precision {}+- {}".format(np.mean(precisions), np.std(precisions)))
print("Recall {}+- {}".format(np.mean(recalls), np.std(recalls)))
print("Accuracy {}+- {}".format(np.mean(accuracy), np.std(accuracy)))
```

100%|[redacted]| 5/5 [5:43:16<00:00, 4119.28s/it]

F1 0.8363744646349167+- 0.002428783569789654
Precision 0.8440833206263691+- 0.0017097205795177435
Recall 0.8288088642659279+- 0.0034351016136174094
Accuracy 0.8300919206579584+- 0.0023382769179670173

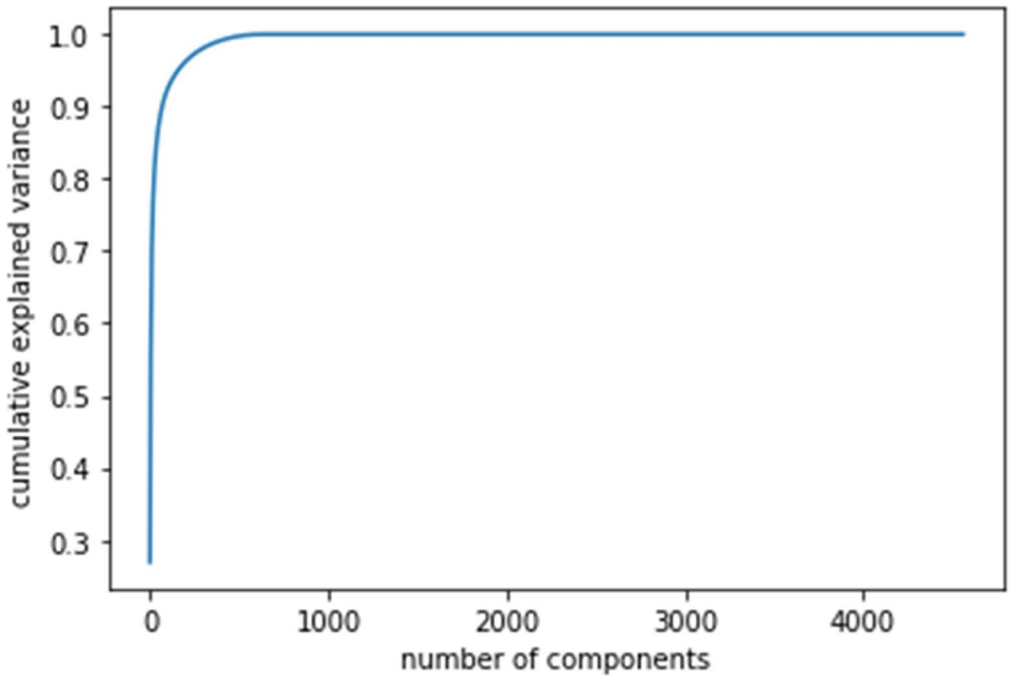
GBDT – Sampling Strategy – Oversample the minority

```
import pandas as pd

data = pd.read_csv("analysis_frame_all2.csv")
data
data = data.dropna()
```

```
data['completed_phase_2'].value_counts()
```

```
True    3445
False   3071
Name: completed_phase_2, dtype: int64
```




```
from imblearn.over_sampling import RandomOverSampler
# we will overrsamplesample the data
xcols = [x for x in list(data.columns) if x != 'completed_phase_2' and 'comp_measure' not in x]
oversample = RandomOverSampler(sampling_strategy='minority')
X = data[xcols]
Y = data[['completed_phase_2']]
x_over, y_over = oversample.fit_resample(X, Y)
print((x_over.shape, y_over.shape))
```

```
((6890, 4559), (6890, 1))
```

PCA

```
from sklearn import decomposition, datasets
import numpy as np
import matplotlib.pyplot as plt
%matplotlib inline
pca = decomposition.PCA().fit(x_over)
```

```
plt.plot(np.cumsum(pca.explained_variance_ratio_))
```

```
plt.xlabel('number of components')
plt.ylabel('cumulative explained variance');
```

```
print(np.cumsum(pca.explained_variance_ratio_))
```

```
x_pca = decomposition.PCA(n_components=100).fit(x_over)
x_pca.singular_values_
components = x_pca.transform(x_over)
x_projected = x_pca.inverse_transform(components)
print(x_projected)
```

```
from sklearn.model_selection import train_test_split
x_train, x_test, y_train, y_test = train_test_split(x_projected,y_over, test_size=0.30) #x_projected, x_o
ver
print((x_train.shape, x_test.shape, y_train.shape, y_test.shape))
```

((4823, 4559), (2067, 4559), (4823, 1), (2067, 1))

```
x_train
```

GDBT

```
from sklearn.ensemble import GradientBoostingClassifier
from sklearn import metrics
from sklearn.metrics import classification_report, confusion_matrix
from tqdm import tqdm
from sklearn.metrics import recall_score, precision_score,f1_score, accuracy_score
import pickle
f1 = []
precisions = []
recalls = []
accuracy = []
for i in tqdm(range(0,5)):
    clf = GradientBoostingClassifier(n_estimators=700, learning_rate=0.5, max_depth=5).fit(x_train, y_t
rain.values.ravel())
    y_pred = clf.predict(x_test)
    f1.append(f1_score(y_test, y_pred))
    precisions.append(precision_score(y_test, y_pred))
    recalls.append(recall_score(y_test, y_pred))
```

```
    accuracy.append(accuracy_score(y_test, y_pred))
    filename = 'GDBT_Oversamp.sav'
    pickle.dump(clf, open(filename, 'wb'))
print("F1 {}+- {}".format(np.mean(f1), np.std(f1)))
print("Precision {}+- {}".format(np.mean(precisions), np.std(precisions)))
print("Recall {}+- {}".format(np.mean(recalls), np.std(recalls)))
print("Accuracy {}+- {}".format(np.mean(accuracy), np.std(accuracy)))
```

```
100%|██████████████████████████████████████████████████████████████████████████| 5/5 [10:36:30<00:00, 7638.01s/it]
```

F1 0.8468325965473307+- 0.004829796671166811
Precision 0.8408634375540475+- 0.005264509246650846
Recall 0.8529069767441861+- 0.005985831477317997
Accuracy Score 0.8459603289791968+- 0.004814651303192936

Appendix J: Baseline and post-training 20mSRT total shuttles completed by males and females from 2013 – 2018 in the SFC

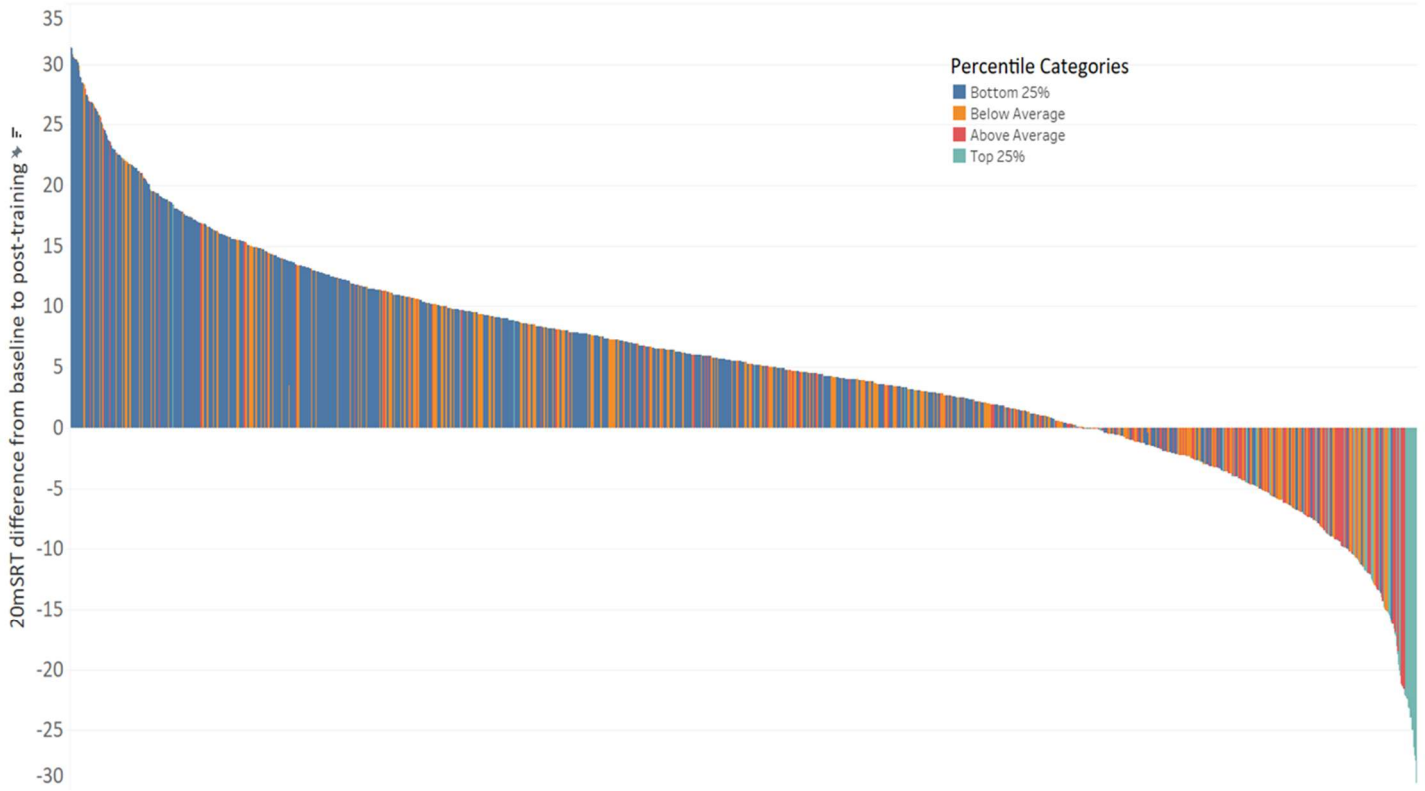
	Baseline	Post-training
Males		
2013	53.6±13.2	59.8±12.7‡
2014	54.0±12.6	60.9±13.6‡
2015	54.7±13.0	63.2±11.6‡
2016	58.0±14.1	61.7±12.7‡
2017	58.7±13.5	62.5±12.8‡
2018	55.1±13.5	61.2±12.7‡
Females		
2013	36.4±11.1	41.2±10.3‡
2014	38.3±11.9	44.6±11.8‡
2015	38.1±11.2	45.1±11.4‡
2016	41.4±11.2	43.9±11.5‡
2017	42.8±11.8	46.3±11.8‡
2018	41.9±11.5	45.9±10.4‡

Values presented are mean±SD. ‡ $p<0.001$ v Baseline each year;

Appendix K: 20mSRT results by year, gender and school DEIS/Fee status at baseline and post-training

Year	Gender	Deis Fee	Baseline	Post-training
2013	Male	NFND	55.4±12.1	62.9±12.2
		DEIS	49.2±14.5	53.6±11.8
		Fee Paying	63.5±6.2	65.4±6.7
	Female	NFND	37.1±10.5	42.2±9.9
		DEIS	33.5±11	38.1±10.7
		Fee Paying	47.0±7.9.0	48.9±4.9
2014	Male	NFND	54.3±11.9	60.3±12.5
		DEIS	52.8±14.9	61.2±16.6
		Fee Paying	57.0±8.2	69.3±7.0
	Female	NFND	38.5±10.3	44.5±10.4
		DEIS	36.9±13.1	43.3±14.3
		Fee Paying	46.5±11.5	51.6±9.9
2015	Male	NFND	55.5±13.6	65.5±12.8
		DEIS	49.9±10.8	56.4±13.9
		Fee Paying	62.9±10.3	67.7±11.3
	Female	NFND	39.3±11.4	47±10.8
		DEIS	33.5±9.5	38.5±11.9
		Fee Paying	43.6±9.4	48.5±7.9
2016	Male	NFND	61.5±12.5	65.5±10.1
		DEIS	50.4±16.8	51.4±14.3
		Fee Paying	52.4±7.3	60.1±8.9
	Female	NFND	42.6±10.3	46.2±9.9
		DEIS	32.1±9.6	34±12.8
		Fee Paying	48.2±8.0	47.6±8.5
2017	Male	NFND	61±14.2	64.3±13.2
		DEIS	51.4±10.4	55±9.9
		Fee Paying	60±8.5	66.9±8.7
	Female	NFND	43.5±11.3	47.4±10.8
		DEIS	34.8±10.5	36.1±11
		Fee Paying	51.0±8.6	54.0±9.0
2018	Male	NFND	55.7±13.2	62±11.8
		DEIS	50.4±15.7	52.8±15.5
		Fee Paying	57.7±11.8	68.1±8.1
	Female	NFND	41.9±10.5	45.4±9.4
		DEIS	36±13.3	39.9±12.8
		Fee Paying	49.3±9.5	53.9±8.2

Appendix L: Fan Chart displaying mean differences in 20mSRT between baseline and post-training, categorized by percentile category



Appendix M: DCUREC/2018/164

Dublin City University
RESEARCH ETHICS COMMITTEE

APPLICATION FOR APPROVAL OF A PROJECT INVOLVING **HUMAN PARTICIPANTS**

Application No. *(office use only)* DCUREC/2018/164

Please read the following information carefully before completing your application. Failure to adhere to these guidelines will make your submission ineligible for review.

- **Applications must be e-mailed to the DCU Research Ethics Committee at rec@dcu.ie** –no hardcopy required**.**
- **Student applicants must cc their supervisor on that e-mail** – this applies to all masters by research and PhD students. The form should be checked, approved and signed by the supervisor in advance of submission to REC. ***NB – Taught Masters and Undergraduate students apply for ethical review via their local review panels, not via REC.***
- **The application should consist of one electronic file only,** with an electronic signature from the PI. The completed application must incorporate all supplementary documentation, especially that being given to the proposed participants. It must be proofread and spellchecked before submission to the REC**.**
- **All sections of the application form must be answered as instructed and within the word limits given.**

Applications which do not adhere to all of these requirements will not be accepted for review and will be returned directly to the applicant.

Applications must be completed on the form; answers in the form of attachments will not be accepted, except where indicated. No hardcopy applications will be accepted. **Research must not commence until written approval has been received from the Research Ethics Committee.**

Note: If your research requires approval from the Biosafety Committee (BSC), or review by the School of Nursing and Human Sciences Ethics Advisory Committee (SNHSEAC), this must be in place prior to REC submission. Please attach the responses from these committees to this submission as directed below.

PROJECT TITLE	**L**ifestyle **I**ntervention **F**or **E**veryone: The **LIFE** Study
PRINCIPAL INVESTIGATOR(S)	Prof Niall M. Moyna
START AND END DATE	16.09.18 to 31.12.22
LEVEL OF RISK	Full review

Please confirm that all supplementary information is included in your application (in electronic copy). If questionnaire or interview questions are submitted in draft form, please indicate this by putting (draft) after YES. A copy of the final documentation must be submitted for final approval when available.

My application has been collated as one electronic file which includes the following documentation:	INCLUDED (mark as YES)	NOT APPLICABLE (mark as N/A)
Bibliography	YES	
Recruitment advertisement		N/A
Plain language statement/Information Statement	YES	
Informed Consent form	YES	
Personal Data Security Statement	YES	
Evidence of external approvals related to the research		N/A
Questionnaire/Survey	YES	
Interview/Focus Group Questions		N/A
Debriefing material		N/A
Other (e.g. BSC approval, SNHSEAC review letter)		N/A

Please note:

1. Any amendments to the original approved proposal must receive prior REC approval.
2. As a condition of approval investigators are required to document and report immediately to the Secretary of the Research Ethics Committee any adverse events, any issues which might negatively impact on the conduct of the research and/or any complaint from a participant relating to their participation in the study

1. ADMINISTRATIVE DETAILS

PROJECT TYPE: (mark Y to as many as apply)	Research Project	**Y**	Funded Consultancy	
			Clinical Trial	
	Student Research Project (please indicate level, e.g. PhD/MSc Research)	**Y**	Other - Please Describe:	
	PhD / Other Doctorate	**Y**		
	MSc Research			

1.1 INVESTIGATOR CONTACT DETAILS

PRINCIPAL INVESTIGATOR(S):

NAME	*SCHOOL/UNIT*	*EMAIL*
Prof. Niall Moyna	Health and Human Performance	niall.moyna@dcu.ie

OTHER INVESTIGATORS:

NAME	*SCHOOL/UNIT*	*EMAIL*
Dr. Brendan Egan	Health and Human Performance	brendan.egan@dcu.ie
Kevin O'Brien	Health and Human Performance	vevin.obrien7@mail.dcu.ie
Aidan Brady	Health and Human Performance	aidan.brady39@mail.dcu.ie
Nicola Hurley	Health and Human Performance	nicola.hurley5@mail.dcu.ie
Eoin Durkan	Health and Human Performance	eoin.durkan@dcu.ie
Dr. Andrew McCarron	School of Computing	andrew.mccarron@dcu.ie
Jason McKernan	Health and Human Performance	jason.mckernan2@mail.dcu.ie
Brian Guerin	Health and Human Performance	brian.guerin2@mail.dcu.ie
Liam Boland	Health and Human Performance	liam.boland8@mail.dcu.ie
Jonathan McCarron	Health and Human Performance	jonathan.mccarron7@mail.dcu.ie
Rachel O'Reilly	Health and Human Performance	rachel.reidy2@mail.dcu.ie

Bronwyn Grace	Health and Human Performance	bronwyn.grace3@mail.dcu.ie
Sophie Harrison	Health and Human Performance	sophie.harrison7@mail.dcu.ie
Eamonn Blake	Health and Human Performance	eamonn.blake8@mail.dcu.ie

1.2 WILL THE RESEARCH BE UNDERTAKEN ON-SITE AT DUBLIN CITY UNIVERSITY?

YES or NO
No

Data will be collected in DEIS schools in the Great Dublin Region.

1.3 IS THIS PROTOCOL BEING SUBMITTED TO ANOTHER ETHICS COMMITTEE, OR HAS IT BEEN PREVIOUSLY SUBMITTED TO AN ETHICS COMMITTEE?

YES or NO
No

N/A

7DECLARATION BY PRINCIPAL INVESTIGATOR(S)

The information contained herein is, to the best of my knowledge and belief, accurate. I have read the University's current research ethics guidelines, and accept responsibility for the conduct of the procedures set out in the attached application in accordance with the form guidelines, the REC guidelines (https://www.dcu.ie/researchsupport/researchethics.shtml), the University's policy on Conflict of Interest, Code of Good Research Practice and any other condition laid down by the Dublin City University Research Ethics Committee. I have attempted to identify all risks related to the research that may arise in conducting this research and acknowledge my obligations and the rights of the participants.

If there exists any affiliation or financial interest for researcher(s) in this research or its outcomes or any other circumstances which might represent a perceived, potential or actual conflict of interest this should be declared in accordance with Dublin City University policy on Conflicts of Interest.

I and my co-investigators or supporting staff have the appropriate qualifications, experience and facilities to conduct the research set out in the attached application and to deal with any emergencies and contingencies related to the research that may arise.

Electronic Signature(s):

Principal investigator(s):

Print Name(s) here: Niall Moyna

Date: *November 1, 2019*

2. PROJECT OUTLINE

1 LAY DESCRIPTION

Cardiovascular disease (CVD) refers to coronary heart disease, stroke and blood vessel disease, and is the leading cause of death in Ireland.[1] Although clinical heart disease occurs in middle-age and in older individuals, the presence of fatty plaque in large arteries and organ changes related to high blood pressure, and type II diabetes are now evident in childhood.[2] Children and youth who meet the dietary and physical activity guidelines are more likely to have a favorable cardiometabolic health profile and a reduced risk for CVD, obesity and type 2 diabetes (T2DM).[3] Socio-economic status is strongly related to health inequality and is a reliable predictor of youth health disparities.[4] In Ireland, children and youth groups from poorer families are perceived to be at higher risk than other young people, of experiencing ill health due to early exposure to chronic disease risk factors including sedentary behaviour, low participation in regular exercise and poor nutrition habits.[4] This is concerning considering that health behaviours track from childhood to adulthood.[6]

The purpose of this project is to evaluate the effect of a 6-week **L**ifestyle **I**ntervention **F**or **E**veryone **(LIFE)** programme on cardiometabolic health and aerobic fitness in children attending Deis schools. The LIFE programme is an inclusive, non-competitive, challenging and engaging exercise and nutrition intervention designed to empower young people from disadvantaged communities to improve their health and fitness.

2 AIMS OF AND JUSTIFICATION FOR THE RESEARCH

Lifestyle-mediated chronic diseases including obesity, T2DM and CVD begin early in life due to exposure to risk factors.[7] The duration of risk factor burden is a major factor governing the development of these chronic conditions (asymptomatic phase).[8] Children and youth who meet the physical activity and dietary guidelines are more likely to have a favorable cardiometabolic health profile and a reduced risk for CVD, obesity and T2DM.[9] In contrast, sedentary behaviour, low participation in regular exercise and poor nutrition habits during childhood and adolescence result in poor health in adulthood.[8]

Socio-economic status is strongly related to health inequality and is a reliable predictor of youth health disparities.[8] In Ireland, children and youth groups from poorer families are perceived to be at higher risk than other young people, of experiencing ill health due to early exposure to chronic disease risk factors. Among Irish children, low socio-economic status has an influence on diet, and participation in sport and physical activity.[9] For example, girls, from less socio-economically advantaged households are more likely to be overweight.[10] In addition, higher levels of exercise are associated with higher social class. Almost 40% of 13-year-olds in the lowest social group indicating have never participated in organised sports, compared with 17% in the highest social group.[11]

Greater focus needs to be placed on ecologically valid and sustainable primordial and primary prevention strategies to reduce sedentary behaviour, increase CRF levels and improve nutritional knowledge in youth from lower socio-economic communities. The purpose of this project is to evaluate the effect of a 6-week **L**ifestyle **I**ntervention **F**or **E**veryone **(LIFE)** programme on selected health parameters in children attending Deis schools. The LIFE programme is an inclusive, non-competitive, challenging and engaging exercise and nutrition intervention designed to empower young people from disadvantaged communities to improve their health and fitness. The primary aim of this study is to evaluate the effect of LIFE on sedentary behaviour, cardiorespiratory fitness, vascular health and dietary intake/knowledge in children and youth from disadvantaged communities.

2.3 DESCRIBE THE METHODOLOGY BEING USED TO ACHIEVE YOUR STATED AIMS

STUDY OVERVIEW

Experimental Design

The study is a randomized controlled trial. First year male and female students will be recruited to participate in this study.

Upon consent, participating students from one year will be randomly assigned to an intervention group or an age- and gender-matched control group.

Following a power calculation, 52 students are required to show a significance of 1 MET (3.5/ml/kg/min of VO_2) improvement in estimated VO_2 max. Estimating a dropout rate of 15%, a sample of 60 in each group will be recruited.

Should we fail to recruit >x students from a 1st year within a single school, we will recruit students from 1st year in additional post-primary school(s). Recruitment will continue until x students have been recruited to participate in this study.

Testing Day 1 (Baseline and follow-up): Body composition, hand grip strength and dietary intake will be measured after which participants will complete a 20 m shuttle run test (20 m SRT). They will be fitted with an ActivPal activity monitor which they will wear for the next 7 days. (Dietary intake will be reassessed in both groups at week 3)

Testing Day 2 (Baseline and follow-up): Participants will arrive to school following an overnight fast. Within 2 h of arriving to school, participants will have a blood sample drawn, carotid intima-media thickness imaged* and their blood pressure and the stiffness of their arteries assessed.

*Carotid intima-media thickness will only be assessed at baseline.

ASSESSMENT PROTOCOLS

Please note, a female researcher will carry out the following tests on girls participating in this study.

Body composition: Height will be measured using a portable stadiometer (SECA). Weight and body composition will be measured using an electronic balance scales with bioelectrical impedance (Tanita Body Comp Analyzer TBF300WA). Footwear and any heavy clothing will be removed prior to measurement. The participant will be asked to stand with arms by their sides, feet placed close together, and weight evenly distributed across their feet. Waist circumference will be measured at the approximate midpoint between the lower part of the last palpable rib and the top of the iliac crest. The measurement will be taken at the end of a normal expiration. Hip circumference will be measured around the widest aspect of the buttocks.

Handgrip Strength: A handheld dynamometer (Takei - Hand Grip Dynamometer Digital) will be used to measure handgrip strength. While standing upright, with the dyanamometer in their dominant hand and elbow at 90 degrees, the participants will to squeeze maximally and hold the contraction for 5 sec.

Cardiorespiratory Fitness: A 20m shuttle run test (SRT) will be used to estimate cardiorespiratory fitness. Participants will run back and forth between two lines 20 m apart, keeping in time with a series of audio signals (bleeps). The initial speed will be 8.0 km/hr and will increase by 0.14 m/sec every min. The test will be terminated if a participant stops voluntarily, or is unable to maintain the set pace. Heart rate will be continuously monitored using a receiver attached to a strap (Polar) worn around the chest.

Carotid Intima-Media Thickness: Thickness of the carotid intima-media will be assessed using MultiHertz linear-array transducer (Siemens, Acuson P500) and Siemens portable ultrasound system (Acuson P500 FROSK). Ultrasound images of the carotid artery will be obtained with the participant resting in a supine position, with the head turned slightly to the contralateral side. The common coronary artery (CCA), including the carotid bulb, will be visualized, and 2 longitudinal B-mode images

of the left and the right common carotid arteries will be recorded and electronically stored. Carotid Studio software by Quipu will be used to instantaneously measure IMT by real-time processing of B-mode ultrasound image sequences from longitudinal section of the artery. The method uses an edge detection algorithm and works in real-time with a frame rate equal to 25 frames/sec. The intima media thickness will be computed during the last 8 sec of the examination.

Blood Pressure Measurement: Blood pressure will be measured using a sphygmomanometer and a stethoscope, following 5 min of seated rest.

Arterial Stiffness: Participants will rest in a supine position with shoes and socks/tights removed. The participant's head and shoulders may be supported by a pillow and the bed adjusted so that the neck is not compressed onto the chin and the upper body is at an angle of approximately 30 degrees (Figure 3). A pressure sensor cuff will be placed around their neck. A blood pressure cuffs will also be placed around the upper thigh (Figure 3), upper arm (Figure 1), and ankle (Figure 2). A sensor clip will also be place on the big toe of right foot (Figure 2) and on the middle finger of right hand (Figure 4.) to assess arterial stiffness via pulse wave velocity and ankle brachial index (Vicorder 2 Electronics module). The blood pressure cuffs can be placed over thin clothing (e.g. t-shirt, blouse, trousers, jeans etc.). Following cuff placement, the distance between the sternoclavicular joint to the midpoint of the ankle blood pressure cuff will be measured using a Seca measuring tape. The participant will then be left to rest quietly for 5 – 10 min

Blood Sample: A blood sample will be drawn via a single venipuncture in the forearm to measure fasting glucose, blood lipids, insulin and other cardiometabolic biomarkers including high-sensitivity C-reactive protein.

Physical Activity Monitoring: a small inertial monitoring unit (ActivPal, Pal Technologies) will be placed on the thigh. A clear adhesive tegaderm dressing will be used to secure the unit to the participants' leg. Participants will be required to wear the ActivPal for 1 week during the baseline testing and follow-up testing phases. The ActivPal unit will be collected from each participant after seven days of wear.

Physical Activity Recall: Participants will be asked to fill in a Physical Activity Questionnaire designed for children and adolescents depending on their age. Participants aged 10-14 will be complete the PAQ-C whereas those between 14-18 year will complete the PAQ-A.

24 h Dietary Recall: A 24 h dietary recall will be undertaken using an online software programme (https://intake24.co.uk)

INTERVENTION GROUP

Nutrition: Following the completion of the baseline testing, Dr. Brendan Egan (PI) will deliver three nutrition information sessions to the intervention group, and one to their parents/guardians.

Exercise Sessions:

The intervention group will participate in 3 exercise sessions per week for 6 weeks and will attend 3 nutrition classes during this time. Their parents/guardians will also be given the opportunity to attend a nutrition class tailored for parents. Participants will be assessed on two separate days, with a minimum of 24 h between each testing day at baseline and following a 6-week period.

The exercise sessions will take place during school time and will be designed and delivered by qualified exercise specialists. The exercise sessions will involve games, challenges and resistance exercises. Exercise session intensity will be monitored during weeks 1, 3 and 5 using heart rate monitors (Polar Team 2 system).

CONTROL GROUP

The control group will undergo the same baseline and 6-week follow-up testing as the intervention group. They will also complete a 24 h dietary recall at week 3. The control group will not participate in any of the LIFE exercise sessions or attend the LIFE nutrition sessions.

Videography/Photography

Throughout the programme images or video footage may be taken of the group exercise sessions for the following reasons:

1) To provide feedback to the participants during the exercise teaching to enhance learning
2) For the creation of an exercise programme that will be available to the students and their teachers when the programme is completed
3) For possible use on social media platforms to highlight and promote the work being done in the community
4) For possible use in print in the media
5) For possible use on the DCU website to highlight the work being done in the community
6) For possible use in presentations at conference proceedings

No image published will not be associated with the name of a child and will primarily be in group settings. Faces of children will be blurred in any images used for publication.

2.4 PARTICIPANT PROFILE

One hundred and twenty boys and girls (approximately 1 post primary school year) between the ages of 12-18 years will be recruited to participate in the study. Sixty students will be assigned to the intervention group and sixty to the control group.

2.4(a) PARTICIPANT VULNERABILITY

Participants in this study will be boys and girls between 12 and 18 years of age. Aside from being classified as minors (<18 years), participants are not considered to be vulnerable in any way.

2.4(b) CHILD PARTICIPANTS (anyone under 18 years old)

Please indicate your compliance with the following guidelines:	**Mark here**
We confirm that we have read and agree to act in accordance with the DCU Child Protection policy and procedures	Yes
We confirm that we have put in place safeguards for the children participating in the research	Yes
We confirm that we have supports in place for children who may disclose current or historical abuse (whether or not this is the focus of the research)	Yes

2.5 EXPLAIN HOW PARTICIPANTS ARE TO BE RECRUITED

A letter (Appendix 1) providing a brief summary of the research project will be sent to principals of Deis schools, in the greater Dublin region. Upon expression of interest plain language statements, informed consent and assent forms will be sent to the schools to be distributed.

2.6 PLEASE EXPLAIN WHEN, HOW, WHERE, AND TO WHOM RESULTS WILL BE DISSEMINATED, INCLUDING WHETHER PARTICIPANTS WILL BE PROVIDED WITH ANY INFORMATION AS TO THE FINDINGS OR OUTCOMES OF THE PROJECT?

The results will be published in peer-reviewed publications and conference presentations. The identity of the individual participants will remain anonymous. Information, as a group, will only be presented

2.7 ARE OTHER APPROVALS REQUIRED TO GAIN ACCESS TO ANOTHER LOCATION, ORGANISATION ETC.?

YES or NO
Yes

The Principal in each school will be asked to consent to their school's involvement, as described in section 2.5

2.8 HAS A SIMILAR PROPOSAL BEEN PREVIOUSLY APPROVED BY THE DCU REC?

YES or NO
No

3. RISK AND RISK MANAGEMENT

3.1 JUSTIFICATION OF STATED LEVEL OF RISK TO RESEARCH PARTICIPANTS

With the exception of arterial stiffness measurement, the current research project involves standardised protocols, that have been previously approved by the REC for studies involving boys and girls between the ages of 12 and 18 years. The necessary training and appropriate supervision are in place.

8
9 **3.2 DOES THE RESEARCH INVOLVE:**

	YES or NO
• use of a questionnaire? (attach copy)?	YES
• interviews (attach interview questions)?	NO
• observation of participants without their knowledge?	NO
• participant observation (provide details in section 2)?	NO
• audio- or video-taping interviewees or events?	YES
• access to personal and/or confidential data (including student, patient or client data) without the participant's specific consent?	NO
• administration of any stimuli, tasks, investigations or procedures which may be experienced by participants as physically or mentally painful, stressful or unpleasant during or after the research process?	YES
• performance of any acts which might diminish the self-esteem of participants or cause them to experience embarrassment, regret or depression?	NO
• investigation of participants involved in illegal activities?	NO
• procedures that involve deception of participants?	NO
• administration of any substance or agent?	NO
• use of non-treatment of placebo control conditions?	NO
• collection of body tissues or fluid samples?	YES
• collection and/or testing of DNA samples?	NO
• participation in a clinical trial?	NO
• administration of ionising radiation to participants?	NO

3.3 POTENTIAL RISKS TO PARTICIPANTS AND RISK MANAGEMENT PROCEDURES

Drawing blood may cause a slight pain and discomfort and can result in localized bruising where the needle is inserted. An individual trained in phlebotomy will draw the blood samples. A volume of approximately 30 mL of blood will be drawn. Blood samples are required to assess fasting glucose, blood lipids, insulin and other cardiometabolic biomarkers including high-sensitivity C-reactive protein.

3.4 ARE THERE LIKELY TO BE ANY BENEFITS (DIRECT OR INDIRECT) TO PARTICIPANTS FROM THIS RESEARCH?

YES or NO
YES

Study participants will receive a copy of their fitness test results and the following blood results: glucose, total cholesterol, HDL-cholesterol, LDL-cholesterol and high-sensitivity C-reactive protein. They will also receive a lay summary of the study when it is concluded.

3.5 ARE THERE ANY SPECIFIC RISKS TO RESEARCHERS?

Examples include use of dangerous materials, asking certain types of questions, research being undertaken in certain locations, researchers working alone in isolated areas, etc.

YES or NO
NO

3.6 DEALING WITH ADVERSE/UNEXPECTED OUTCOMES

The research team involved in this study has the capabilities to deal with all aspects of this study and an emergency plan is in place for adverse events. All minor injuries will be addressed by referring the participant to each school's health service area. In the unlikely event of a serious adverse outcome, either an ambulance will be called or the participant will be brought to a local hospital. The school's own policies and procedures will be followed in all instances. Furthermore, a first aid kit and mobile phone will be on site at all times.

In the event of an unexpected outcome, it will be brought to the attention of Dr. Noel McCaffrey, medical director in the School of Health and Human performance. Based on Noel's interpretation, if it is deemed results warrant follow up, a letter will be sent to parents with a request that they make an appointment to see the appropriate medical personnel.

3.7 HOW WILL THE CONDUCT OF THE PROJECT BE MONITORED?

The principal investigators will be involved in all aspects of the research, including participant recruitment and data collection. The research team will have weekly meetings to update on all aspects of the study. All researchers, including students, are familiar with the procedures and the Safety Statement prior to beginning data collection.

3.8 SUPPORT FOR PARTICIPANTS

N/A

3.9 DO YOU PROPOSE TO OFFER PAYMENTS OR INCENTIVES TO PARTICIPANTS?

YES or NO
No

3.10 DO ANY OF THE RESEARCHERS ON THIS PROJECT HAVE A PERSONAL, PHILOSOPHICAL, FINANCIAL OR COMMERCIAL INTEREST IN ITS OUTCOME THAT MIGHT INFLUENCE THE INTEGRITY OF THE RESEARCH, OR BIAS THE CONDUCT OR REPORTING OF THE RESEARCH, OR UNDULY DELAY OR OTHERWISE AFFECT THEIR PUBLICATION?

YES or NO
No

4. INVESTIGATORS' QUALIFICATIONS, EXPERIENCE AND SKILLS *(Approx. **200 words**)*

- Prof. Niall Moyna is an exercise physiologist and has extensive experience in cardiovascular research, phlebotomy and exercise testing
- Dr. Brendan Egan is a sports nutritionist with extensive experience delivering nutrition seminars to athletes and the general population. Dr. Egan also has a extensive experience in the area of skeletal muscle adaptation to exercise and nutrition strategies to enhance this
- Dr Andrew McCarron is a statistician
- Aidan Brady, Eoin Durkan, and Nicola Hurley are PhD students in the School of Health and Human Performance. Each has extensive experience with the experimental procedures to be used in the study
- Kevin O'Brien, BSc Sport Science and Health, is a PhD student in the School of Health and Human Performance. Kevin has assessed hundreds of athletes, school children and adults across various sports in laboratory and field based settings. Kevin has experience working with large excel databases through previous employment in IT Carlow, coaching and assessing athletes in his career. Kevin was awarded the "Outstanding Researcher of the Year" in 2005 for his undergraduate thesis.

5. CONFIDENTIALITY/ANONYMITY

5.1 WILL THE IDENTITY OF THE PARTICIPANTS BE PROTECTED?

YES or NO
Yes

IF YOU ANSWERED YES TO 5.1, PLEASE ANSWER THE FOLLOWING QUESTIONS:

5.2 HOW WILL THE ANONYMITY OF THE PARTICIPANTS BE RESPECTED?

All data will be anonymized by assigning an ID code to each participant. The participants name will not appear on research document or publication.

5.3 LEGAL LIMITATIONS TO DATA CONFIDENTIALITY

The following statement will be included in the plain language statement.
"Confidentiality of information provided can only be protected within the limitations of the law. It is possible for data to be subject to subpoena, freedom of information claim or mandated reporting by some professions".

6. PERSONAL DATA - COMPLIANCE WITH THE GENERAL DATA PROTECTION REGULATION

Personal data is data relating to a living individual (i.e. the 'Data Subject') who is, or can be, identified either from the data itself or from the data in conjunction with other information that is in, or is likely to come into, the possession of the 'Data Controller' (i.e. DCU and its constituent units e.g. research teams etc.). ***Further information available at https://www.dcu.ie/ocoo/dp/guides.shtml***

6.1 IS PERSONAL DATA BEING PROCESSED AS PART OF THIS PROJECT?

YES or NO
YES

If YES, Please indicate your compliance with the following guidelines:	Mark here
We confirm that we have read and agree to act in accordance with DCU guidance and procedures regarding personal data	YES
We confirm that we have put in place a Personal Data Security Schedule (PDSS) for the project and have attached it to this application	YES

IF YOU ANSWERED YES TO 6.1, PLEASE ANSWER THE FOLLOWING QUESTIONS:

6.2 WHAT KIND OF PERSONAL DATA IS BEING PROCESSED?

The following personal data will be collected as part of this research study:

- Name
  - Date of birth/age
- Race
- Informed consent
- Informed assent
- Anthropometric data (i.e. body composition)
- Blood markers
- Aerobic fitness results
- Carotid intima-media thickness measurement
- Arterial stiffness score
- Physical activity profile
- Dietary intake
- Blood pressure
- Heart rate

6.3 WILL ANONYMISATION/PSEUDONYMISATION OF THE PERSONAL DATA BE UNDERTAKEN?

YES or NO
YES

7. DATA/SAMPLE STORAGE, SECURITY AND DISPOSAL

For the purpose of this section, "Data" includes that in a raw or processed state (e.g. interview audiotape, transcript or analysis). "Samples" include body fluids or tissue samples.

7.1 HOW AND WHERE WILL THE DATA/SAMPLES BE STORED?

Data collection forms will be stored in a secure, locked cabinet in the Vascular Health Research Unit in the School of Health and Human Performance at DCU. All personal data will be anonymised and electronic data will be saved in a password- protected computer in the School of Health and Human Performance at DCU. Blood samples will be stored in a -70°C freezer in the School of Health and Human Performance at DCU.

7.2 WHO WILL HAVE ACCESS TO DATA/SAMPLES?

The principal investigators and named collaborators listed on this ethics application will have access to the data.

7.3 HOW LONG IS THE DATA TO BE HELD/RETAINED FOR?

All personal data will be anonymised and saved in a password protected file on a computer at DCU. Data collection sheets and files containing identifiable data will be shredded and erased using a secure electronic shredder, respectively, following anonymisation.

7.4 IF DATA/SAMPLES ARE TO BE DISPOSED OF, PLEASE EXPLAIN HOW, WHEN AND BY WHOM THIS WILL BE DONE?

Blood samples will be placed in medical waste and hard copies of data collection sheets with personalised data will be shredded. Electronic data will be anonymized and stored for potential future use.

8. FUNDING OF THE RESEARCH

8.1 HOW IS THIS WORK BEING FUNDED?

This research study is being funded by TUSLA under the Quality and Capacity Building Initiative - "Enhancing Children's and Young People's Outcomes"

8.2 PROJECT GRANT NUMBER *(If relevant and/or known – otherwise mark as N/A)*

N/A

8.3 DOES THE PROJECT REQUIRE APPROVAL BEFORE CONSIDERATION FOR FUNDING BY A GRANTING BODY?

YES or NO
No

8.4.1 HOW WILL PARTICIPANTS BE INFORMED OF THE SOURCE OF THE FUNDING? *(e.g. included in the Plain Language Statement)*

It is included in the plain language statement

8.5 DO THE FUNDERS OF THIS PROJECT HAVE A PERSONAL, FINANCIAL OR COMMERCIAL INTEREST IN ITS OUTCOME THAT MIGHT COMPROMISE THE INDEPENDENCE AND INTEGRITY OF THE RESEARCH, OR BIAS THE CONDUCT OR REPORTING OF THE RESEARCH, OR UNDULY DELAY OR OTHERWISE AFFECT THEIR PUBLICATION?

YES or NO
No

9. PLAIN LANGUAGE STATEMENT *(Attach to this document. Approx. 400 words)*

DUBLIN CITY UNIVERSITY

Plain Language Statement

Project Title: **Lifestyle Intervention For Everyone: The LIFE Study**

Principal Investigators: Prof. Niall Moyna, School of Health and Human Performance

Email: niall.moyna@dcu.ie,

I. Introduction to the Research Study

Cardiovascular disease (CVD) refers to heart disease, stroke and blood vessel disease, and is the leading cause of death in Ireland. While CVD is usually associated with middle-age and older individuals, the presence of the disease is now evident in childhood. Many people are now experiencing ill health at a younger age, due to prolonged exposure to disease risk factors such as cigarette smoking, sedentary behaviour, low participation in regular exercise and poor nutrition habits.

Children and adolescents with higher fitness levels have a much lower chance of developing this disease.

In addition, improving a young person's basic understanding of nutrition may help them to make healthier, better decisions about the types of food and drinks they eat and drink.

The **L**ifestyle **I**ntervention **F**or **E**veryone **(LIFE)** programme is an inclusive, non-competitive, challenging and engaging exercise and nutrition intervention designed to empower young people to improve their health and fitness.

The purpose of this research study is to examine the effect of the 6-week LIFE programme on the cardiovascular health of children in secondary schools.

II. What will happen if the person decides to participate in the research study?

Participation in the study involves participating in a 6-week exercise programme that will take places in school, during school time. The exercise programme involves three 60-minute exercise classes each week (18 in total) for the 6-week period. During some of the exercise sessions, participants will wear a heart rate monitor to measure their heart rate. Before the exercise programme begins participants will attend 3 nutrition information sessions. An additional nutrition information session will be offered to participants' parents/guardians before the programme begins.

Before and after the 6-week programme the following tests will be carried out:

- Height and weight will be measured using a height measuring device and an electronic scales
- Hip and waist size will be measured using a measuring tape

Handgrip strength will be measured by gripping a device called a dynamometer in the participant's hand and squeezing as tightly as possible (see picture 1 below).

- 

- Cardiovascular fitness will be measured using the 20m shuttle run test. This test involves running back and forth between two lines 20 m apart, keeping in time with a series of audio signals (bleeps). Participants will be encouraged to run for as long as they can and will wear a strap around their chest to measure heart rate during this test. At any point during this test the participant can stop voluntarily.
- The health of the arteries in the neck will be measured by taking 2 images of the neck with an ultrasound machine (see picture 2below). Participants will lie on their back, with their head turned first to the right and then to the left in order to take the images.



Picture 2

- Participants will rest in a seated position for 5 min before they have their blood pressure measured, and the stiffness of their blood vessels assessed by measuring the speed at which the blood travels through the body. During these tests participants will wear a sensor cuff around their neck, blood pressure cuffs on their upper arms and legs, and a sensor clip on the big toe of their right foot and on the middle finger of right hand (See picture 3)



Picture 3

- Physical activity will be monitored for 7 days by wearing a physical activity monitor on the upper leg. The physical activity monitor will be returned to the researchers at the end of the 7 days
- Food and drinks consumed over the course of one day (24h) will be recorded on a computer during a supervised session in a classroom in school. On one other occasion, in the middle of the 6-week programme, an additional recording of food and drink consumption for one full day (24h) will take place
- On one morning participants will arrive to school having not eaten any food, and only drank water, since 22:00hr the night before. A blood sample will be taken from a small vein in their arm

- Throughout the programme images or video footage may be taken of the group exercise sessions for the following reasons:
    7) To provide feedback to the participants during the exercise teaching to enhance learning
    8) For the creation of an exercise programme that will be available to the students and their teachers when the programme is completed
    9) For possible use on social media platforms to highlight and promote the work being done in the community
    10) For possible use in print in the media
    11) For possible use on the DCU website to highlight the work being done in the community
    12) For possible use in presentations at conference proceedings

  No image published will be associated with the name of a child and will primarily be in group settings. The faces of children will be blurred in any images used for publication.

III. Arrangements to protect confidentiality of data

- Participant identity and other personal information will not be revealed, published or used in further studies or third parties
- All personal data will be anonymised and saved in a password protected file on a computer at DCU. Data collection sheets and files containing identifiable data will be shredded and erased using a secure electronic shredder, respectively, following anonymisation.
- Only named investigators on this research project will be allowed to view the data
- Electronic data will be stored on a password-protected computer in the School of Health and Human Performance at DCU
- We may require the assistance of sub-processors such as; a medical pathology lab (to analyse blood samples in a specific way) or online platform providers (to manage the dietary recall). All our sub-processors are GDPR compliant and processor agreements will be in place with all of our sub-processors. During any of these processes, sub-processors will have no access to personal data
- Under the Data Protection Act/GDPR you have the right to access all of the personal data we hold that relates to you. You can request a Subject Access Request by emailing niall.moyna@dcu.ie. We will do everything in our power to supply, correct or delete any personal information as soon as possible

IV. Potential risks from involvement in the Research Study

During the process of taking a blood sample, a slight pain may be experienced when the needle is inserted. Some individuals may experience slight bruising afterwards in the area where the needle was inserted.

VI. Benefits from involvement in the Research Study

Participants will receive a summary of their own results and a comparison to other individuals of the same gender and age.

VII. Involvement in the Research Study is voluntary

Involvement in the study is voluntary. Participants may withdraw from the Research Study at any point. There will be no penalty for withdrawing before the research study has been completed.

VIII. How will participants find out what happens with the project?

Information regarding any research publications or conference proceedings will be sent to the principals of the participating schools. The participants will receive copy of their aerobic fitness results and the following blood results: glucose, total cholesterol, HDL-cholesterol, LDL-cholesterol and high-sensitivity C-reactive protein. They will also receive a lay summary of the study when it is concluded.

IX. How will unexpected outcomes be dealt with?

In the event of an unexpected outcome, Prof. Moyna will contact the parents and request that they make an appointment to see the appropriate medical personnel.

If participants have concerns about this study and wish to contact an independent person, please contact:

The Secretary, Dublin City University Research Ethics Committee, c/o Office of the Vice-President for Research, Dublin City University, Dublin 9. **Tel**: 01-7008000

10. INFORMED CONSENT FORM *(Attach to this document. Approx. 300 words)*

Research Study Title

Lifestyle Intervention For Everyone: The LIFE Study

Principle Investigator
Prof. Niall Moyna, School of Health and Human Performance

II. Purpose of the research

The purpose of this research study is to examine the effect of the 6-week LIFE programme on the cardiovascular health of children in secondary schools.

III. Participant Requirements

Participants in this study will:

- take part in an exercise programme that involves three exercise classes per week for 6 weeks (a total of 18) that will take place in school, during school time
- wear a heart rate monitor strap around their chest during a number of these exercise sessions
- attend 3 nutrition information sessions. An additional nutrition information session will be offered to participants' parents/guardians

Throughout the programme images or video may be taken of the group exercise sessions for educational and promotional reasons

Before and after the 6-week programme the following tests will be carried out on the participating boys and girls:

- Height, weight, hip and waist size will be measured
- Food and drinks consumed over the course of one full day (24h) will be recorded. On one other occasion, in the middle of the 6-week programme, an additional recording of food and drink consumption for one full day (24h) will take place
- Physical activity will be monitored for 7 days by wearing a physical activity monitor on the upper leg
- Participants will return the physical activity monitor after wearing it for 7 days
- Handgrip strength and aerobic fitness will be assessed
- Participants will rest in a seated position for 5 min before having their blood pressure measured and the stiffness of their blood vessels assessed
- 2 images will be taken of the carotid arteries in the neck using an ultrasound machine
- On one morning participants will arrive to school having not eaten any food, and only drank water, since 22:00hr the night before. A blood sample will be taken from a small vein in their arm

IV. Confirmation of particular requirements as highlighted in the Plain Language Statement

Please complete the following (Circle Yes or No for each question)

I have read the Plain Language Statement (or had it read to me)	Yes ☐ No ☐
I understand the information provided	Yes ☐ No ☐
I have had an opportunity to ask questions and discuss this study	Yes ☐ No ☐
I have received satisfactory answers to all my questions	Yes ☐ No ☐

V. Confirmation that involvement in the Research Study is voluntary

Participants can withdraw from the research study at any point

VI. Advice as to arrangements to be made to protect confidentiality of data, including that confidentiality of information provided is subject to legal limitations

Participant's name and other personal information will not be revealed, published or used in further studies. All personal data will be anonymised and saved in a password protected file on a computer at DCU. Data collection sheets and files containing identifiable data will be shredded and erased using a secure electronic shredder, respectively, following anonymisation.

The named investigators will have access to the unidentifiable data.

Confidentiality is insured, but you must be aware that confidentiality of information provided can only be protected within the limitations of the law. It is possible for data to be subject to subpoena, freedom of information claim or mandated reporting by some professions.

VII. How will unexpected outcomes be dealt with?

In the event of an unexpected outcome, Prof. Moyna will contact the parents and request that they make an appointment to see the appropriate medical personnel.

Parent's Signature:

I have read and understood the information in this form. My questions and concerns have been answered by the researchers, and I have a copy of this consent form. Therefore, I consent to allow my child take part in this research project

Participant's name: _____

Parent's Signature: _____

Name in Block Capitals: _____

Contact number: _____

Witness: _____

Date: _____

Are you happy for photographs or video footage to be taken of your child during this programme
Any photos used of your childs face will be blurred for publication.

Please tick the box.

Yes, I consent to photographs or video footage being taken of my child during this programme ☐

No, I do not consent to photographs or video footage being taken of my child during this programme ☐

DUBLIN CITY UNIVERSITY

Assent Form

Research Study Title: Lifestyle Intervention For Everyone: The LIFE Study

I have been told that if I take part in this study:

- I will attend three exercise sessions per week for 6 weeks (a total of 18)
- The exercise sessions will take place in my school, during school time
- During some of these exercise sessions I will wear a strap around my chest to monitor my heart rate
- On one morning before and after the 6-week exercise programme:
    1) I will arrive to school without eating breakfast and having only drank water since 10pm the night before. The researcher from Dublin City University will take a blood sample, using a needle, from a vein in my forearm. I know that taking a blood sample can cause a brief sharp "pinch-like" pain and can sometimes result in a bruise afterwards
    2) I will sit for 5 minutes in a quiet room, before blood pressure cuffs are placed on my upper arm and leg, a pressure sensor around my neck, and a sensor clip on my big toe and middle finger. These cuffs will inflate and deflate a number of times to measure my blood pressure and the speed blood travels through my body. The cuff may squeeze my arm and leg a little but never too tight
    3) I will then lie on a bed and turn my head to the side. The researcher from Dublin City University will use an ultrasound machine to take a photograph of a blood vessel in my neck. I will turn my head to the opposite side and the researcher will take a photograph of the blood vessel on the other side of my neck. This test will take about 10 minutes
- On another day before and after the 6-week exercise programme:
    1) I will have my height, weight, waist and hip measured
    2) I will squeeze a handle as hard as I can to test my strength
    3) I will run for as long as I can in the 20-meter shuttle run to test my aerobic fitness
    4) I will be given a physical activity monitor to wear on my leg for 7 days to measure how active I am. I will return the monitor to the researchers after the 7 days
    5) I will record all of the food and drinks I consume over the course of one full day (24hours) on a computer in a classroom in school. There will be an adult there to help me do this and to answer any of my questions. On one other occasion, in the middle of the 6-week programme, I will record my food and drink for one full day (24h) again
- I will attend all of the testing days and take part in all of the exercise classes organised by the researchers
- I will attend the nutrition talks and encourage my parents/guardians to attend the talk that will be organised for them
- I know that at any point I can stop taking part in any of the tests or this research study
- I know that the researchers from Dublin City University, my teachers or my parents/guardians will not be upset with me if I decide not to take part in this study, or if I wish to stop taking part in the study

- I know that throughout the programme there may be photographs or video footage taken of me to improve the programme or to promote the programme

SIGNED: _____ DATE: _____
(Participant's name)

SIGNED: _____ DATE: _____
(Witness name)

Are you happy for photographs or video footage to be taken of you during this programme
Please tick the box.

Yes, I consent to photographs or video footage being taken of my child during this programme ☐

No, I do not consent to photographs or video footage being taken of my child during this programme ☐

DCUREC/2018/164 - Appendix 1

School of Health and Human Performance
Faculty of Science and Health
Dublin City University
Dublin 9

Tel: +353 (0)1 700 5914

Email: sarah.kelly@dcu.ie

August 2018

Dear Principal:

Following recent participation in the Children's Sport Participation and Physical Activity Study we would like to invite boys and girls from your school to take part in a follow-up study commencing in September 2018.

Cardiovascular disease (CVD) refers to heart disease, stroke and blood vessel disease, and is the leading cause of death in Ireland. While CVD is usually associated with middle-age and older individuals, the presence of fatty plaque in large arteries and organ changes related to high blood pressure, and type II diabetes are now evident in childhood. Many people are now experiencing ill health at a younger age, due to prolonged exposure to disease risk factors such as cigarette smoking, sedentary behaviour, low participation in regular exercise and poor nutrition habits.

Children and adolescents with higher aerobic fitness levels (CRF) have a more favourable cardiovascular risk profile and a reduced risk of heart attack, stroke, and death later in adulthood. In addition, improving a young person's basic understanding of nutrition may help them to make healthier, informed decisions about the types of food and drinks they consume.

The **L**ifestyle **I**ntervention **F**or **E**veryone **(LIFE)** programme is an inclusive, non-competitive, challenging and engaging exercise and nutrition intervention designed to empower young people to improve their health and fitness. The purpose of this research study is to examine the effect of the 6-week LIFE programme on the cardiovascular health of children in secondary schools.

If you are interested in your students participating in this proposed study or would like more information please feel free to me directly

Thank you for taking the time to read this letter.

Best wishes,

_____
Prof. Niall M. Moyna

DCUREC/2018/164 - *Appendix 2*

Physical Activity Questionnaire (Children Aged 10-14)

Name:_____ Age:_____ Boy / Girl (please circle)

We are trying to find out about your level of physical activity from ***the last 7 days*** (in the last week). This includes sports or dance that make you sweat or make your legs feel tired, or games that make you breathe hard, like tag, skipping, running, climbing, and others.

Remember:

1. There are no right and wrong answers — this is not a test.
2. Please answer all the questions as honestly and accurately as you can — this is very important.

1. Physical activity in your spare time: Have you done any of the following activities in the past 7 days (last week)? If yes, how many times? (Mark only one X per box.)

	1-2	3-4	5-6	7 or more
Gaelic Football				
Hurling □				
Soccer				
Rugby				
Walking for exercise				
Cycling				
Jogging or running				
Aerobics □				
Swimming □				
Cricket				
Dance □				
Football □				
Badminton □				
Skateboarding □				
Soccer □				
Hockey □				
Volleyball □				
Boxing □				
Basketball □				
Other: □				
□				

2. In the last 7 days, during your physical education (PE) classes, how often were you very active (playing hard, running, jumping, throwing)? (Circle one only)
I don't do PE
Hardly ever
Sometimes
Quite often
Always

3. In the last 7 days, what did you do most of the time *at small break*? (Circle one only)
Sat down (talking, reading, doing schoolwork)
Stood around or walked around
Ran or played a little bit
Ran around and played quite a bit
Ran and played hard most of the time

4. In the last 7 days, what did you normally do *at lunch* (besides eating lunch)? (Circle one only)
Sat down (talking, reading, doing schoolwork)
Stood around or walked around
Ran or played a little bit
Ran around and played quite a bit
Ran and played hard most of the time

5. In the last 7 days, on how many days *right after school*, did you do sports, dance, or play games in which you were very active? (Check one only)
None
1 time last week
2 or 3 times last week
4 times last week
5 times last week

6. In the last 7 days, on how many *evenings* did you do sports, dance, or play games in which you were very active? (Circle one only)
None
1 time last week
2 or 3 times last week
4 or 5 last week
6 or 7 times last week

7. *On the last weekend*, how many times did you do sports, dance, or play games in which you were very active? (Circle one only)
None
1 time
2 — 3 times
4 — 5 times
6 or more times

8. Which *one* of the following describes you best for the last 7 days? Read *all five* statements before deciding on the *one* answer that describes you. (Circle one only)
A. All or most of my free time was spent doing things that involve little physical effort

B. I sometimes (1—2 times last week) did physical things in my free time (e.g. played sports, went running, swimming, bike riding, did aerobics)
C. I often (3—4 times last week) did physical things in my free time
D. I quite often (5 — 6 times last week) did physical things in my free time
E. I very often (7 or more times last week) did physical things in my free time

9. Mark how often you did physical activity (like playing sports, games, doing dance, or any other physical activity) for each day last week.

	Little bit	None
Monday	☐	☐
Tuesday	☐	☐
Wednesday	☐	☐
Thursday	☐	☐
Friday	☐	☐
Saturday	☐	☐
Sunday	☐	☐

10. Were you sick last week, or did anything prevent you from doing your normal physical activities? (Check one.)
Yes ..... ☐
No ..... ☐
If Yes, what prevented you? _____

Physical Activity Questionnaire (14-18)

Name:_____ Age:_____Sex: M_____ F_____

We are trying to find out about your level of physical activity from ***the last 7 days*** (in the last week). This includes sports or dance that make you sweat or make your legs feel tired, or games that make you breathe hard, like tag, skipping, running, climbing, and others.

Remember:

There are no right and wrong answers — this is not a test

Please answer all the questions as honestly and accurately as you can — this is very important.

1. **Physical activity in your spare time: Have you done any of the following activities in the past 7 days (last week)? If yes, how many times? (Mark only one box per row.)**

	1-2 days	3-4 days	5-6 days	7 or more
Gaelic Football				
Hurling				
Soccer				
Rugby				
Walking for exercise				
Cycling				
Jogging or running				
Aerobics				
Swimming				
Cricket				
Dance				
Football				
Badminton				
Skateboarding				
Soccer				
Hockey				
Volleyball				
Boxing				
Basketball				
Other:				

2. In the last 7 days, during your physical education (PE) classes, how often were you very active (playing hard, running, jumping, throwing)? (Circle one only)
I don't do PE
Hardly ever
Sometimes
Quite often
Always

3. In the last 7 days, what did you normally do *at lunch* (besides eating lunch)? (Circle one only)
Sat down (talking, reading, doing schoolwork)
Stood around or walked around
Ran or played a little bit
Ran around and played quite a bit
Ran and played hard most of the time

4. In the last 7 days, on how many days *right after school*, did you do sports, dance, or play games in which you were very active? (Circle one only)
None
1 time last week
2 or 3 times last week
4 times last week
5 times last week

5. In the last 7 days, on how many *evenings* did you do sports, dance, or play games in which you were very active? (Circle one only)
None
1 time last week
2 or 3 times last week
4 or 5 last week
6 or 7 times last week

6. *On the last weekend*, how many times did you do sports, dance, or play games in which you were very active? (Circle one only)
None
1 time
2 — 3 times
4 — 5 times
6 or more times

7. Which *one* of the following describes you best for the last 7 days? Read *all five* statements before deciding on the *one* answer that describes you. Circle one only
All or most of my free time was spent doing things that involve little physical effort
I sometimes (1 — 2 times last week) did physical things in my free time (e.g. played sports, went running, swimming, bike riding, did aerobics)
I often (3 — 4 times last week) did physical things in my free time
I quite often (5 — 6 times last week) did physical things in my free time
I very often (7 or more times last week) did physical things in my free time

8. Mark how often you did physical activity (like playing sports, games, doing dance, or any other physical activity) for each day last week.

Monday ..... ☐ ☐
Tuesday ..... ☐ ☐
Wednesday ..... ☐ ☐
Thursday ..... ☐ ☐
Friday ..... ☐ ☐
Saturday ..... ☐ ☐
Sunday ..... ☐ ☐

9. Were you sick last week, or did anything prevent you from doing your normal physical activities? (Circle one)

Yes No

If Yes, what prevented you? _____

DCUREC/2018/164 - Appendix 3

Ethical justification for blood sampling associated with human studies conducted within DCU

Version 1 September 2006

1) Briefly explain why blood sampling is required

Circulating levels of fasting glucose, blood lipids, insulin, and other cardiometabolic biomarkers such as high-sensitivity C-reactive protein (HSCRP) can only be measured in blood samples

2) Outline the analytes, components or general applications to be investigated in subject blood (now and any future studies)

- Serum total cholesterol (TC), triglycerides (TG), low-density lipoprotein-cholesterol (LDL-C), high-density lipoprotein-cholesterol (HDL-C) and high-sensitivity C-reactive protein (HSCRP) will be determined using enzymatic assays (Liquicolor, Human, Germany/Randox direct, Randox, Northern Ireland) and measured spectrophotometrically (MODULAR, Hitachi, Japan)
- Glucose will be analysed using an automated YSI 2300 STAT PLUS analyser.
- Serum insulin will be determined by a dissociation enhanced lanthanide fluorescent immunoassay (DELFIA) using a commercially available kit (Perkinelmer, Wellesley MA, USA).

3) Are any alternatives available to substitute the venous sampling of blood?

No.

4) Will sampling require cannulation or direct vein puncture?

Yes. Direst vein puncture

5) Outline the minimum volume of original subject blood (i.e. not serum or plasma) required to measure the required components.

30.0ml

6) Are steps being taken in the protocol to minimise the volume of blood samples being taken?

Yes. We will be taking the minimum volume of blood that will allow us to measure the desired biomarkers

7) Are steps included to minimise the number of blood samples/vein puncture being taken?

Yes, we will take a single venepuncture

8) Anticipated sampling methodology

Volume of blood to be taken per sample	30.0ml
Maximum number of samples to be taken per "sitting"	1
Maximum number of samples taken per day	1
Maximum number of samples to be taken over the course of the full study (if long duration study indicate the amount taken in an active 1 month period)	1
Maximum anticipate number of vein puncture episodes	1
Total volume of blood that will be taken from subject.	30.0ml

9) I certify that:-

- all persons sampling blood in this study are certified to do so through the school/unit where this work is being conducted
- that all those manipulating the resultant samples are fully trained in the safe practice of handling blood
- all persons handling this blood have received appropriate information according to current vaccination policy.

DCUREC/2018/164 Appendix 4: **Bibliography**

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Signature of Study PI:

Date: November 1, 2019