Acute Response to Strength Training in Young People with Congenital Heart Disease

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RESEARCH QUESTION/AIM(S)

1) To evaluate the acute responses to progressive strength training session on muscle strength and muscle fatigue in young people with ConHD.
2) To evaluate acute muscular, physiological responses (blood pressure, blood oxygen saturation, and heart rate), rating of perceived exertion (RPE), and physical activity enjoyment to different intensities during a strength training session in young people with ConHD.
   To compare differences in acute physiological, and psychological responses to progressive strength training session in young people with congenital heart disease and healthy young people.

METHODS

The study will be a quasi-experimental design to compare the differences in acute response in strength training in young people with ConHD and healthy young people. The study will be conducted at the Children's Health and Exercise Research Centre (CHERC), at the St Luke's Campus of the University of Exeter. The study will be approved by the Ethics Committee of the NHS Health Research Authority.

Participants

Inclusion criteria for young people with ConHD:

(1) Young people aged 15 to 24 years
(2) People diagnosed with different types of ConHD
(3) All participants with ConHD are New York Heart Association (NYHA) class I (patients will not experience discomfort in normal daily activities) to class II (patients will feel some fatigue, shortness of breath, palpitations, and other symptoms, but will not be affected during the resting state), the New York NYHA ratings for people with ConHD *[1]*.

Inclusion criteria for healthy young people:

(1) The age, gender, and strength training experience of the healthy participants will be matched to those with ConHD.
(2) The absence of cardiovascular and respiratory diseases.
(3) The ability to perform moderate to vigorous activity (70% - 85% 1 RM), and adherence to verbal commands related to experimental procedures *[2]*. Participants will complete a Physical Activity Readiness Questionnaire to assess their health status and exercise adaptability before the experiment.

Exclusion criteria for young people with ConHD:

(1) personal history of documented life-threatening arrhythmias *[3]*,

(2) inability or contraindication to perform required physical activity *[4]*,
(3) significant depression of left or right ventricle function (subjective or left ventricular ejection fraction < 54%) *[5]*,
(4) Severe aortic stenosis or severe left ventricular outflow tract obstruction *[5]*,
(5) Presence of significant non-cardiac causes that impair mobility (including respiratory, neurological, or musculoskeletal) *[6]*.
(6) Physical inability to perform a cardiopulmonary exercise test (CPET), participation in other exercise training programmes, and contra-indications for exercise (arrhythmias) *[4]*.

Recruitment

People with ConHD

Potential participants will be identified by a search of the University Hospitals Bristol and Weston NHS Foundation Trust (UHBW) Epic electronic patient record. This will be completed by Dr Dan Dorobantu, consultant cardiologist at the Bristol Royal Infirmary (BRI). The clinical record will be interrogated to match pre-specified inclusion criteria. After eligible participants have been identified through a search of the electronic patient record system by Dr Dan Dorobantu, a separate cardiologist from the care team, will send out an invitation email to eligible patient participants, including the research coordinator's (KH) contact information to avoid any conflict of interest. Dr Dorobantu will not have any direct contact with potential participants regarding the study. We will also advertise through the Southwest regional network for congenital heart disease through the coordinator, who will disseminate our advertisement information. We will contact the South Wales and Southwest Congenital Heart Disease (SWSW CHD) Network administrative leads via email to request support with participant recruitment. Study information sheets and invitations will be disseminated through the Network's communication channels, including its patient representatives, peripheral clinic consultants, ConHD specialist nurses, and its newsletter. Potential participants will be invited to self-refer by contacting the research team directly.

When expressions of interest from prospective participants or their parent/guardian are expressed (e.g., by responding to a poster or email, or through referral by the network), Dan will review all self-referred participants against the inclusion and exclusion criteria. The research coordinator (KH) will initiate contact via email. This email will include:

- A Participant Information Sheet (PIS)

- A training video explaining the purpose and procedures of the study

Then, participants and their parents/guardians (where applicable) will be invited to attend an online meeting with the research team. This meeting will provide an opportunity to discuss the study in detail, answer any questions, and ensure participants and/or their guardians fully understand the nature of their involvement. After the meeting, the consent form and/or will be sent to the participant via email:

- Participants aged 18 and over will be required to sign and return an informed consent form.

- Participants aged 15–17 will need to return both a signed parental/guardian consent form and a signed assent form.

Only upon receipt of the completed consent and/or assent forms will the participant be formally enrolled in the study. Consent will be obtained prior to Visit 1, and no study-related procedures will occur before informed consent is confirmed.

Healthy people

Healthy participants will be recruited through public advertisements. Recruitment posters will be distributed through the University of Exeter mailing lists and social media platforms managed by CHERC. These materials will include key eligibility criteria and a QR code.

Individuals who express interest will be contacted via email by the research coordinator (KH) and provided with a PIS, a study poster, and a link to an introductory video. Where appropriate, a video meeting will be arranged to discuss the study in more detail. Adult participants will be required to provide signed informed consent before enrollment. For participants aged 15 to 17, both parental/guardian consent and participant assent will be required before inclusion in the study.

Study design

The research will be conducted in CHERC and St Luke's Sports Centre at the St Luke's Campus of the University of Exeter. The training description and replication template checklist will be used for guidance and reporting [7]. The strength training study will use a quasi-experimental design, including a ConHD and healthy control groups. This study includes young people with ConHD who meet the inclusion criteria. Before the training session, a meeting [face to face or virtual as agreed with the participant] will be held to watch a video demonstrating standard exercises and precautions. Participants will visit the St Luke's Campus of the University of Exeter twice, with at least 96 hours of rest between visits up to a maximum of 28 days. All participants will be instructed to avoid vigorous exercise for at least 48 hours before the visits e.g., high-intensity strength training, intense team sports, and high-intensity interval training[8]. No verbal encouragement will be provided during the sessions to standardise the experimental conditions and limit the influence of the researcher on perceptual and affective responses [8].

At the first visit to the University of Exeter, participants will be briefed about the upcoming procedures, complete questionnaires, and baseline testing. After completing the health screen questionnaire, physical activity questionnaire, muscle-strengthening exercise questionnaire, anthropometric measurements, and measuring resting blood pressure, heart rate, and oxygen saturation, participants will complete the body composition test, muscle strength test, and CPET in this sequence. Participants will also be tested for their 1 repetition maximum (1RM) of each exercise 15 minutes before CPET. Based on an individual's performance, 40% (low intensity), 60% (moderate intensity), and 80% (vigorous intensity) of the 1RM will be calculated [9]. Participants will have a 5–10-minute rest after each test to reduce the effects of fatigue. Participants may be withdrawn if any abnormal results are found during the first visit.

To fully recover from the fatigue that may result from visit 1, the strength training session will be conducted during the second visit after a period of 96 hours of rest but within 28 days. Upon arrival at the St Luke's Campus, participants will have measured their resting blood pressure, heart rate, oxygen saturation, and delayed onset muscle soreness (DOMS). Following this, they will perform a 10-minute warm-up and complete muscle strength and fatigue tests. Once all measurements are completed, the strength training session will commence. The strength training session will consist of four exercises

during each of the three sets. The first set will be conducted at an intensity of 40% 1RM (12 repetitions), and then incrementally adjusted to 60% 1RM (8 repetitions), and for the final set incremented to 80% 1RM (6 repetitions), with a 60-second rest after each exercise and a 120-second rest after each set [4]. Muscle strength tests will be measured before and immediately after strength training (10 minutes after the session). Blood pressure and physical activity enjoyment scale (PACES) will be measured immediately after each set. RPE and FS will be measured immediately after each exercise. Heart rate and blood oxygen saturation will be continuously monitored throughout the training session. Participants will be followed up for three days after Visit 2 via daily self-reported logs of delayed onset muscle soreness (DOMS) [via telephone or email] and identify any delayed adverse events. If any unexpected or adverse symptoms are reported during this period, participants will be monitored until resolution or referred for medical evaluation as appropriate. No further follow-up is planned beyond this period unless clinically indicated. Figure 1 and Figure 2 show the study design, visits, and measurements.

Strength training session

Strength training will include resistance training focused on lower body strengthening exercises including calf muscle strengthening (Table 1). These exercises were selected based on relevant literature [4,6]. The training will take place in one session, lasting approximately one hour, and will include a 10-minute warm-up, 10 minutes of familiarisation exercises, 30 minutes of progressive strength training, and 10 minutes of cool down/stretching (see study flow chart). The principal investigator will be involved throughout the training process to provide ongoing support/guidance, ensure the safety and effective delivery of the training, and ensure the quality of training delivery.

Strength training session process

Participants will warm up having previously learnt how to perform the exercise with proper technique and ensure they are fully prepared for the session (see Table 1). The warm-up will consist of walking on a treadmill with an incline (+5%) or cross-trainer [4], and the familiarisation will consist of repeating four strength training movements at an intensity of 15 RM for 10 repetitions with 60 seconds of rest between exercises. After warm-up and familiarisation, participants will perform 30 minutes of progressive strength training with four exercises and three sets with a 60-second rest after each exercise and a 120-second rest after each set. The exercise of strength training will include squats, standing calf raises, deadlifts, and seated leg extensions. The resistance of each machine will be set at 40% (12 repetitions), 60% (8 repetitions), and 80% (5 repetitions) of 1RM during three sets based on the results of the RM test, with RPE ≥ 6 as the target, with the self-perceived exercise intensity being defined as moderate intensity to avoid overexertion [6]. Cordina et al and Scheffers et al reported that high-intensity strength training can significantly improve the muscle strength and cardiorespiratory fitness of people with ConHD [4,6].

Strategies for effective and safe training

To facilitate the implementation process, several strategies will be employed, including:

1) Training workshop before a training session with researchers and participants.
2) Lifting the weight slowly and controlled.
3) Avoid breath holding (Valsalva manoeuvre) by giving breathing directions.

4) If symptoms occur, discontinue the training immediately (vertigo, arrhythmias, dyspnea, and angina pectoris)
5) The principal investigator responsible for delivering the training session will be required to maintain a training logbook recording aspects such as attendance, doses delivered and received, and adverse events.
6) The study coordinator (KH) is a certified strength and condition coach and has first aid training.
7) The study coordinator (KH) has experience working on strength training for cardiac patients in the ISCA centre, a cardiac rehabilitation center.

Safety

1) Participants can only be included in the study when the consultant, based on their clinical judgment, determines that the participant's physical condition is capable of safely undertaking the designed strength training session.
2) Heart rate: participants will wear a heart rate monitor (Polar heart rate monitor, Polar Electro, Finland) to facilitate real-time monitoring of their heart rate throughout the training session. If the participant's heart rate exceeds 85% of HR max during the training session, the exercise will be stopped[6].
3) Oxygen saturation: To evaluate the exercise intensity and test the exercise endurance, participants will wear a pulse oximeter (Onyx Vantage Pulse Oximeter, Nonin Medical, Inc., Plymouth, USA) that monitors changes in oxygen saturation during exercise and reflects the oxygen supply capacity of the muscles. If oxygen saturation drops below 90% or hypoxia persists during the training session, the oxygen supply may be insufficient, and training will be stopped [6]. If the baseline oxygen saturation value of the participant is likely to be low (e.g. long-term maintenance of 93-95%) and the oxygen saturation drops more than 3%-5% from the baseline value, even if it does not fall below 90%, the training will be stopped.
4) CPET: Performing CPET before the start of a strength training session can initially screen and assess the participant's cardiorespiratory fitness for strength training. CPET can also determine a safe range of exercise intensity by determining the maximum heart rate, ensuring that they do not exceed their body's ability to withstand the training. Participants may be withdrawn if any abnormal results are found during the first visit.
5) Participants will be asked to report their Borg RPE during the rest period following each exercise to prevent excessive fatigue.
6) Participants will be instructed to breathe out during the contractive phase and breathe in during the relaxation phase to prevent breath holding (Valsalva manoeuvre) [6].
7) Emergency equipment and personnel are available during the session. The training location will be equipped with first aid equipment [including an automated external defibrillator] and supervised personnel who have attended first aid courses. Any adverse events will be recorded such as trips, falls, dropped weights, muscle injury, adverse events (AEs), or serious adverse events (SAEs) such as arrhythmias or cardiac events. AEs are defined as any untoward clinical investigation subject administered to a pharmaceutical product that does not necessarily have to have a causal relationship with this treatment [10]. And SAEs are defined as Any untoward medical occurrence that at any dose: 1. Results in death; 2. Is life-threatening; 3. Requires inpatient hospitalisation or prolongation of existing hospitalisation; 4. Results in persistent or significant disability/incapacity; 5. Is a congenital anomaly/birth defect [10].

8) In the event that a participant loses capacity (as defined by the Mental Capacity Act 2005) prior to their scheduled appointment or during the study, they will be withdrawn from the study immediately. This is to ensure compliance with ethical and legal requirements for research involving human participants.

Baseline and Outcome measurements

The measurements will be recorded by the study coordinator (KH) in CHERC and St Luke's sports centre at the St Luke's Campus of the University of Exeter. Demographic information will be collected and recorded in Excel software. All measurements will be introduced and explained during the training workshop and will be described again before the commencement of the measurements to ensure clarity (Table 2).

Baseline measurements

Cardiorespiratory fitness

CPET will be used to assess maximum exercise capacity and heart rate to ensure the safety of participants in strength training. All patients will receive the maximum CPET (ramp protocol) by electric bicycle dynamometer: Jaeger ER9000 (Viasys Healthcare; Hoechberg, Germany). The maximum CPET will begin with 1 minute (min) of unloaded cycling at 60-80 repetitions per minute, gradually increasing in intensity after exercise until exhaustion (ramp protocol). The work rate increment was 10% per minute of the estimated maximal work rate, previously determined as follows; 1.7 W/kg for people with ConHD procedure and 3.2 W/kg for healthy people [11]. Participants continue to be monitored until exhaustion. Peak VO_2 is defined as the maximal averaged value occurring at peak workload. Then end the 3-minute recovery phase. The following CPET variables will be measured: peak oxygen uptake (peak VO_2), peak work rate (W), peak ventilation (peak VE), peak heart rate (peak HR), peak oxygen pulse (peak O_2 pulse), gas exchange threshold (GET), and ventilatory equivalent for carbon dioxide slope (VE/VCO_2 slope). A smaller or recumbent bike will not be required, as the cycle ergometer used in this study is highly adaptable. The bike allows adjustments to seat height, handlebar height, and crank length, accommodating a wide range of participant sizes. Based on prior experience with this equipment, we have successfully tested children as young as 8 years old (120 cm in height) without difficulty. Therefore, participants meeting the study's inclusion criteria will be able to use the bike safely and comfortably.

Body composition

Body composition measurement will be performed with a total body composition scan by bioelectrical impedance (Bodystat Quadscan 4000, Bodystat, Douglas, Isle of Man, UK). Measurements will be taken after 10 minutes of supine rest as the participant lies on a bench or examination couch with their arms away from their body and their legs slightly apart. Measurements will be obtained before meals and after voiding. The participants will remove their shoes and socks. Aluminium electrodes will be placed on the right side over the wrist joints between the ulna-radial styloid processes of the wrist and between the joints of the ankle. Resistances and reactance will be measured under discrete frequencies of 5, 50, 100, and 200 kHz [12]. Values for total lean mass and appendicular lean mass (sum of arms and legs) will be obtained. Lean mass indexes will be calculated by dividing lean mass by height squared (kg/m^2). The appendicular lean mass index (ALMI) will be used as a measure of skeletal muscle mass. Total percentage body fat (%BF) will be calculated by dividing total fat mass by total body mass (sum of bone mineral content, lean mass, and fat mass). The fat mass index will be calculated by dividing total fat

mass by height squared. Body mass index (BMI) will be calculated using a formula: BMI=weight (kg)/height $(m)^2$.

1RM test

Participants will first complete a warm-up consisting of 5–10 minutes of dynamic activity, followed by 3–5 repetitions of squats, at 50–70% of the estimated 1RM: Beginners are 40% to 60% of body weight, and experienced people are 60% to 80% of body weight [9]. The load will then progressively increase by 5–10% per attempt, with 1–3 repetitions performed and 2–4 minutes of rest between trials, until the participant can complete only one full repetition, which will be recorded as the 1RM [9]. Participants will then complete the 1RM test of standing calf raises, deadlifts, and seated leg extensions in turn. If participants cannot complete the direct 1RM test, their maximal strength will be estimated using multiple repetition maximum (nRM) testing, applying predictive equations: the Brzycki formula [13].

$$1\ RM = \frac{Weight\ Lefted}{1.0278 - 0.0278\ \times Repetitions}$$

Outcome measurements

Muscle strength

Handgrip strength (N) will be measured using a handgrip dynamometer (Takei 5001 Grip Dynamometer Analogue, Takai Scientific Instruments Co., Ltd., Niigata City, Japan). While standing, participants', with their elbows bent at a 90° angle, will maximally squeeze the handgrip dynamometer. Maximum handgrip force will be tested three times on the dominant hand, measured in Newton (N). To allow for complete muscular strength recovery, each measurement will be performed one minute apart [14]. The average of the three handgrip strength tests will be recorded. Additionally, an Isokinetic dynamometer (Biodex System 3 Medical Systems 830-200, Shirley, N.Y. 11967 USA) will measure dominant leg muscle strength of knee extension and flexion. To familiarise themselves with the test procedure and the equipment, participants will be placed in a seated position with the knee flexed at approximately 90° and perform 3 submaximal muscle contractions. Then participants will perform maximal voluntary knee extension and flexion contractions at an angular velocity of 60°/s (3 repetitions) to determine the peak knee extensor torque (measured in newton-metres, Nm). The average of the three measurements will be taken as the maximum muscle strength. To control for the effects of body size on muscle strength, mathematical modelling will adjust for body size. After a 3-minute rest, participants will perform 20 consecutive maximal voluntary contractions at 180°/s to assess knee extension and flexion fatigue resistance [15]. The study coordinator will record the average peak moment (Nm) for the first 5 contractions and the average peak moment (Nm) for the last 5 contractions. Fatigue Index (%) will be calculated as:

$$FI = \frac{Mean\ Torque\ (First\ 5\ contractions) - \ Mean\ Torque\ (\ Last\ 5\ contractions)}{Mean\ Torque\ (First\ 5\ contractions)} \times 100\%$$

Blood pressure

An automatic blood pressure monitor (Omron M6 Comfort Digital Blood Pressure Monitor, Omron Healthcare Co. Ltd, Kyoto, Japan) will record resting blood pressure. The blood pressure of the left arm will be measured at two intervals of two minutes apart and the average of the measurements will be used for analysis [16].

Physical Activity Enjoyment Scale

The 4-item PACES scale will be used to assess enjoyment [17]. Participants will be asked to rate "how you feel at the moment of the strength training you have been doing". The scale contains four questions, When I am physically active: 1) I enjoy it. 2) I find it pleasurable. 3) it is very pleasant. 4) it feels good. There are also five options for participants to choose from: strongly disagree, somewhat disagree, neither agree nor disagree, somewhat agree, and strongly agree. We will quantify these five options using a Likert scale, with strongly disagree to strongly agree to represent 1 to 5 points respectively. Higher PACES scores reflect greater levels of enjoyment (see Table 4).

RPE scale

The RPE is a scale (rated between 0-10 points) and is used to measure the degree of physical exertion perceived by an individual when performing exercise [18]. It is based on the participant's subjective feelings rather than objective physiological indicators. The scale from 0 to 10 represents the participant's subjective perception of exercise intensity gradually increasing: 0 is rated as extremely easy and 10 is rated as extremely hard (see Figure 3).

Feeling scale

Affective valence will be measured with FS [19]. The FS is an 11-point bipolar rating scale ranging from −5 (I feel "very bad") to +5 (I feel "very good"). The FS has been widely used to assess affective valence during exercise and has demonstrated satisfactory validity through correlations with other measures of affective valence (Table 3) [20].

Delayed onset muscle soreness

Lower extremity muscular soreness will be measured using the visual analogue scale (VAS), which is a psychometric response scale to investigate a unidimensional measure of pain intensity, and it is widely used in clinical research to examine the intensity or frequency of pain [21].

Participants will be instructed to mark the point representing their overall lower extremity muscular soreness on a 100 mm line (Figure 4). The pain intensity during a functional activity will be assessed after performing a standing to sitting movement. Participants will be instructed to descend slowly with the upper limbs crossed over the chest, to achieve the final position of sitting on the chair with their knees at -90° [22]. Immediately after, participants will mark the intensity of DOMS. Record once a day

for three times. In this study, we will consider VAS to be reported in centimeters, i.e. on a scale of 0–10.

$$1\,RM = \frac{Weight\,Lefted}{1.0278 - 0.0278\ \times Repetitions}$$

Power calculation

To ensure adequate statistical power and to minimise the risk of Type II error, a priori power analysis was conducted to determine the appropriate sample size for this study. Given the limited study of exercise intervention for acute muscle response in young people with ConHD and the need to detect meaningful changes in muscle strength following strength training, careful consideration was given to the selection of the effect size parameter. Previous studies investigating the acute muscular response to strength training in healthy individuals have reported large effect sizes (e.g., f ≥ 0.40) [23–25]. For example, in a previous acute strength training study, the peak muscle strength of knee extension in healthy young people (median age 23.6 ± 1.5 years) before and after the intervention was 671 ± 118 and 470 ± 106 N, respectively [24]. The effect size can be calculated as 0.82 (large effect size). However, these studies were conducted in populations with no known cardiovascular limitations and may have exhibited different neuromuscular adaptability due to their baseline physiological capacity. Given these considerations, a conservative approach was adopted by assuming a medium effect size (f = 0.35) for power calculations. This choice ensures that the study is sufficiently powered to detect meaningful changes, while also accounting for potential inter-individual variability in training response. Based on a G*Power (Version 3.1) calculation [26] and using a 2 × 3 repeated measures ANOVA with an assumed effect size of (f = 0.35) (medium effect), 80% power [the measure of the ability of an experimental design and hypothesis testing setup to detect a particular effect if it is truly present], a priori α level of $p < 0.05$, and a correlation of 0.5 among repeated measures, it is estimated that 23 participants in each group are required. However, anticipating a potential dropout rate of 15% [27], 27 people with ConHD and 27 healthy people will be included in this study.

Statistical Analyses

Demographic and baseline characteristics will be summarised as mean ± standard deviation for normally distributed data, or as median and interquartile range for non-normally distributed data. Normality will be assessed using the Kolmogorov-Smirnov test, skewness/kurtosis values, and histogram inspection.

Between-group differences in baseline characteristics will be assessed using independent-samples t-tests for normally distributed continuous variables and Mann–Whitney U tests for non-normally distributed continuous variables. Homogeneity of variance will be assessed using Levene's test, and Welch's t-test will be applied where the assumption of equal variances is violated. Categorical variables will be compared using Fisher's exact test. All tests are two-sided, with statistical significance set at $p < 0.05$.

Linear mixed models will be used to examine within-group and between-group differences in repeated outcome variables measured before, during, and after the ST session. Separate models are conducted for each outcome variable, including muscle strength, total work, systolic blood pressure (SBP), diastolic

blood pressure (DBP), heart rate, oxygen saturation, RPE score, FS score, exercise enjoyment, and delayed-onset muscle soreness. For each model, group (ConHD and healthy control), time, and the group × time interaction will be included as fixed effects. Participant ID will be included as a random effect to account for repeated measurements within the same participant. Age will be included as a covariate. The main effect of time will be used to examine within-participant changes across measurement points, while the main effect of group will be used to examine overall differences between participants with ConHD and healthy controls. The group × time interaction will be used to assess whether the pattern or magnitude of change over time differed between groups. Where significant main effects or interactions will be identified, post-hoc pairwise comparisons will be performed to examine specific within-group changes and between-group differences at individual time points.

To further characterise within-session responses in the ConHD group, additional linear mixed-effects models will be conducted for heart rate, RPE and FS, which will be assessed following each exercise. Exercise (calf raises, squats, leg extensions and deadlifts), set (Sets 1–3), and the exercise × set interaction will be included as fixed effects, with participant ID as a random effect and age included as a covariate. The main effects of exercise and set will be used to determine whether responses differed among exercises and across sets, respectively, while the exercise × set interaction will be used to examine whether exercise-specific responses varied between sets. Where significant effects will be identified, Sidak-adjusted pairwise comparisons will be performed to identify specific differences between exercises or sets. Separate within-ConHD models will be conducted for post-set SBP and DBP to examine whether post-set blood pressure differed across successive sets.

Model outputs will be reported using estimated mean differences, 95% confidence intervals, and corresponding p-values. Model assumptions will be assessed by visually inspecting residual plots for normality and homoscedasticity. The independence of residuals will be considered in relation to the repeated-measures structure of the data, and participant-level random effects will be used to account for the non-independence of observations within individuals. All analyses will be conducted using IBM SPSS Statistics for Windows (version 28.0; IBM Corporation, Armonk, NY, USA), with statistical significance set at $p < 0.05$.

End of Study

The end of the study will be defined as the date when the last participant completes their final follow-up assessment (three-day post-Visit 2 monitoring) and all associated data collection described in this protocol has been completed. After this point, no further data will be collected from participants. Subsequent study activities will be limited to data cleaning, anonymisation, statistical analysis, and preparation of the PhD thesis and any resulting publications.

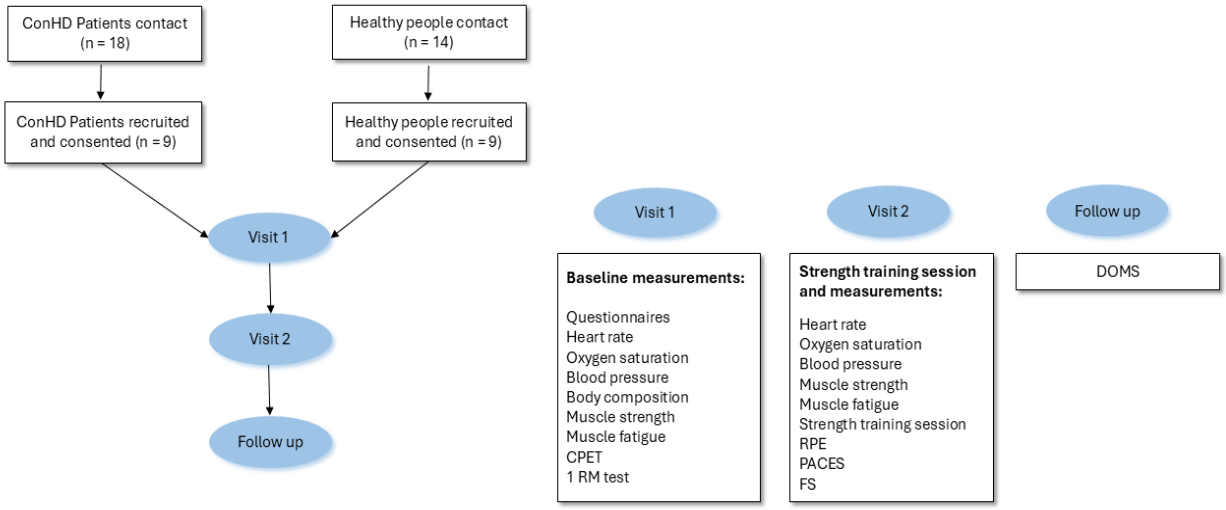


Figure 1: Study design, visits and measurement assessments. This figure shows the study design and the measurements performed on each visit in detail. ConHD, Congenital heart disease; CPET, cardiopulmonary exercise test; RPE, rating of perceived exertion; PACES, physical activity enjoyment scale; FS, feeling scale; ST, strength training; DOMS, delayed onset muscle soreness.

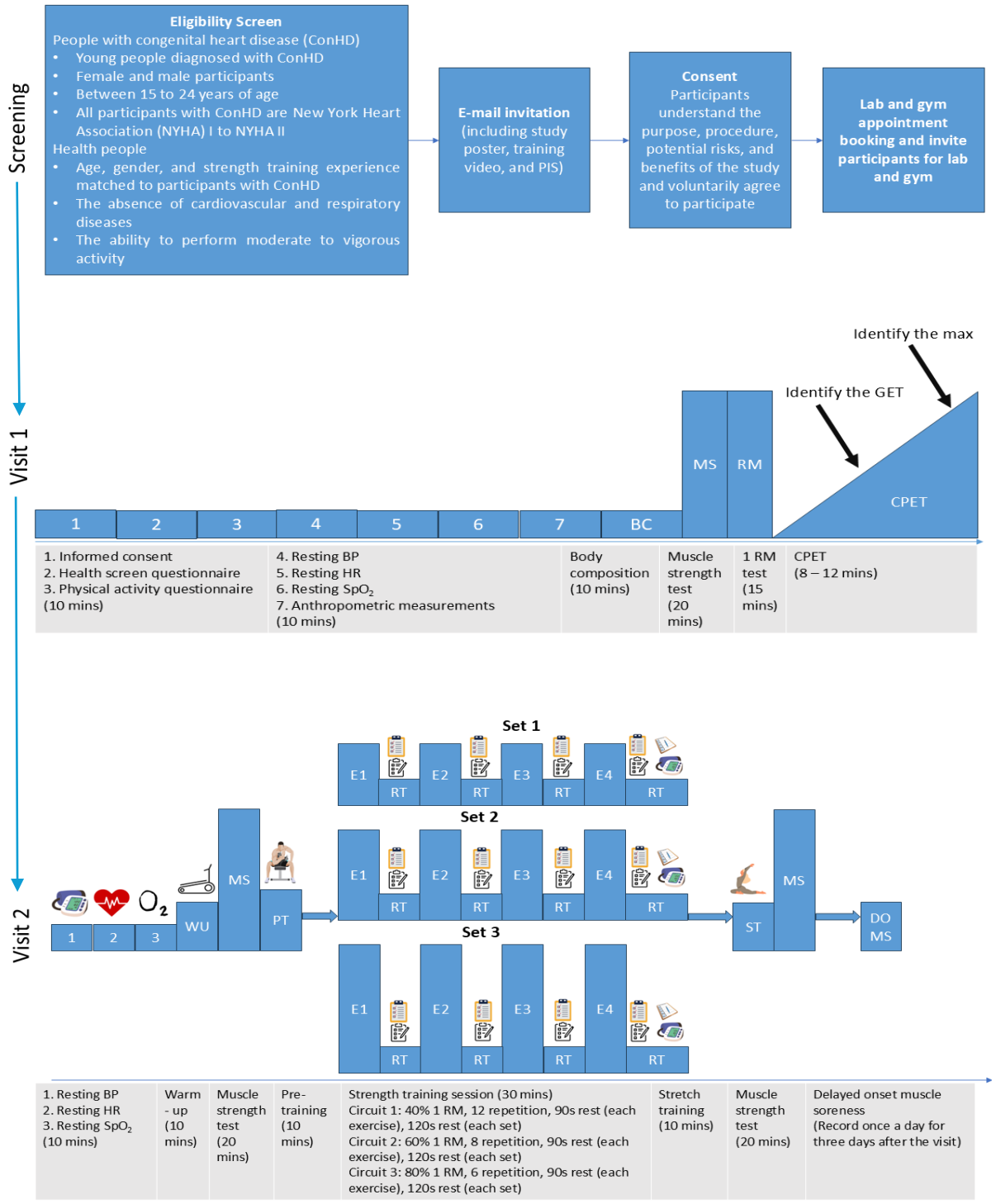


Figure 2: Specific study design, visits and measurement assessment procedure. ConHD, congenital heart disease; NYHA, New York Heart Association; PIS, participants information sheet; BP, blood pressure ( ); HR, heart rate ( ); SpO_2, oxygen saturation ( ); GET, gas exchange threshold; CPET, Cardiopulmonary Exercise Test; MVC, maximal voluntary contraction; PACES, physical activity enjoyment scale ( ); RPE, rating of perceived exertion ( ); FS, Feeling scale ( ); BC, body composition; MS, muscle strength; RM, repetition

maximum; WU, warm up (); PT, pre-training (); E1, exercise 1; E2, exercise 2; E3, exercise 3; E4, exercise 4; RT, rest time; ST, stretch training (); DOMS, delayed onset muscle soreness.

Table 1. Implementation of strength training programme

Training programme	Training objectives	Intensity	Repetitions	Training volume	Exercise
Warm-up	To increase blood flow, muscle temperature, and joint range of motion To activate the nervous system Mental preparation Injury prevention	Heart Rate zone 2-3, 85% - 95% of VT2 + 10 beats	1	10 mins	walking on a treadmill with an incline (+5 - 10%) or cross-trainer. *Each training session speed on treadmill/ cross-trainer was increased, when heart rate zones were exceeded, speed was decreased again.
Familiarisation	To learn and practice the current perception and exercise	20% 1RM	10	1 circuit during each session Rest period: 60s	Standing calf raise, Squats, Deadlifts Seated leg extensions
Strength training	To increase muscle mass (hypertrophy) and muscle strength To improve intra-muscular coordination	40% 1RM 60% 1RM 80% 1RM	12 8 6	Set 1 Set 2 Set 3 Rest period: 90s (each exercise) Rest period: 120s (each set)	Standing calf raise Squats, Deadlifts Seated leg extensions
Stretch training	To promote muscle relaxation and flexibility	-	10 -15		Standing hamstring stretch

	Injury prevention				Quadriceps stretch. Chest stretch Shoulder stretch Triceps stretch.
Special direction for training: Standardised exercise Lift the weight slowly and control. Avoid breath holding (Valsalva manoeuvre) by giving breathing directions. Blood pressure measurement at the beginning and end of the training If symptoms occur, discontinue the training immediately (vertigo, arrhythmias, dyspnoea, angina pectoris)					

RPE: rating of perceived exercise; MVC, maximum voluntary contraction.

Table 2. Outcome variables, tools, and timing for outcome measurements.

Outcomes	**Tools**	**Timing**	**Location**
CRF	An electric bicycle dynamometer	Visit 1	The lab in university
Muscular strength	Handgrip dynamometer Isokinetic dynamometer	Visit 1, 2	The lab in university (first) The St Luck sports centre (second)
Body composition	Bioelectrical impedance	Visit 1	The lab in university
Blood pressure	Blood pressure monitor	Visit 1, 2	The lab in university The St Luck sports centre
Heart rate	Heart rate monitor	Before, during and after the strength training session	The lab in university The St Luck sports centre
Oxygen saturation	Pulse oximeter	Before, during and after the strength training session	The lab in university The St Luck sports centre
RPE	Borg RPE Scale	Before, during and after the strength training session	The St Luck sports centre
Physical activity enjoyment scale	Physical activity enjoyment scale Feeling scale	Before, during and after the strength training session	The St Luck sports centre
Delayed onset muscle soreness	visual analogue scale	Visit 2 and three days after visit 2	The St Luck sports centre Home

Table 3: Feeling scale.

Feeling Scale	
+5	Very Good
+4	
+3	Good
+2	
+1	Fairly Good
0	Neutral
-1	Fairly Bad
-2	
-3	Bad
-4	
-5	Very Bad

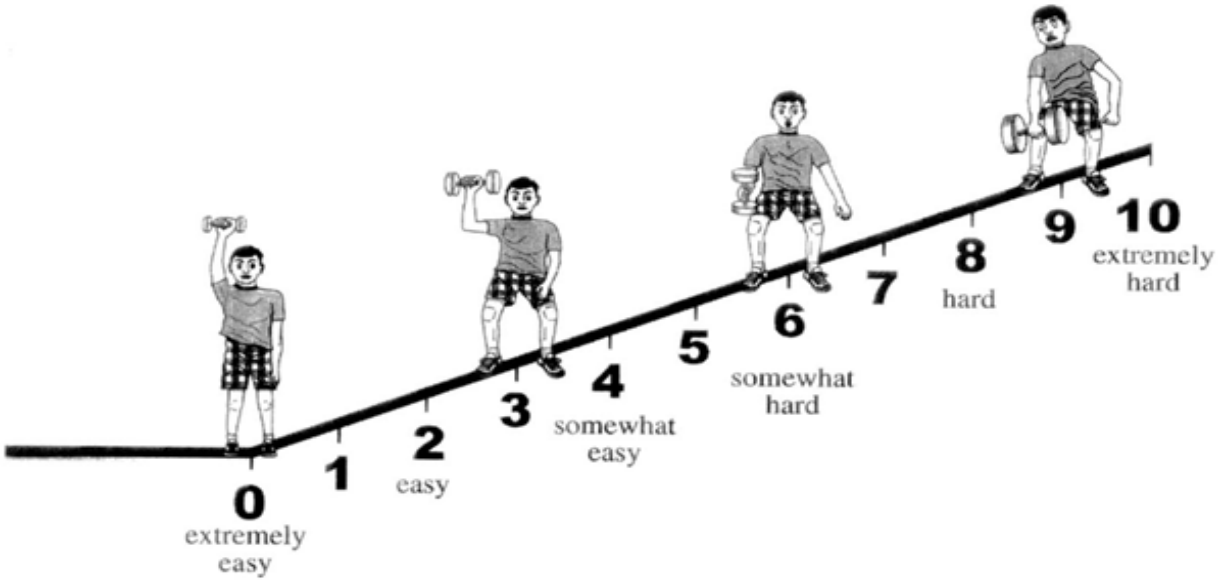


Figure 3: Borg RPE scale

Table 4: Physical Activity Enjoyment Scale

Physical activity enjoyment					
When I am physically active...					
	strongly disagree	somewhat disagree	neither agree nor disagree	somewhat agree	strongly agree
1. I enjoy it.	❑	❑	❑	❑	❑
2. I find it pleasurable.	❑	❑	❑	❑	❑
3. it is very pleasant.	❑	❑	❑	❑	❑
4. it feels good.	❑	❑	❑	❑	❑

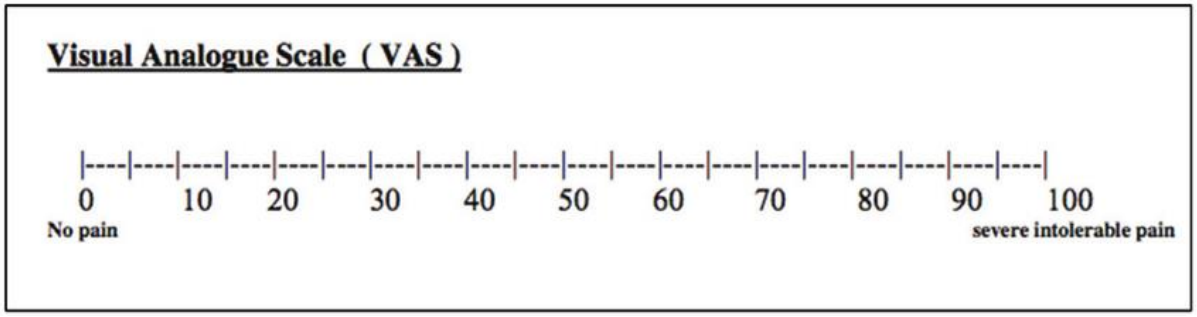


Figure 4: Visual analogue scale

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