

Fractional O₂ extraction and fitness among physically active and inactive children during post-exercise recovery

Extracción fraccional de O₂ y condición física entre niños activos e inactivos físicamente durante la recuperación post ejercicio

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Abstract. This study aimed to determine the differences in muscle O₂ extraction capacity and physical fitness between physically active and sedentary schoolchildren. 19 students aged 10 to 14 years participated, categorized as physically active or inactive. In addition, a battery of basic physical condition and cardiovascular variables assessments was carried out. Physically active children demonstrated significantly greater efficiency in muscle O₂ extraction and resaturation during post-exercise recovery compared to sedentary counterparts (17.8 ± 8.11 s vs 26.1 ± 8.54 s; $p = 0.004$; $\eta^2p: 0.271$). In the physical fitness tests there were only significant differences in the 30s Chair Stand Test (27.8 ± 3.97 vs. 19.4 ± 2.88 reps. $P < 0.001$ $\eta^2p: 0.614$). These findings underscore the potential of regular physical activity to optimize peripheral vascular response and muscle oxygen utilization during post-exercise recovery in children.

Keywords: NIRS; Physical Fitness; Exercise Recovery; Muscle Oxygenation; Physical Activity

Resumen. El objetivo de este estudio fue determinar las diferencias en la capacidad de extracción de O₂ muscular y la condición física entre escolares físicamente activos y sedentarios. Participaron 19 estudiantes de 10 a 14 años, categorizados como físicamente activos o inactivos. Además, se llevó a cabo una batería de evaluaciones de la condición física básica y de variables cardiovasculares. Los niños físicamente activos demostraron una eficiencia significativamente mayor en la extracción y resaturación de O₂ muscular durante la recuperación post-ejercicio en comparación con sus homólogos sedentarios ($17,8 \pm 8,11$ s vs $26,1 \pm 8,54$ s; $p = 0,004$; $\eta^2p: 0,271$). En la prueba de aptitud física sólo hubo diferencias significativas en la prueba de sentarse y pararse de la silla durante 30s ($27,8 \pm 3,97$ vs. $19,4 \pm 2,88$ repeticiones. $p < 0,001$ $\eta^2p: 0,614$). Estos hallazgos subrayan el potencial de la actividad física regular para optimizar la respuesta vascular periférica y la utilización del oxígeno muscular durante la recuperación post-ejercicio en niños.

Palabras clave: NIRS; Condición física; Recuperación del ejercicio; Oxigenación muscular; Actividad física.

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Introduction

Physical fitness, or the ability to perform physical activity or exercise, is considered a future predictor of the development of diseases related to a decrease in their components, particularly in children with low levels of physical activity during childhood (Herazo-Beltrán, 2018; Vidarte Claros et al., 2022). In this regard, the World Health Organization (Bull et al., 2020) published global guidelines on physical activity and sedentary behavior for children and adolescents, recommending at least an average of 60 minutes of daily moderate-to-vigorous-intensity aerobic physical activity, including activities that strengthen muscles and bones at least three days a week. Compliance with these recommendations is related to better health indicators (Chaput et al., 2020).

In relation to physical fitness levels in schoolchildren, studies such as ESSCOLA (Alvero-Cruz et al., 2010), AVENA and HELENA (Ruiz et al., 2006) emphasize the importance of flexibility, grip strength, jumping ability, body mass index (García Ordóñez, 2022; Castro-Piñero et al., 2009; España-Romero et al., 2010), and cardiorespiratory fitness (Silva et al., 2022). In addition to this, within the

school context, Latorre-Román et al., (2018) show that cardiorespiratory fitness, speed-agility, motor coordination, and perceptual-motor ability had the strongest association with executive function, including attention, memory, and inhibition, evidencing that high levels of physical activity and physical fitness are associated with higher academic performance and executive function.

Even with this evidence as a background, behavioral changes in the population, exacerbated by the pandemic, have led to an increase in sedentary lifestyles, high rates of physical inactivity and low levels of physical fitness. Recent studies show a significant reduction in physical activity levels and an increase in childhood sedentary lifestyle (Alonso-Martínez et al., 2021), associated with a decrease in cardiorespiratory and muscular fitness (Rodríguez-Núñez, 2021), showing in different studies that children spend almost 70% of their time in sedentary behaviors, much of it in schools (Dowd et al., 2012; Kariippanon et al., 2019). More time spent carrying out sedentary behavior is associated with health risks, as well as with the development of becoming overweight and obese (Rey-López et al., 2008). Regarding physical inactivity, it is estimated that worldwide,

only 20% of children and adolescents comply with the recommended levels of physical activity (Guthold et al., 2020)

On the other hand, while a significant number of studies have explored the effects of moderate to vigorous physical activity on physical fitness in children and adolescents through validated tests in this population, there is little evidence on muscle response and exercise-induced fatigue in active and inactive children and adolescents. which makes this study a new insight into peripheral vascular response in this demographic. In this regard, muscle oxygen saturation (SmO₂), obtained by near-infrared spectroscopy (NIRS), has been investigated as a means of assessing muscle oxygen dynamics (Wakasugi et al., 2018), and the change in SmO₂ during exercise is a useful indicator to assess energy metabolism in terms of muscle oxygen consumption during muscle activity (Shirai et al., 2023).

NIRS was used in the present study because it is a non-invasive, relatively inexpensive, and easy-to-use analysis tool that provides real-time information on muscle metabolism during and after exercise. NIRS, a cost-effective tool, aims to assess local oxygenation responses that reflect the balance between oxygen supply and utilization at the microvascular level within skeletal muscle (Perrey et al., 2022). It is based on the absorption of light by oxygenated and deoxygenated hemoglobin (Hb) and myoglobin (Mb) in the near-infrared spectrum, using the interaction of light at different wavelengths. This technique allows measuring changes in oxyhemoglobin (O₂Hb), deoxyhemoglobin (HHb), total hemoglobin and tissue saturation index (TSI) in skeletal muscle during exercise, with TSI being a reliable indicator to analyze fractional O₂ extraction (Kime et al., 2013).

Physically active children exhibit elevated muscle energy metabolism, experiencing exercise-induced fatigue more slowly (Callewaert et al., 2013). Conversely, impaired muscle energy metabolism results in poor exercise performance and recovery (Owen-Jones et al., 2020). Muscle fatigue and poor performance are primarily associated with the depletion of energy substrates such as muscle glycogen and the buffering capacity of metabolic waste products. Compared to adults, children have a lower anaerobic capacity and are more susceptible to energy depletion (Kaczor et al., 2005). In addition, O₂-based metabolism in muscles is a significant compensatory mechanism in energy production during exercise in children, although it becomes more inefficient when oxygen is depleted. Therefore, it is valuable to identify differences in muscle energy metabolism between sedentary and physically active children.

This study aimed to determine the differences in muscle O₂ extraction capacity and physical fitness between physically active and sedentary schoolchildren. This research aims to expand our understanding of how physical activity influences vascular and muscle responses to exercise, specifically

through the lens of fractional O₂ extraction during post-exercise recovery periods, employing near-infrared spectroscopy (NIRS) for assessment. We hypothesize that physically active children will demonstrate significantly greater efficiency in muscle extraction and resaturation of O₂ during post-exercise recovery compared to their sedentary counterparts. This increased efficiency is expected to correlate with improved fitness levels, showing the potential of regular physical activity to optimize peripheral vascular response and muscle oxygen utilization.

Materials and methods

Sample size

An a priori calculation was performed using the average differences in maximal oxygen uptake (VO₂max: -11.68 ml/kg/min) between physically active and inactive children from Runacres et al., 2023. An alpha error of 5% with a power of 80% and an intergroup ratio of 1:1 was used. Based on these criteria, a sample estimate was estimated with a minimum of 6 participants for each group. The calculations were performed with the G*Power software version 3.1.9.7 (Düsseldorf, Germany).

Participants

This is a quantitative, descriptive, comparative and correlational study that included a sample of 19 students aged between 10 and 14 years (mean age 12.1 ± 0.3 years), in this study only male children participated. They were previously identified as physically active (n=10; 12.3 ± 0.4) or inactive (n = 9; 12.1 ± 0.2 years) according to the international guidelines of the World Health Organization (Bull et al., 2020). The inclusion criteria were children in the specified age range who participated in at least 80% of the measurement sessions without any underlying clinical conditions. Exclusion criteria covered children with contraindications or clinical conditions at the time of assessment. In addition, removal criteria were applied to children who did not meet the threshold of 80% participation in the evaluation sessions or to those who voluntarily withdrew from the study. Informed consent was obtained in October before the start of evaluations, reviewed, and adapted by the research team to Chilean terminology before distribution to potential participants. The study's objectives and safety considerations were explained before measurements. This research adhered to the Helsinki Declaration guidelines for human studies and was approved by the Scientific Ethics Committee of Universidad Viña del Mar (Code R62-19a). To ensure confidentiality and anonymity, participant names were coded, and collected data was stored on the principal investigator's personal computer, accessed via a personal password.

Procedure

All the evaluations were performed in a laboratory room located in the educational establishment. First, the groups of participants were classified as physically active and inactive, then the anthropometric and physical condition evaluations were performed. After completing these tests, the 30 seconds chair stand test was performed, and fractional oxygen extraction was analyzed with NIRS. The methodology is shown in Figure 1.

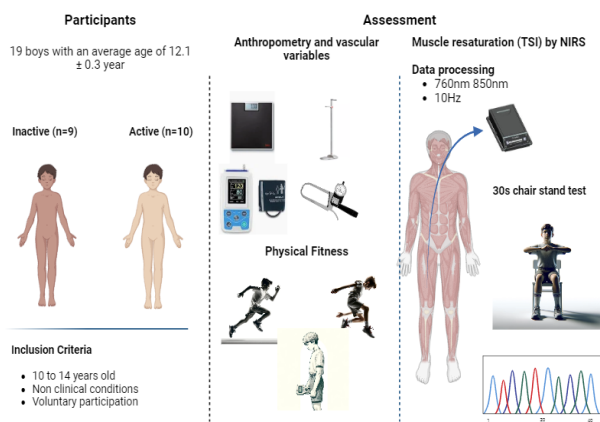


Figure 1. Methods of study

Measurement

Level of physical activity

The level of physical activity was assessed by using accelerometers for one week. Actigraph® GTX3 devices were used for this. The calibration and determination of physical activity intensity and minutes of moderate and vigorous physical activity were analyzed from a previous study in this population (Tuesta-Roa et al., 2020). The following cut-off points were used to estimate the level of physical activity: sedentary: 0-149 cpm, light: 150-499 cpm, moderate: 500-3999 cpm, vigorous: 4000-7599 cpm and very vigorous >7600 cpm. To identify moderate/vigorous physical activity, the criterion selected was for all movement above moderate intensity, i.e., with a cpm >500 (Freedson et al., 2005). For the daily calculation of moderate to vigorous physical activity, the daily average obtained was used, considering 60 minutes of moderate to vigorous physical activity per day as a cut-off point. Based on the data obtained from the accelerometer, only physical activity intensity data were considered based on the cut-off points indicated above. Reminders were sent to students every day about using the device when sleeping, entering the pool and showering, and accelerometers were also checked to identify correct daily use by children. Data from accelerometers that ran out of battery or that students did not use during the scheduled 7 days were excluded. The division into physically active and physically inactive was made considering the latest update of the WHO physical activity recommendations for children and adolescents considering a cut-

off point of a minimum of 60 minutes de moderate to vigorous activity per day to identify physically active children (Chaput et al., 2020).

Blood pressure and heart rate assessment

Prior to the assessment, participants were instructed to avoid stimulants (such as caffeine, energy drinks, and others), smoking, or physical activity 24 hours before the assessments. The appropriate cuff size was selected based on the arm circumference measured halfway between the elbow and shoulder. The device was placed on the arm above the antecubital fossa, and the student sat in a calm and warm environment. A room with an average ambient temperature of 20 degrees Celsius was used for the evaluation of blood pressure, which was heated with an electrical device. To ensure a calm atmosphere, ambient music was played and people outside the evaluation process were prevented from entering. The average value of the two blood pressure measurements was considered. Following the guidelines of the American Heart Association Council, two measurements were taken: the first after 3 to 5 minutes of sitting rest, followed by a second measurement 1 minute later (Pickering et al., 2005). Blood pressure was measured with an OMRON® model 7220 device (Kyoto, Japan) and heart rate was analyzed with a POLAR® model H10 chest strap (Kempele, Finland).

Anthropometry

Anthropometric measurements were performed at the beginning of the assessments to determine the health status of the students prior to the application of the NIRS. Measurements included weight, height, body mass index (BMI), and thigh fold, following guidelines from the International Society for the Advancement of Kinanthropometry (ISAK). Body weight was measured with an accuracy of 0.1 kg using a SECA® model 803 scale (Hamburg, Germany), and height was measured with a SECA® portable stadiometer (Hamburg, Germany). The thickness of the skinfolds was measured in the muscle belly of the vastus lateralis quadriceps, approximately 15 cm above the upper border of the patella and 5 cm laterally, parallel to the muscle fibers using a Harpenden® caliper (London, UK). The NIRS device was subsequently applied at this site. BMI was calculated using the formula $\text{weight (kg)}/\text{height (m)}^2$ (Quetelet, 1889).

Fitness assessment

Horizontal Jump Test

The horizontal jump test assesses the explosive strength of the lower limbs through a standardized protocol (Castro-Piñero et al., 2009). Before the assessments were conducted, verbal instructions were given and how to perform the test was also demonstrated. To avoid inter-rater effects, the assessment was performed by the same person. Each student

made three jumps and the highest jump obtained was recorded. A metal tape measure with an accuracy of 0.1 cm was used for the evaluation. Participants stood behind the jump line with their feet shoulder-width apart, bent their knees with their arms extended parallel to the ground in front, then swung their arms, pushed each other hard, and jumped as far as possible. They were instructed to land with both feet simultaneously in an upright position. A retry was allowed if the participant fell backwards or touched the surface with any part of the body other than the feet (Ruiz et al., 2011).

Speed and agility, 4x10 meter event

This test aims to measure agility, speed, and coordination. Prior to the evaluations, a familiarization process was carried out where each participant practiced the course three times. A Chronojump® photocell system was used to time the times. The test was performed twice by the same evaluator and the best time obtained from the two attempts was considered. It consists of marking two parallel lines on the ground 10 meters apart, each demarcated with a cone. On the starting line, there is one sponge (B), and on the opposite line, there are two sponges (A,C). At the start signal, the participant, without a sponge, runs as fast as possible to the other line and returns to the starting line with a sponge (A), crossing both lines with both feet. The sponge (A) is changed to sponge B on the starting line. The participant then runs to the opposite line, swaps sponge B for sponge C, and returns to the starting line. Participants were instructed to run at their maximum speed, covering the distance in the shortest possible time, twice from one line to another. When participants dropped a sponge, they had to retake the test (Ruiz et al., 2011).

Dynamometer measurements

Handgrip strength dynamometry measures maximal static muscle strength, reflecting bone mineral content, lean mass, and serving as a potential estimator of physical conditions and nutritional status. It is crucial to monitor hand grip strength during growth to obtain baseline values for health status or performance assessment (Cohen et al., 2010). The optimal grip size was determined based on the recommendations of the Alpha Fitness battery. To do this, the size of the hand (right or left) was measured at maximum width and measuring the distance separating the distal ends of the index and fifth fingers. The measurement accuracy was 0.5 cm. The hand size results were rounded to the nearest whole centimeter. In some cases, the children's hand was placed on the table-ruler to see the measure of the optimal grip according to the size of the hand. The rest time between evaluations was 2 minutes. Participants squeezed the dynamometer gradually and continuously for at least 2 seconds, performing the test twice (alternating hands) with the optimal grip size adjusted to the hand size (previously calculated with a ruler table) and allowed a

short break between measurements. The hand to be tested first was chosen at random, ensuring that the elbow was fully extended and avoiding contact with the dynamometer against any part of the body except the hand being measured (Vaquero-Cristóbal et al., 2013). A JAMAR® digital dynamometer model J00105 (California, USA) was used for the evaluation.

30-Second Sit-to-Stand Test

Studies have demonstrated that performance in the sit-to-stand test is closely associated with lower limb strength measurements. Chairs of different sizes were used so that all children were fully supported on the soles of their feet during the evaluation. Complete repetitions were considered when the children performed a full knee extension, the verification was performed by an evaluator. In this test, participants are seated in the middle of a chair placed against a wall, with feet flat on the floor and arms crossed over the chest. Upon starting the evaluation, subjects were required to stand up fully and return to the seated position as many times as possible within 30 seconds. After completing the test, participants remained seated for an additional minute (Vaquero-Cristóbal et al., 2013).

Muscle oxygenation with NIRS

The evaluation of fractional O₂ extraction was carried out during the 30-second sit-stand test. Prior to the assessments, participants sat in a chair with an ergonomic backrest and the measurement area was cleaned with 70° isopropyl alcohol. A continuous wave (CW) NIRS device from Artinis Medical System, model Portamon® (Elst, Netherlands), was placed in the vastus lateralis area. The vastus lateralis quadriceps was visually analyzed in each of the participants, from which the device was installed. The NIRS was adjusted to wavelengths of 760 nm and 850 nm with a sampling rate of 10 Hz (Cohen et al., 2010). During the evaluation, a visual inspection was performed to identify the stabilization of the NIRS signal. Before the test, participants were instructed not to engage in physical activity. The evaluation began 5 minutes after setting up the device. The measurement site was marked with a dermatographic pencil, and the NIRS device was secured with adhesive tape, covered with a black cloth to prevent ambient light interference. Data analysis utilized the NIRS's third recording channel (40 mm) due to its deeper tissue penetration capability (Sanni y McCully, 2019). After the assessment, data were reviewed and analyzed using Oxysoft® software, then transferred to an Excel spreadsheet on a computer for further statistical analysis. The baseline tissue saturation index (TSI_b) was calculated as the average of the minute before exercise once the NIRS signal stabilized. The minimum saturation value (TSI_{min}) was determined based on the lowest value reached during the test, and the maximum saturation value (TSI_{max}) was calculated during the test. The reoxygenation

rate from minimum to baseline (Δ TSIreox Min-Baseline post-exercise (s)) was calculated based on the time it took for TSI to return to baseline levels after exercise. In the study, resaturation velocities were considered and the previous baseline value obtained before physical exercise was taken into account for comparisons.

Statistical Analysis

The mean and standard deviation were used to present the variables. The Shapiro-Wilk test evaluated the normality of the data, a Levene test was performed for homogeneity of variances, finding homogeneity in the study variables, followed by ANOVA with Bonferroni post-hoc for group comparisons. For the variables of oxygenation and physical capacity, a partial eta-square test (η^2p) was applied, with values of < 0.25 , $0.26 - 0.63$ and > 0.63 indicating small, medium and large effect sizes, respectively (Richardson, 2011). All analyses were performed with JAMOVI® software version 2.3.16 and a $p < 0.05$ was considered significant.

Results

Table 1 presents the results for the basic variables; Differences in the level of physical activity were only found between the groups ($p < 0.001$; $\eta^2p: 0.825$).

Table 1. Descriptive and Post Hoc Analysis of Anthropometric and Basic Variables Across Groups.

Variable	Active (n = 10)	Inactive (n = 9)	Δ	F	p	η^2p
Age (years)	12.3 ± 0.4	12.1 ± 0.2	0.2	0.750	0.889	0.000
Weight (kg)	52.7 ± 9.2	54.2 ± 13.5	-1.5	0.087	0.771	0.005
Height (cm)	159 ± 10.1	156 ± 7.5	3.0	0.482	0.497	0.028
BMI (kg/m ²)	19.8 ± 2.2	22.0 ± 4.5	-2.2	1.96	0.180	0.103
Systolic BP (mmHg)	107 ± 13.0	115 ± 18.9	-8.0	1.25	0.279	0.069
Diastolic BP (mmHg)	70.0 ± 11.3	73.2 ± 5.8	-3.1	0.615	0.444	0.035
Resting HR (bpm)	86.9 ± 14.9	96.0 ± 10.6	-9.1	0.230	0.148	0.119
Thigh Skinfold (mm)	13.4 ± 6.17	17.2 ± 5.5	-3.8	1.99	0.177	0.105
Physical Activity (Min/w)	617 ± 133*	180 ± 64.5*	437	80.1	<0.001	0.825

Table 2 shows the results for the variables of physical capacity and muscle oxygenation. The active group demonstrated a higher number of repetitions in the 30-second sit-stand test (Active: 27.8 ± 3.97 repetitions; Inactive: 19.4 ± 2.88 reps; $p = 0.001$) with a moderate effect size ($\eta^2p = 0.614$). While no differences were observed in other variables, there was a trend toward better performance in the physically active group.

Figure 2 shows that physically active children had a higher rate of reoxygenation analyzed with the TSI from the minimum to baseline value compared to physically inactive children, with a moderate effect size ($17.8 \pm 8.11s$ vs. $26.1 \pm 8.54 s$; $p = 0.004$; $\eta^2p: 0.271$).

Table 2. Descriptive and Post Hoc Analysis of Physical Capacity and Muscle Oxygenation Variables Across Groups.

Variable	Active (n = 10)	Inactive (n = 9)	Δ	F	p	η^2p
30s Chair Stand Test (reps)	27.8 ± 3.9*	19.4 ± 2.8*	8.4	27.1	<0.001	0.614
Jump (cm)	142 ± 16.5	137 ± 16.5	5.0	0.476	0.500	0.027
Handgrip Right (kg)	26.1 ± 5.2	24.1 ± 5.9	2.0	0.596	0.451	0.034
Handgrip Left (kg)	24.9 ± 3.8	23.3 ± 6.4	1.6	0.412	0.530	0.024
Handgrip Mean (kg)	25.5 ± 4.3	23.7 ± 6.1	1.8	0.535	0.474	0.031
4 x 10m Test (s)	12.5 ± 0.8	13.0 ± 1.1	-0.5	0.906	0.354	0.051
TSI Baseline (%)	73.1 ± 11.5	75.8 ± 4.0	-2.7	0.027	0.870	0.002
TSI Min (%)	63.0 ± 14.4	63.0 ± 12.9	0.0	0.703	0.993	0.000
Δ TSI (%)	17.1 ± 10.9	17.8 ± 13.4	-0.7	0.017	0.897	0.001

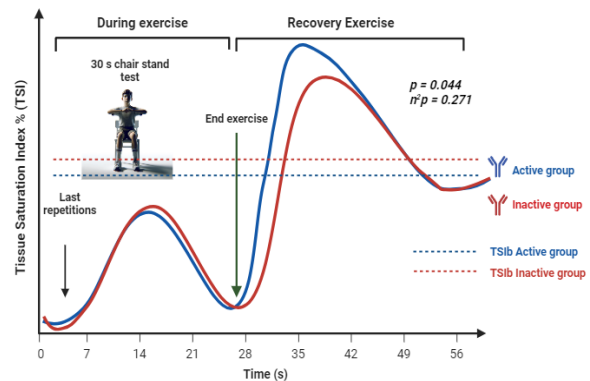


Figure 2. TSI resaturation level between physically active and inactive groups

Discussion

The aim of this study was to determine the differences in O2 extraction capacity and physical fitness between physically active and sedentary schoolchildren. Guided by the initial hypothesis that physically active children would demonstrate superior efficiency in muscle extraction and resaturation of O2 during post-exercise recovery, the results corroborate this premise. Active participants showed a significantly higher rate of reoxygenation (TSI) after a 30-second sit-stand test, underscoring an optimized peripheral vascular response and enhanced fractional O2 extraction. This result not only addresses the hypothesis, but also enriches our understanding of the physiological benefits conferred by regular physical activity in the pediatric population.

Previous research has shown that active individuals show better muscle oxygenation profiles than their inactive counterparts. A study conducted in active and inactive men revealed that a lower reliance on deoxyhemoglobin after cuff release in an ischemia-reperfusion test among trained individuals suggested faster and more efficient reperfusion, which could facilitate a faster return to aerobic metabolism compared to untrained individuals (Soares and McLay, 2017). Rascica et al., (2022) compared the microvascular response between trained and untrained people using an ischemia-reperfusion test, finding that reperfusion rates analyzed with TSI were faster in trained subjects and that this speed correlated

with the VO₂max achieved in an incremental test, a finding similar to that reported by Posser et al., (2016).

Incorporating the improved rates of muscle reoxygenation observed in physically active children, our research aligns with existing literature underscoring the significant impact of physical activity on muscle and vascular efficiency. Gerz et al. (2013) affirm the reproducibility of NIRS in the assessment of tissue oxygenation during exercise, highlighting its reliability in reflecting muscle metabolism. This corroborates our findings, emphasizing the critical role of regular physical activity in optimizing muscle oxygen utilization and improving vascular responses. This knowledge not only validates the methodology used in our study, but also underscores the importance of encouraging physical activity from an early age to improve physiological health outcomes.

The better fractional O₂ extraction observed in the group of physically active children during post-exercise recovery can be explained by the adaptations generated by physical activity in vascular modulation and nitric oxide bioavailability (Song et al., 2022). This includes optimizing endothelial function, decreasing blood pressure and resting heart rate, decreasing sympathetic tone, and increasing vagal tone, which improves baroreflex sensitivity at rest and during exercise. Other adaptations such as increased blood plasma and improved cardiac function (Seravalle & Grassi, 2022) would explain the increased muscle capacity for O₂ extraction during recovery. In addition, physical activity-induced improvements in mitochondrial biogenesis and enhanced formation of respiratory chain supercomplexes in human skeletal muscle optimize electron transport chain function for O₂ utilization and fractional extraction (Greggio et al., 2017). Lastly, physical activity promotes angiogenesis through VEGF activation (Ross et al., 2023), which could support improvements in fractional O₂ extraction through increased blood flow associated with improved mitochondrial function and increased endothelial response in physically active children.

In relation to the physical fitness tests, although there was a significant difference in the lower limb muscle strength test, the manual grip, jumping and agility strength tests did not show differences between the groups. Evidence in this regard indicates that sedentary behavior is associated with lower muscle strength and endurance (Ciesla et al., 2014) and lower levels of physical fitness (Tremblay et al., 2011), and children with high levels of physical activity perform better on tests of muscle strength and endurance (Dong et al., 2021; Chen et al. 2018)

Limitations of the study and future lines of research.

The study's limitations section highlights two main limitations: the small and unrepresentative sample size, which cau-

tions against generalizing the findings to the general population, and the absence of measurements of autonomic response during exercise through heart rate variability. He suggests that future research should include these regional measures. To improve this section, one could delve into the potential impacts of these limitations on study findings and discuss strategies to address these issues in future research. For example, future studies could target a larger, more diverse sample to improve generalizability and incorporate comprehensive autonomic system assessments to better understand physiological responses to exercise in different populations. Future research could focus on longitudinal studies to assess the long-term effects of physical activity on fractional oxygen extraction and recovery processes in children, including a wider range of demographic backgrounds to increase the generalizability of findings. Incorporating comprehensive autonomic system assessments, such as heart rate variability during and after exercise, could offer deeper insight into physiological responses to exercise. In addition, examining the impact of different types of physical activity and intensity levels on oxygen extraction and recovery could further refine our understanding of how exercise influences children's cardiovascular health. This approach not only addresses current limitations, but also opens up new avenues for research into the benefits of physical activity from an early age.

Practical applications

The practical application of this study underscores the vital role of regular physical activity in improving vascular and muscle efficiency from an early age. Demonstrating that physically active children exhibit faster muscle reoxygenation rates after exercise, this research highlights the importance of incorporating physical activity into daily routines to optimize peripheral vascular response and improve fractional oxygen extraction. These findings suggest that physical education programs and health policies should emphasize the promotion of regular and varied physical activities for children to foster better cardiovascular health and fitness. By doing so, we can lay a solid foundation for lifelong health benefits, potentially reducing the risk of cardiovascular disease and improving overall well-being. This approach not only supports the development of healthier individuals, but also contributes to the broader goal of mitigating the public health challenges associated with sedentary lifestyles and poor cardiovascular health from an early age.

Conclusions

In conclusion, our study reveals that physically active schoolchildren show fractional upper O₂ extraction after a 30-second sit-stand test, along with increased lower-extrem-

ity strength and endurance compared to their physically inactive peers. These findings provide crucial evidence to the current discourse on the benefits of regular physical activity from an early age, emphasizing the need for policies and educational frameworks that promote greater participation in physical exercise within school settings. The physiological advantages observed, including optimizing peripheral vascular response and improving muscle reoxygenation rates, highlight the potential of physical activity to instigate beneficial vascular adaptations during the critical developmental years. Accordingly, this study advocates for the implementation of structured physical education programs designed to cultivate an active lifestyle among children, thus laying the foundation for healthier future generations. The evidence presented in this paper should serve as a cornerstone for health and education policymakers to prioritize and expand physical activity opportunities for school-aged children, in order to promote lasting cardiovascular health and physical well-being.

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