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ORIGINAL ARTICLE

Feasibility and effectiveness of a distance-adapted physical activity intervention in adolescents with obesity during the COVID-19 pandemic

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ABSTRACT

BACKGROUND: Pediatric obesity represents one of the most important public health challenges and its prevalence significantly increased during the COVID-19 pandemic. Our prospective study aimed to assess the feasibility of a remote adapted physical activity (PA) intervention and its effectiveness in improving anthropometric indices, metabolic health parameters, as well as cardiopulmonary function and fitness in adolescents with obesity.

METHODS: A PA intervention involving synchronous online lessons combined with asynchronous sessions and promotion of independent PA and "active breaks" to interrupt prolonged sedentary behaviors was proposed to 20 adolescents aged 11-17 years with obesity over a 4-month period. Clinical and anthropometric parameters (weight, height, waist, body composition, blood pressure), metabolic parameters (glycemia, insulinemia, glycated hemoglobin, oral glucose tolerance test [OGTT], lipid profile, presence of hepatic steatosis), cardiopulmonary function and fitness indices (VO_2max, six-minute walking test [6MWT], upper and lower limb strength test) were evaluated before and after the intervention.

RESULTS: Twenty adolescents with obesity were enrolled (11 male [55%], aged 14.1±1.5 years, BMI SDS 3.1±0.5). Eighteen participants (90%) successfully completed the project, and no adverse events were reported. We observed an increase in cardiovascular and muscle fitness [higher VO2peak, maximal workload, better performance at limb strength and 6MWT (all P<0.05)], increased lean body mass (P=0.005), and an improvement of glucose metabolism response with a reduction of insulin concentrations during OGTT (P=0.043).

CONCLUSIONS: Participation in the training program was feasible and effective in improving cardiovascular fitness, glucose metabolism, body composition, strength, and endurance in adolescents with obesity during the COVID-19 pandemic.

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KEY WORDS: Exercise; Physical fitness; Pediatric obesity; Adolescent; Glucose metabolism disorders; COVID-19.

Obesity represents one of the most critical public health concerns, which has reached epidemic proportion nowadays.[1] Overweight and obesity are the most common nutritional diseases in pediatric age. According to the last World Health Organization (WHO) European Region Report, 7.9% of children under the age of 5 and one in three school-aged children live with overweight or obesity.[2] Obesity is a complex multifactorial disease that poses substantial health risks.[2] Pediatric overweight/obesity is a risk factor for the obesity persistence into adulthood, paving the way for the development of metabolic and cardiovascular complications such as hypertension, dyslipidemia, type 2 diabetes mellitus (T2D), metabolic syndrome, cardiovascular diseases, having an important impact on global morbidity and mortality.[3] Remarkably, over 60% of prepubertal children with overweight will maintain this condition in adult age,[1] further emphasizing the need to provide early effective preventive and therapeutic interventions. The most common cause of obesity in children is a chronic positive energy balance, due to a caloric intake higher than calorie expenditure, combined with a genetic predisposition.[4] Lifestyle interventions based mainly on dietary modification and increased physical activity are the cornerstone of the management of overweight and obesity in the pediatric population.[4, 5] Recent WHO guidelines emphasize the critical role of physical activity in the management of excess fat mass for weight reduction and prevention of related complications in all pediatric ages starting from 5 years of age. In children and adolescents with obesity, an average of 60 minutes per day of moderate-to-vigorous physical activity is recommended, including both aerobic and strength components.[6, 7] Such activity is known to result in reduction in fat mass, improved insulin sensitivity, reduced glycated hemoglobin values, increased peak oxygen consumption, and improved overall cardiac function.[8, 9] Currently, data demonstrate that less than 50% of children and adolescents reach the recommended daily physical activity.[10] This trend has increased over the past three years due to the COVID-19 pandemic, which has contributed reduced opportunities to practice physical activity and organized sports (*i.e.*, schools and sports facilities, gyms, and swimming pools closure) increasing the risk factors related to obesity condition.[2, 11] Especially children and adolescents have been affected by the restrictive measures implemented to slow the spread of the virus and contain the disease. In fact, restrictions introduced during lockdown resulted in an increase in sedentary behaviors with a reduction in all types of social and physical activities.[12, 13] For that reason, distance learning and different remote organized physical activity programs have been proposed and found useful to counteract this transitory problem.[14] Physical activity training in remote modalities, even in the form of interactive video games, may represent a useful tool,[14, 15] especially for adolescents with obesity, whose participation in sports activities may be limited and inhibited due to psychological problems related to body shame and social pressure.[16] Nevertheless, there is currently limited evidence on the feasibility and efficacy of a structured online exercise program for children with obesity[17] and no further studies in adolescents are available. Therefore, we hypothesized that the implementation of a remote training protocol, according to an ecological and multidisciplinary approach, may prove both feasible and effective in enhancing overall metabolic health and cardiovascular fitness in adolescents with obesity. The first aim of our one-arm longitudinal prospective intervention study was to evaluate the feasibility and didactic-educational problems of a remote adapted physical activity intervention in adolescents with obesity during the COVID-19 pandemic. The secondary aim was to verify the effectiveness of the program on anthropometric, metabolic, cardiopulmonary, and fitness parameters.

Materials and methods

Subjects

Twenty adolescents with obesity (11 males: 14.2±1.7 years, BMI SDS 3.3±0.4; 9 females: 13.9±1.4 years, BMI SDS 2.9±0.6) were consecutively enrolled at the Pediatric B Unit of Diabetes and Metabolic Disorders, University Hospital of Verona (Italy) from March 2021 to September 2021. Inclusion criteria: European ethnicity; age between 11 and 17 at the time of the recruitment; obesity according to sex and age-specific BMI cutoff for obesity (BMI SDS >2 according to WHO growth references);[18] prescription of moderate-intense physical activity after the cardiopulmonary exercise testing (CPET) using the cycle ergometry; motivation to participate in a remote physical activity project with peers suffering from obesity. Exclusion criteria: individuals aged over 17 or under 11 at the time of recruitment, genetic or endocrine causes of obesity; any contraindications to physical activity; associated chronic diseases or diagnosed psychiatric comorbidities. All subjects underwent a CPET and a medical evaluation with a sport medicine specialist at baseline (T0). Eighteen out of the 20 subjects successfully completed the 4-month training protocol and underwent follow-up evaluations. All the assessments described below were performed at the time of enrollment (T0) and at the end of the training protocol (T1). In Figure 1 is presented a flow chart with the study design. As the recruitment was carried out when patients were referred to the pediatric unit for obesity, standard and general suggestions were given to all subjects at their first nutritional counselling to follow a healthy diet (*e.g.*, eat 5 meals a day, avoid high-energy and low nutrient density foods [*e.g.*, sweetened, or energizing drinks, fruit juices, fast food, high-energy snack]).[4] No other nutritional interventions nor nutritional follow-up was performed during the training protocol.

Physical examination

At recruitment, physical examination, including weight and height measures, was performed according to standard procedures, as previously described.[19] BMI was calculated as weight (in Kilograms) divided by height (in meters) squared. BMI values were standardized using age- and sex-specific median, standard deviation (SD), and power of the Box-Cox transformation (least mean square method) based on WHO growth references.[18] Waist circumference was measured to the nearest 0.5 cm while the subjects were standing as the minimal circumference measurable on the horizontal plane between the lowest portion of the rib cage and the iliac crest, after gently exhaling.[20] Body composition and body fat percentage were measured using a body composition analyzer (Tanita bioimpedance meter, MC-780 MA, Tanita Europe BV, Amsterdam, the Netherlands). The parameters considered were percentage of fat body mass (FBM), FBM in kg, and lean body mass (LBM) in percentage and in

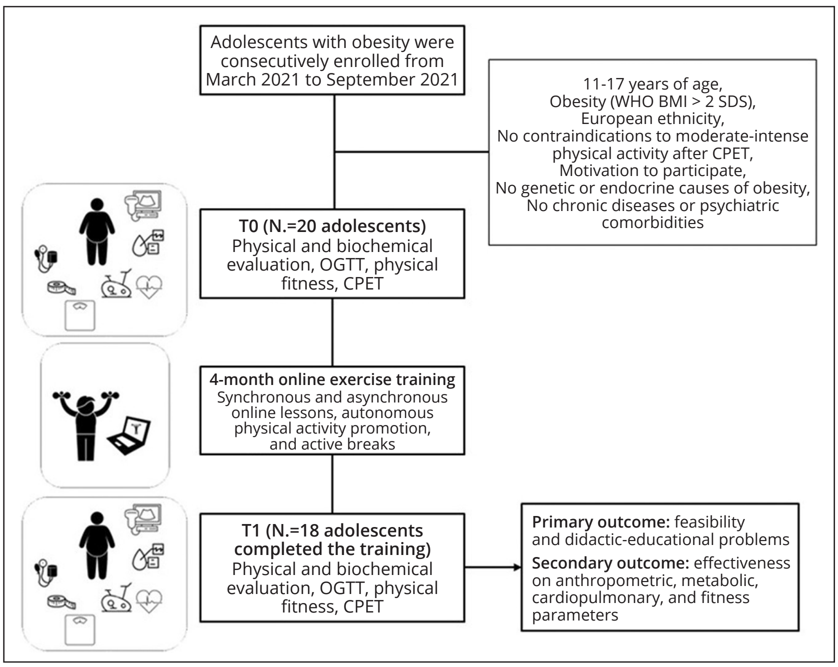

Figure 1.—Flow chart of the study protocol.
Twenty adolescents (11-17 years old) with obesity were recruited for a 4-month remote exercise training intervention including synchronous and asynchronous online activity, autonomous activity, and active breaks. Clinical and anthropometric parameters (weight, height, waist, body composition, blood pressure), metabolic parameters (glycemia, insulinemia, glycated hemoglobin, oral glucose tolerance test [OGTT], lipid profile, presence of hepatic steatosis), cardiopulmonary function (CPET) and fitness indices (VO_2max, six-minute walking test, upper and lower limb strength test) were collected at the baseline (N.=20) and at the end of the intervention (N.=18).

kg.[21] The pubertal stage was assessed according to Tanner criteria.[22] Subjects were categorized in prepubertal (Tanner stage 1), pubertal (Tanner stage 2-4), and postpubertal (Tanner stage 5). Systolic blood pressure (SBP) and diastolic blood pressure (DBP) were recorded three times on the right arm in mmHg using a manual sphygmomanometer and the average of the three blood pressure measurements was used for analysis.[23] As part of the investigation, patients underwent abdomen ultrasonography to detect the presence or not of hepatic steatosis.[24]

Biochemical measurements

All patients underwent fasting blood tests for measuring plasma glucose, serum insulin concentration, glycated hemoglobin (HbA1c), lipid profile, aspartate aminotransferase (AST), and alanine aminotransferase (ALT) (19). Participants underwent a 10-points standard 75 g oral glucose tolerance test (OGTT) after overnight fasting, and the following OGTT-derived indexes were calculated as previously described:[25] Matsuda Index and Oral Disposition Index.

Cardiopulmonary test

The CPET was performed by Sport Medicine Department of the University Hospital of Verona, Italy. The instruments used included a cycle ergometer (Ergoline, Ergoselect 100/200, 2016-03-15/Rev 02; Ergoline Gmbh, Bitz, Germany) connected to and an electrocardiograph (Cardiosoft, GE Medical Systems, Information Technologies Gmbh, Freiburg, Germany) and to a metabolites analyzer (CareFusion, Type Vyntus CPX; CareFusion Germany 234 Gmbh, Hoechberg, Germany). At baseline resting blood pressure and electrocardiogram (ECG) were detected. The subjects carried out an exercise test with periodic measurements of blood pressure, continuous ECG recording, and continuous measurement of oxygen saturation in ambient air. Tests were performed with an incremental ramp protocol (10 Watt/min increments). The test was performed on all participants in the preliminary phase of the training program and was repeated at the end of the training to participants that completed the program. The parameters considered to compare fitness were the maximum oxygen uptake (VO_2max) (mL/kg/min) and the ratio, expressed as percentage, between the VO_2 peak and the predicted theoretical VO_2 peak value based on the subject's characteristics (age, sex, etc.), and the ratio, also expressed as percentage, between the maximum heart rate (HR) achieved and the predicted theoretical maximum HR value.

Training protocol

The intervention training protocol was carried out by the Sport Science Section of the Neuroscience, Biomedicine and Movement Department of the University of Verona, Italy. Distance supervised physical activity training of 4 months of duration has been structured for groups of 10 subjects each. Several intervention strategies have been proposed. The first, was a synchronous online activity of 60 minutes 3 times per week always scheduled in the afternoon after school time, using the University Zoom Platform (Zoom Video Communications Inc., San Jose, CA, USA), allowing video sharing and live interaction among instructors and subjects. The activity consisted of circuit training achievable in the domestic context with no specific equipment, with the aim of increasing aerobic capacity and muscular strength. The exercises were chosen from various disciplines, such as basketball, kick boxing and bodyweight muscle strengthening, to meet the participants' satisfaction as much as possible. The activity was characterized by an initial 2-3 minutes of exercise for joint mobility, a 5-/10-minute warm-up, a central part with 8-station circuits (the number of circuit repetition were increased during the program adapting to the level of training); and a closing section dedicated to stretching and cool down. The second interventional strategy was asynchronous online activity through video-registered lessons of 60 minutes 1 time per week. The third strategy included autonomous activity at least one day per week (the subjects have been instructed to practice autonomously physical activity with the aim to reach a total of 10,000 steps/day monitored by dedicated smartphone app). The fourth interventional strategy included active breaks of prolonged sedentary behaviors have been promoted by 4 videos, each one lasting 10 minutes, showing simple low-intensity exercises or promoting self-managed activities. At the beginning of the project a live physical activity has been proposed to motivate the group participants and to give instructions about the program. The protocol training was specifically designed to meet the needs of participants and their families, being economically and organizationally sustainable. In addition, the program, during its course, was adjusted and tailored according to participants´ feedback and proposals making it more enjoyable and trying to increase motivation and adherence to the lessons.

Physical fitness tests and physical activity monitoring

At the first evaluation, a portable instrument equipped with an accelerometer was delivered for the effective quantification of physical activity carried out remotely for the first month. Common test batteries were performed by sport science specialists for monitoring physical fitness: the six minutes walking test (6MWT) was used to evaluating the aerobic capacity of the subjects;[26] also, hand grip strength test and the leg extension strength test were use for evaluating the maximum isometric strength exercised by the upper and lower limb. Leg extension in isometry with load cell test was measured in Newtons (S2Tech S.r.l. mod. 546QDT 550kg CV2; S2Tech S.r.l., Milan, Italy). The Physical Activity Questionnaire for Older Children (PAQ-C) was evaluated to recall physical activity performed the previous 7 days at baseline and at the training conclusion.[27] At each synchronous online live session, the Session Rating of Perceived Exertion (RPE) Scale was used to assess the effort degree at the end of the training.[28] Furthermore, subjects were suggested to record in a diary the type of physical activity they did during the day, the number of steps they took during the day, and the type of training they did in asynchronous mode. At the end, overall satisfaction was recorded, and participants were asked if they would like to continue the training project. An overview of the entire intervention protocol is summarized in Figure 1.

Statistical analysis

Categorical variables were described as counts and percentages; quantitative variables as the mean and standard deviation (SD) as they were normally distributed, according to the Shapiro-Wilks Test. The T0-T1 comparisons were conducted using a paired samples *t*-test. Two sides P value <0.05 was considered as statistical significance threshold. A generalized linear model (GLM) repeated measures was used to compare T0-T1 OGTT glycemic and insulin data concentrations, independent of the following anthropometric variables: sex, age, BMI SDS and WHtR. Analysis was performed with SPSS v29 (SPSS Inc., Chicago, IL, USA). For our study we considered the following a priori sample size calculation: the sample size of 20 individuals had an 80% power to detect, with a 5% alpha error, a pre-/postintervention variable change of at least 67% of the variable standard deviation, assuming a correlation between T0 and T1 values of at least 0.5.

Results

Twenty adolescents were recruited (11 male [55%], aged 14.1±1.5 years, BMI 36.1±5.9, BMI SDS 3.1±0.5). Eighteen out of 20 subjects completed the training protocol (90%), no adverse events nor difficulty using technology were re-

Table I.—*Anthropometric characteristics of the total sample (20 subjects recruited).*

Variables	Mean (or n)	SD (or %)
Age (years)	14.1	1.5
Sex (M)	11	55
Height (cm)	164.1	8.8
Weight (kg)	97.6	19.5
Pubertal stage		
Prepubertal	3	15
Pubertal	6	30
Postpubertal	11	55
BMI	36.1	5.9
BMI SDS	3.1	0.5
Waist (cm)	107.1	16.9
WHtR	0.65	0.9
SBP (mmHg)	116.0	10.1
DBP (mmHg)	69.5	8.7
FBM (kg)	43.8	13.0
FBM (%)	44.5	7.1
LBM (kg)	54.2	11.7
Hepatic steatosis (yes)	14	70

Data are described as mean and standard deviation (SD) or number and percentages. For pubertal stage, subjects were categorized in prepubertal (Tanner stage 1), pubertal (Tanner stage 2-4), and postpubertal (Tanner stage 5).
BMI: Body Mass Index; SDS: Standard Deviation Score; WHtR: Waist-to-Height Ratio; SBP: systolic blood pressure; DBP: diastolic blood pressure; FBM: fat body mass; LBM: lean body mass.

Table II.—*Physical, biochemical, and clinical characteristics of the 18 subjects that completed the training program and comparison between baseline (T0) and after training (T1).*

Variables	T0		T1		P value
	Mean (or n)	SD (or %)	Mean (or n)	SD (or %)	
BMI SDS	3.1	0.5	3.1	0.5	0.277
FBM (kg)	42.7	11.7	43.6	6.2	0.713
LBM (kg)	54.1	11.9	57.3	13.0	0.010*
WHtR	0.6	0.1	0.6	0.1	0.134
SBP (mmHg)	116.3	11.1	118.5	6.2	0.384
DBP (mmHg)	69.0	9.3	72.7	8.6	0.294
Glucose 0' (mg/dL)	97.1	8.8	95.3	8.7	0.375
Insulin 0' (mUI/L)	43.0	32.0	34.8	23.3	0.040*
HOMA-IR	10.0	8.7	8.2	5.3	0.120
Matsuda Index	1.4	1.0	1.7	1.2	0.198
Disposition Index	5.4	3.2	6.3	3.1	0.280
Total cholesterol (mg/dl)	155.6	29.4	162.1	34.1	0.172
HDL cholesterol (mg/dl)	46.7	14.7	45.5	10.2	0.680
Triglycerides (mg/dl)	116.1	95.4	106.2	83.1	0.152
ALT (U/L)	36.0	25.6	34.6	22.5	0.617
Uric Acid (mg/dl)	6.0	1.5	6.3	1.7	0.222
HbA1c (mmol/mol)	36.3	3.5	36.2	4.4	0.947
Hepatic Steatosis (yes)	14	78%	14	78%	-

Quantitative variables are expressed as mean and standard deviation (SD), and categorical variables are described as number and percentages.
BMI: Body Mass Index; SDS: Standard Deviation Score; WHtR: Waist-to-Height Ratio; SBP: systolic blood pressure; DBP: diastolic blood pressure; FBM: fat body mass; LBM: lean body mass; HOMA-IR: Homeostatic Model Assessment for Insulin Resistance; HDL: high-density lipoprotein; HbA1c: glycated hemoglobin; ALT: Alanine transaminase.
*Statistically significant.

ported. The anthropometric characteristics of the recruited total sample are described in Table I, while anthropometric, clinical, and biochemical characteristics at baseline (T0) of the 18 subjects that completed the project are reported in Table II. The subjects recruited were characterized by a severe central obesity with a mean WHtR of 0.65±0.9 and a FBM (%) of 44.5±7.1. Furthermore, 70% of the patients suffered from hepatic steatosis. After supervised physical activity training over a 4-month period, the subjects showed a significant improvement in LBM (P=0.01), with unchanged BMI SDS, and a reduction in basal insulinemia (P=0.040) (Table II). No significant differences were found in the other analyzed measures: blood pressure, prevalence of hepatic steatosis or other biochemical parameters (*e.g.*, lipid profile). Although not statistically significant, a tendency to increase insulin sensitivity can be seen by looking at Matsuda Index before and after training, with a concomitant improvement trend in the disposition index. Focusing on 10-points OGTT results, we could detect a significant reduction of glycemia at 150' (P=0.031) and a concomitant reduction in insulinemia at 150' (P=0.021) (Supplementary Digital Material 1: Supplementary Table I, II). The trend of the OGTT glycemic and insulin values is represented in Figure 2 and an overall significant difference between the means of insulinemia at the different time points (T0-T1) was detected by repeated measures GLM (P=0.043). The protocol training was effective in improving the fitness of the participants. In detail, we found a significant increase in VO_2max and maximal workload comparing pre-/postvalues (P=0.007 and P=0.025, respectively) and a significant improvement in the leg strength (P=0.001) and in the 6MWT (P=0.013). No significant differences were found at the PAQ-C Score assessment (Table III) as well as in the measured parameters of physical activity through accelerometers. However, session RPE values reported during synchronous classes were between moderate and high and increased significantly between T0-T1 (P<0.001) (Table III). Although 90% of subjects completed the training, the percentage of participation in the synchronous and asynchronous lessons was 68.8% and 50.2%, respectively, during the total period of the protocol training. Sixty-five percent of the subjects stated that they would participate in the project again.

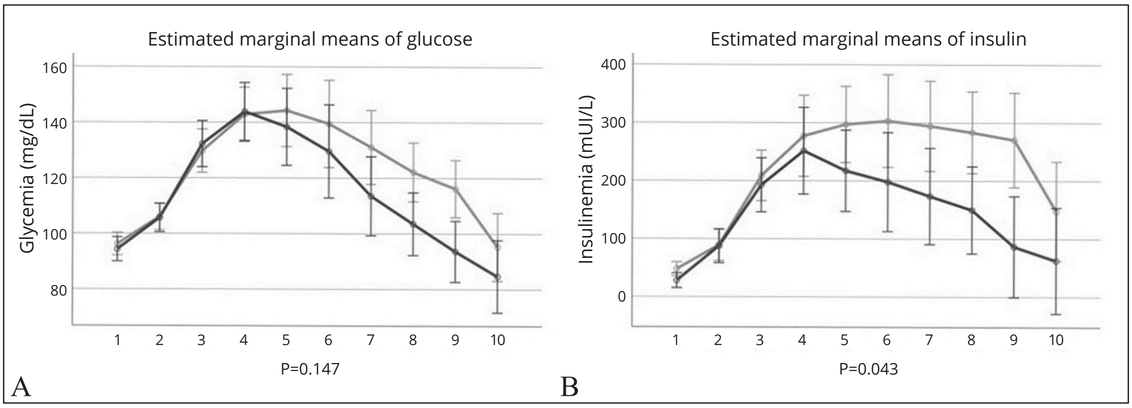

Figure 2.—Comparison of the oral glucose tolerance test between baseline (T0) and after training (T1). A generalized linear model repeated measures was used to compare T0-T1 plasma glycemia (mg/dL) (A) and insulinemia (mUI/L) (B) during the oral glucose tolerance test (OGTT).
Covariates used in the model: sex, age, BMI SDS, WHtR. T0 is represented in grey and T1 in black. Errors bars: 95% CI.

Table III.—*Fitness characteristics of the 18 subjects that completed the training program and comparison between baseline (T0) and after training (T1).*

Variables	T0		ùT1		P value
	Mean	SD	Mean	SD	
VO_2max (mL/Kg/min)	19.7	4.2	22.3	3.3	0.007*
Peak/theoretical VO2	0.59	0.21	0.64	0.21	0.162
Peak/theoretical HR	0.85	0.08	0.88	0.07	0.197
Max workload (Watt)	110.8	29.2	139.1	37.6	0.025*
L-HG	27.5	10.8	28.9	8.2	0.289
R-HG	27.0	10.5	28.9	8.7	0.060
LST (Newton)	130.8	103.0	191.9	117.9	0.001*
6MWT	582.6	59.5	616.7	69.4	0.013*
RPE Scale	4.64	1.45	6.99	1.92	<0.001*
PAQ-C	2.1	0.7	2.4	0.4	0.157

Variables are expressed as mean and standard deviation (SD).
VO_2max: maximum oxygen uptake; L-HG: left-handgrip test; R-HG: right-handgrip test; LST: leg strength test; 6MWT: six-minute walking test; RPE: rating of perceived exertion; PAQ-C: the Physical Activity Questionnaire for Older Children survey.
*Statistically significant.

Discussion

This study demonstrated the acceptability, feasibility, and safety of a remote adapted and supervised physical activity training program for adolescents with obesity. A very low drop-out rate (10%) was detected, even though the percentage of participation in synchronous and asynchronous classes was less than 75%, with specifically reduced participation in asynchronous ones. We found an overall increase in the cardiovascular fitness of the subjects who completed the program, suggested by an improvement in VO_2max and maximum workload, and common motor test scores (*i.e.*, leg strength and 6MWT). Furthermore, when analyzing the participants' subjective perception of physical exertion during exercise using the RPE Scale, the values ranged from moderate to vigorous throughout the duration of the exercise with a significant increase in perceived intensity from T0 to T1, in line with the progressive increase in training intensity and as a consequence of the increased adherence to the proposed workloads. These findings corroborate the results of a previous intervention study by Vandoni *et al*. that employed online exercise training in children with obesity.[29] They observed that structured remote exercise, especially of moderate-vigorous intensity, was associated with improved cardiac autonomic control, reduced systolic arterial pressure, and improved auxologic and metabolic parameters,[30] stressing the importance of a moderate-to-vigorous intensity exercise in improving cardiorespiratory fitness.[31] Regarding anthropometric endpoints, we did not observe an improvement in BMI SDS nor in WHtR, as described by Vandoni *et al.*,[29] however we found a significant increase in the absolute value of LBM, indicative of an increase in muscle mass secondary to training, supporting the effectiveness of the remote training program in improving the fitness of the subjects. Nevertheless, the benefits of exercise overcome those of weight reduction. Several studies showed that physical activity was associated with the reversal of the systemic inflammatory condition seen in subjects with overweight and obesity, reducing oxidative stress and improving endothelial function.[32] Physical activity improved insulin sensitivity, plasma dyslipidemia, blood pressure, reducing the cardiovascular risk from childhood to adulthood.[33-35] Our study, despite the difficulty of engaging adolescents with obesity in regular physical activity, confirmed the positive effect of the online training on glucose metabolism, reducing basal insulin and overall insulin concentration during OGTT, with a considerable improvement in second-phase insulin secretion (Figure 2). Insulin resistance plays a key role in the development of obesity-related comorbidities such as T2D, dyslipidemia, hepatic steatosis, and metabolic syndrome and its presence is a distinctive feature of metabolically unhealthy obesity phenotype.[36] Hence the importance of target this metabolic risk factor for the prevention of diabetes and metabolic syndrome since childhood.[37] Other studies available in literature showed that physical activity improves insulin sensitivity, despite no changes in adiposity indexes.[38, 39] These differences in anthropometric results could be also due to different modalities of training, as aerobic exercise has been reported to be more effective on weight loss, compared to the reported effect of endurance training on insulin resistance.[40, 41] Although the beneficial role of physical activity is well known and is an established cornerstone in the prevention and treatment of pediatric obesity,[42] achieving therapeutic adherence among children and adolescents with obesity to prescribed physical activity is challenging. Furthermore, specific implementation protocols and programs in pediatric settings are not clearly defined or readily available.[43] In general, programs that group children together, such as school programs or participation in team sports, are considered more effective because they also promote socialization and play an educational role.[42] Nevertheless, children and especially adolescents with obesity may have psychological barriers related to body shame and social pressure that preclude their participation in group activities due to the fear of physical activity practice in public.[44] Often these individuals show low overall and physical self-esteem, and physical activity is perceived as particularly strenuous and unrewarding, especially when it is experienced as a challenge with other peers.[45] Moreover, these approaches may pose certain barriers from both economic and organizational perspectives (*e.g.*, transportation requirements, time commitments, participation costs) which usually impact especially families of low socioeconomic status. This group is often the one most in need of dedicated and structured interventions, given the high prevalence of pediatric obesity in low-income or socially disadvantaged families.[46] Therefore, dedicated, and structured remote exercise intervention programs for adolescents suffering from obesity can help to overcome some of these common barriers. These programs may prove more effective from a motivational, educational, and social point of view, fighting the marginalization that individuals may experience in specific situations among their peers. Telemedicine, in general, has been rapidly adopted in healthcare services after the boost received during the COVID-19 pandemic and is expected to play an increasing role in healthcare.[47] There is substantial evidence in literature that remotely delivered exercises using technology have been found to be safe and effective in pediatric, adult, and geriatric populations, especially in times of restricted outings and activities.[48-53] As regards pediatric population and in particular pediatric obesity, a recent narrative review supported the benefits of remote physical activity and gamification in improving sedentary behaviors and anthropometric and metabolic features, despite the limitations of structured online exercise experience for children and adolescents with obesity.[14]

Limitations of the study

Some limitations of the study need to be acknowledged: 1) this study was a feasibility pilot observational study with a little sample size group and the absence of a control group, thus limiting the power of statistical analysis and the value of the results should be supported by further studies; 2) the failure to reduce the BMI SDS may also be due in part to the lack of concurrent nutritional counseling and follow-up, which was not provided to participants so as not to create bias in evaluating the effects of physical activity; and 3) despite the low dropout rate, participation, especially in asynchronous activities, was unsatisfactory, making it clear that interaction and motivation are key to achieving better adherence and highlighting some of the intrinsic limitations of remote exercise. This study has also some strengths: 1) the considerably longer duration of the intervention compared to other studies available in the literature; and 2) deep phenotypic characterization of the participants, including glucose metabolism characterization by 10-points OGTT. To the best of our knowledge, this study represents the first analysis of the feasibility and effectiveness of an online training program specifically designed for adolescents with obesity, employing an ecological and multidisciplinary approach.

Conclusions

A remote adapted physical activity intervention program appeared feasible and effective to improve cardiovascular fitness, endurance, and glucose metabolism in adolescents with obesity. The COVID-19 pandemic has shown us the opportunity to use online exercise for children and adolescents with obesity. Synchronous remote training programs, specifically designed to meet the needs of adolescents with obesity, can be acceptable and sustainable from an economic and organizational point of view. They provide a valid strategy to promote adherence to the prescription of physical activity, according to guidelines, and counteract the onset of obesity-related complications, helping to improve cardiovascular fitness and metabolic control, with the aim of breaking the vicious cycle toward an unhealthy metabolic phenotype of obesity.

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Conflicts of interest
The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

Authors' contributions
Alice Maguolo, Doriana Rudi, Claudio Maffeis and Massimo Lanza have gicejn substantial contributions to the study conception and design; Alice Maguolo, Giulia Ippolito, Giorgia Mazzuca, Mariano Bertaiola, Eleonora Marchiori, Vittoria Venier and Francesco Bordin contributed to the data collection; Alice Maguolo and Massimo Lanza contributed to the data analysis and interpretation; Alice Maguolo and Giorgia Mazzuca contributed to the manuscript draft; Alice Maguolo, Claudio Maffeis and Massimo Lanza contributed to the manuscript editing and discussion. All authors read and approved the final version of the manuscript.

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SUPPLEMENTARY DIGITAL MATERIAL 1

Supplementary Table I.—Glycemia (mg/dL) values during OGTT and comparison between baseline (T0) and after training (T1).

	T0		T1		
Variables	Mean	SD	Mean	SD	P value
Gluc 0’	97.1	8.8	95.3	8.7	0.375
Gluc 10’	107.1	10.8	106.8	11.5	0.926
Gluc 20’	130.6	20.1	132.2	15.4	0.743
Gluc 30’	143.5	23.4	144.9	21.9	0.756
Gluc 45’	138.4	25.2	139.4	31.3	0.810
Gluc 60’	133.9	33.2	130.8	36.6	0.674
Gluc 90’	125.2	30.4	114.8	28.6	0.093
Gluc 120’	115.5	25.6	108.5	24.5	0.199
Gluc 150’	108.1	22.5	94.3	14.3	0.031*
Gluc 180’	94.1	27.4	84.2	17.3	0.182

Variables are expressed as mean and standard deviation (SD). In bold are expressed significant values.

OGTT: oral glucose tolerance test; Gluc: plasma glucose concentration (mg/dL).

*Statistically significant.

Supplementary Table II.—Insulineamia (mUI/L) values during OGTT and comparison between baseline (T0) and after training (T1).

	T0		T1		
Variables	Mean	SD	Mean	SD	P value
Ins 0’	43.0	32.0	34.8	23.3	0.040*
Ins 10’	76.0	43.1	88.0	70.8	0.341
Ins 20’	186.8	123.0	193.9	106.0	0.726
Ins 30’	256.8	186.9	267.8	164.6	0.704
Ins 45’	236.6	165.6	228.4	145.2	0.706
Ins 60’	252.3	199.1	224.0	166.7	0.442
Ins 90’	254.9	213.8	189.6	134.9	0.109
Ins 120’	238.9	231.8	191.9	148.1	0.211
Ins 150’	195.5	177.1	100.1	64.2	0.021*
Ins 180’	141.5	227.5	69.0	55.94	0.176

Variables are expressed as mean and standard deviation (SD). In bold are expressed significant values.

OGTT: oral glucose tolerance test; Ins: plasma insulin concentration (mUI/L).

*Statistically significant.