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# Comparison of VO<sub>2</sub>peak from the Progressive Aerobic Cardiovascular Endurance Run (PACER) and treadmill in children

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## ABSTRACT

**Background/Objectives:** The purpose of this study was to investigate the difference in peak oxygen consumption (VO<sub>2</sub>peak) during a graded treadmill test and the Progressive Aerobic Cardiovascular Endurance Run (PACER) in a sample of 7–14 year old children.

**Methods:** Forty-four participants (25 boys, 19 girls) had VO<sub>2</sub> assessed during a peak treadmill test and the PACER by a portable indirect calorimeter on non-consecutive days. Exercise parameters were compared between exercise tests by paired t-tests.

**Results:** The PACER elicited a greater measured VO<sub>2</sub>peak ( $49.4 \pm 9.4$  vs.  $46.7 \pm 7.5$  ml. kg<sup>-1</sup>.min<sup>-1</sup>) and maximum respiratory exchange ratio ( $1.14 \pm 0.08$  vs.  $1.07 \pm 0.08$ ) than the treadmill test ( $p < 0.05$ ). Rating of perceived exertion was higher ( $8.1 \pm 3.5$  vs.  $7.6 \pm 3.8$ ) during the treadmill test compared to the PACER test ( $p < 0.05$ ). There was no difference in maximum heart rate between treadmill test and PACER test ( $196.9 \pm 9.3$  vs.  $198.6 \pm 8.8$ ,  $p > 0.05$ ).

**Conclusions:** The PACER provides an acceptable measure of cardiorespiratory fitness in children but the finding that children elicit a higher measured VO<sub>2</sub>peak during the PACER compared to a graded treadmill test warrants continual refinement in future aerobic fitness prediction equations from the PACER.

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## 1. Introduction

Cardiorespiratory fitness is an essential component in the assessment of health-related fitness in children.<sup>1</sup> Insufficient levels of cardiorespiratory fitness are associated with a litany of health problems, such as: dyslipidemia,<sup>2</sup> metabolic syndrome,<sup>3</sup> overweight/obesity,<sup>4</sup> poor mental health,<sup>5</sup> and the clustering of cardiovascular disease risk factors.<sup>6</sup> Additionally, higher cardiorespiratory fitness has been associated with enhanced academic achievement.<sup>7</sup> A recent scientific statement from the American Heart Association has further raised awareness on the importance of assessing cardiorespiratory to predict current and future health in apparently healthy youth.<sup>8</sup>

The direct measurement of peak oxygen consumption (VO<sub>2</sub>peak) during a maximal effort, graded treadmill test provides

an objective measure of cardiorespiratory fitness and is recognized as the gold standard assessment in children and adolescents.<sup>9</sup> However, laboratory cardiorespiratory fitness testing is not conducive to the evaluation of a large number of children and adolescents in a short time frame, as is customary in the school setting where the majority of children have cardiorespiratory fitness assessed.<sup>10</sup> Subsequently, to overcome these limitations, a variety of field tests have been developed to estimate VO<sub>2</sub>peak and cardiorespiratory fitness, although concerns with the equations utility have been documented.<sup>11</sup>

The Progressive Aerobic Cardiovascular Endurance Run (PACER) is a commonly administered field test used by Physical Educators, Exercise Physiologists, and Exercise Scientists to predict VO<sub>2</sub>peak and assess cardiorespiratory fitness. The PACER was originally developed with a sample of 8–19 year olds using retro-extrapolation immediately following the progressive, multistage running test to predict VO<sub>2</sub>peak.<sup>12</sup> Currently, the PACER is a standard cardiorespiratory fitness assessment protocol recommended by FITNESSGRAM and the Presidential Youth Fitness Program to predict children's VO<sub>2</sub>peak.<sup>12,13</sup> Children are categorized into one of

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three fitness zones based on their  $\text{VO}_2\text{peak}$ : healthy fitness zone, needs improvement, or needs improvement-health risk.<sup>10</sup> This categorization provides teachers, parents, and children with an indication of a child's fitness level and an appropriate indication of health risk.

Furthermore, predicted PACER  $\text{VO}_2\text{peak}$  has been shown to be correlated with measured treadmill  $\text{VO}_2\text{peak}$ ,<sup>14</sup> and thus, deemed an acceptable measure of cardiorespiratory fitness. However, the precision of the PACER to predict treadmill  $\text{VO}_2\text{peak}$  has resulted in contradictory results, particularly among 8–10 and 11–14 year old youth.<sup>15,16</sup> Melo et al. administered the PACER test in an outdoor setting and compared the  $\text{VO}_2\text{peak}$  values with age-appropriate  $\text{VO}_2\text{peak}$  prediction equations and reported systematic bias in the equations with over-prediction in less fit participants but under-prediction in more fit participants.<sup>16</sup> Additionally, the researchers highlighted accuracy issues of predicting individual  $\text{VO}_2\text{peak}$  from the equations.<sup>16</sup> Batista et al. compared treadmill  $\text{VO}_2\text{peak}$  with four different equations for the 20-m shuttle run test (PACER) according to sex and reported imprecise  $\text{VO}_2\text{peak}$  prediction, particularly for individual estimates.<sup>15</sup> Lastly, Welsman and Armstrong compared treadmill  $\text{VO}_2\text{peak}$  with predicted  $\text{VO}_2\text{peak}$  from the PACER in 11–14 year old boys and reported poor validity.<sup>17</sup>

The PACER is commonly used in the field setting to predict  $\text{VO}_2\text{peak}$  and many studies have compared prediction equations that estimate  $\text{VO}_2\text{peak}$  based on PACER performance<sup>18</sup>; however there appears to be divergent results when  $\text{VO}_2$  is objectively measured during the PACER. No significant differences in measured PACER and treadmill  $\text{VO}_2\text{peak}$  were reported in a sample of 10-to-15 year old youth<sup>19</sup>; however, other researchers have reported  $\text{VO}_2\text{peak}$  differences between the PACER and treadmill in 6-to-10 year old youth and young adults.<sup>17,20,21</sup> Research in young adults indicates shuttle run speed, shuttle run distance, and change of direction requires a greater energy cost in comparison with straight-line running.<sup>22–24</sup> Additionally, there is a greater complexity in motor task required to successfully complete shuttle running compared to treadmill running.<sup>25</sup> As a result, the multiple changes of direction, continuous accelerations and decelerations, and differences in motor task requirements during the PACER may result in divergent  $\text{VO}_2\text{peak}$  values when  $\text{VO}_2$  is objective measured during the PACER.<sup>22–25</sup>

As evidence continues to link cardiorespiratory fitness to various health outcomes, there is a need to assess children's cardiorespiratory fitness utilizing an easily administered test that has minimal measurement errors.<sup>26,27</sup> Therefore, the purpose of the current study was to compare treadmill  $\text{VO}_2\text{peak}$  and PACER  $\text{VO}_2\text{peak}$  in a sample of children to obtain a better understanding of objectively assessed  $\text{VO}_2\text{peak}$  during the PACER. We hypothesized PACER  $\text{VO}_2\text{peak}$  would be greater than treadmill  $\text{VO}_2\text{peak}$  due to the potential increased energy cost associated with shuttle running.

## 2. Methods

### 2.1. Participants

A total of 51 children (31 boys, 20 girls) aged 7 to 14 volunteered for the study. A total of 44 of the 51 children (86.3%) met the pre-defined criteria for each exercise test to qualify as a maximal exercise test. Participants were instructed to avoid intense exercise 24 h prior to an exercise test and avoid eating 2 h prior to the test. A health history questionnaire was completed by a parent/guardian for each child prior to the child participating in the research project to ensure each child was apparently healthy. Written informed parental consent and child assent were obtained prior to children participating in the study. All experimental protocol and procedures were approved by the Institutional Review Board at South

Dakota State University and followed the principles set forth in the Declaration of Helsinki.<sup>28</sup>

### 2.2. Procedures

Participants completed a maximal, graded exercise test on a treadmill and a PACER on non-consecutive days, in a randomized and counterbalanced order. Prior to completing the first exercise procedure, height, body mass, and waist circumference were measured at baseline with participants wearing t-shirt, shorts, and no shoes. Height was assessed in duplicate with a stadiometer (Adult/Child Shorrboard; Shorr Productions, Olney, MD) and reported to the nearest 0.1 cm (cm). Body mass was assessed in duplicate with an electronic scale (Seca Scale 890; Seca, Hamburg, Germany) and reported to the nearest 0.1 kg (kg). The average of the two height and weight measurements were used to calculate BMI ( $\text{kg}/\text{m}^2$ ), which was converted to age and sex specific percentiles according to the Centers for Disease Control and Prevention growth charts. Waist circumference was assessed in duplicate with a Gulick II tape measure (Country Technology, Inc., Gay Mills, WI) and reported to the nearest 0.1 cm in accordance with the National Health and Nutrition Examination Survey Anthropometric Manual. Height and waist measurements were used to calculate a height-to-weight ratio. Procedures to assess Tanner stage were followed as described by Marshall and Tanner.<sup>29,30</sup>

### 2.3. Treadmill protocol

Participants were familiarized to treadmill running under the supervision of trained research personnel. As part of the familiarization process, participants were instructed to walk and run at various speeds and grades and practice discontinuing a test. Once comfortable, participants completed a graded exercise test to volitional fatigue on a motorized treadmill (Trackmaster TMX 55, Newton, KS). A continuous ramped protocol was used with speed or grade increments every 2 min. Participants started running at a relatively easy pace (typically between 6.4 or 8 km per hour [km/h]) for 2 min. At the beginning of the 2nd and 4th minute of the test, the speed was increased by 0.8 km/h. At the beginning of the 6th minute of the test, the speed was maintained, and the treadmill grade increased by 2%. Treadmill grade was increased by 2% with every subsequent 2-min period until the participant could no longer continue. Strong verbal encouragement was provided by research personnel to continue running as long as possible. The Modified Borg Rating of Perceived Exertion (RPE) scale was used during the final 30 s of each stage.  $\text{VO}_2$  was assessed continuously throughout the test.

### 2.4. PACER protocol

Participants were familiarized and followed the standard PACER procedure under the supervision of trained research personnel.<sup>10,12</sup> Participants were instructed to run back and forth across a marked 20-m course in a straight line, pivot and turn on completing a lap, and pace themselves in accordance with an audio recording. Participants were instructed to continue running until the pace could no longer be maintained. Strong verbal encouragement was provided by research personnel to continue running as long as possible. Participants completed the PACER test individually. At the end of each 1-min PACER stage, participants were asked to quickly report their RPE. The total number of laps completed during the test was recorded.  $\text{VO}_2$  was assessed continuously throughout the test.

## 2.5. Exercise measurements

Heart rate was recorded in 5 s intervals throughout the graded treadmill test and PACER using a Polar RS400 telemetry system (Polar Electro, Kempele, Finland).  $\text{VO}_2$  was assessed breath-by-breath and averaged over 5 s intervals with the Oxycon Mobile (Carefusion, San Diego, CA, USA) metabolic measurement system during each exercise test. Prior to each exercise test, the Oxycon Mobile was calibrated in accordance with manufacturer instruction. The Oxycon Mobile has been reported to be a valid and reliable measure of oxygen uptake.<sup>31,32</sup> Participants wore the portable metabolic device via a fitted vest and breathing mask. Child participants who did not meet at least two of the following conditions during the exercise test: a heart rate of at least 185 bpm, a minimum respiratory exchange ratio (RER) of 1.0, and signs of fatigue and intense effort (hyperpnea, facial flushing, grimacing, unsteady gait, excessive sweating) were not included in data analyses.<sup>33</sup>

## 2.6. Statistical analyses

Descriptive statistics were calculated for anthropometric and physiological measurements and stratified by sex. Exercise measures were compared between treadmill and PACER tests. Paired t-tests were used to identify significant differences between demographic and exercise measures. Independent t-tests were used to identify difference between sex. Additionally, the Bland-Altman technique was utilized to graphically compare treadmill  $\text{VO}_2$ peak with PACER  $\text{VO}_2$ peak.<sup>34</sup> The Bland-Altman method allows for the calculation of the mean difference between two methods of measurement and 95% limits of agreement. Statistical analyses were performed using Stata/IC (version 12.1, Stata Corp, College Station, TX, USA). Data are presented as means and standard deviations. Level of significance was set at  $p < 0.05$ .

## 3. Results

### 3.1. Participant characteristics

The descriptive statistics and exercise measurements stratified by sex are shown in Table 1. No significant differences were identified between boys and girls for age, height, weight, BMI percentile, waist circumference, waist-to-height ratio, or Tanner stage ( $p > 0.05$ ).

### 3.2. Exercise measurements

Physiological parameters stratified by exercise test mode and sex are presented in Table 2. Boys had a higher treadmill  $\text{VO}_2$ peak, PACER  $\text{VO}_2$ peak, completed more PACER laps, and achieved a higher maximal speed during the PACER in comparison to girls ( $p < 0.05$ ). Objectively measured  $\text{VO}_2$ peak was significantly higher during the PACER ( $49.4 \pm 9.4 \text{ ml kg}^{-1} \cdot \text{min}^{-1}$ ) than during the

treadmill test ( $46.7 \pm 7.5 \text{ ml kg}^{-1} \cdot \text{min}^{-1}$ ) ( $p < 0.01$ ); however, when stratified by sex this finding was only evident in boys (Table 2). Maximal exercising heart rate did not differ between sexes or exercise tests ( $p > 0.05$ ) and RER was greater during the PACER than the treadmill for both sexes ( $p < 0.05$ , Table 2). RPE was higher during the treadmill test compared to the PACER; however, when stratified by sex this finding was only evident in girls. Additionally, the Bland-Altman plot depicting the mean difference between treadmill  $\text{VO}_2$ peak and measured PACER  $\text{VO}_2$ peak portrays a high degree of variability (Fig. 1).

## 4. Discussion

The primary finding of the current study was the PACER resulted in a greater  $\text{VO}_2$ peak and RER while demonstrating a smaller RPE than a maximal treadmill test in a sample of 7–14 year old children. This finding indicates the cardiorespiratory fitness assessment test commonly used to estimate cardiorespiratory fitness in children and adolescents may elicit a higher physiological demand than a treadmill test. This finding is particularly interesting as PACER  $\text{VO}_2$ peak prediction equations have been developed to estimate  $\text{VO}_2$ peak assessed during maximal exertion treadmill tests with acceptable utility, although there has been concerns at the individual level.<sup>15,16</sup>

The need for extensive equipment and trained personnel, accompanied with the inability to assess large numbers of children at one-time makes the objective assessment of cardiorespiratory fitness in a school setting unmanageable. The PACER has become a routine cardiorespiratory fitness assessment for children, particularly in the school setting.<sup>10,12</sup> Physical Educators, Exercise Physiologists, and Exercise Scientists have used the PACER to predict  $\text{VO}_2$ peak in the past but recent evaluations have suggested prediction of  $\text{VO}_2$ peak from the PACER may have low performance to predict individual  $\text{VO}_2$ peak, particularly among children, which may be due to methodological differences.<sup>15,16,18,35,36</sup> Previous prediction equations have used the PACER to predict treadmill  $\text{VO}_2$ peak, but there is a disagreement in studies that have objectively measured  $\text{VO}_2$  throughout the PACER in children as was done in the current investigation. Rather, researchers have used anthropometric and PACER performance variables to predict cardiorespiratory fitness that was measured with a treadmill test.<sup>20,37–41</sup> In the current study, the same portable metabolic measurement system was used during a maximal treadmill test and the PACER to measure  $\text{VO}_2$  in a younger group of children in order to determine if the exercise tests resulted in different  $\text{VO}_2$ peak outcomes.

In a sample of 10–15 year old children and adolescents, directly measured treadmill and PACER  $\text{VO}_2$  were found to have a non-significant mean difference of  $1.6 \text{ ml}^{-1} \text{ kg}^{-1} \cdot \text{min}^{-1}$  in a sample of 10–15 year old children.<sup>19</sup> The current study used a younger sample of children, a slightly different treadmill protocol, and had a greater number of boys in the project. The mean difference of

**Table 1**  
Subject characteristics – mean (SD).

	All (n = 44)	Girls (n = 19)	Boys (n = 25)
Age (y)	10.93 (1.63)	11.21 (1.47)	10.72 (1.74)
Height (cm)	147.94 (10.22)	149.32 (8.98)	146.9 (11.14)
Weight (kg)	41.09 (11.96)	44.1 (12.6)	38.81 (11.16)
Body mass index percentile	51.02 (29.62)	57.87 (33.07)	45.82 (26.19)
Waist circumference	66.91 (9.64)	69.81 (10.33)	64.72 (8.64)
Waist-to-height ratio	0.45 (0.05)	0.47 (0.06)	0.44 (0.04)
Tanner Stage	2.25 (0.95)	2.11 (0.83)	2.35 (1.04)

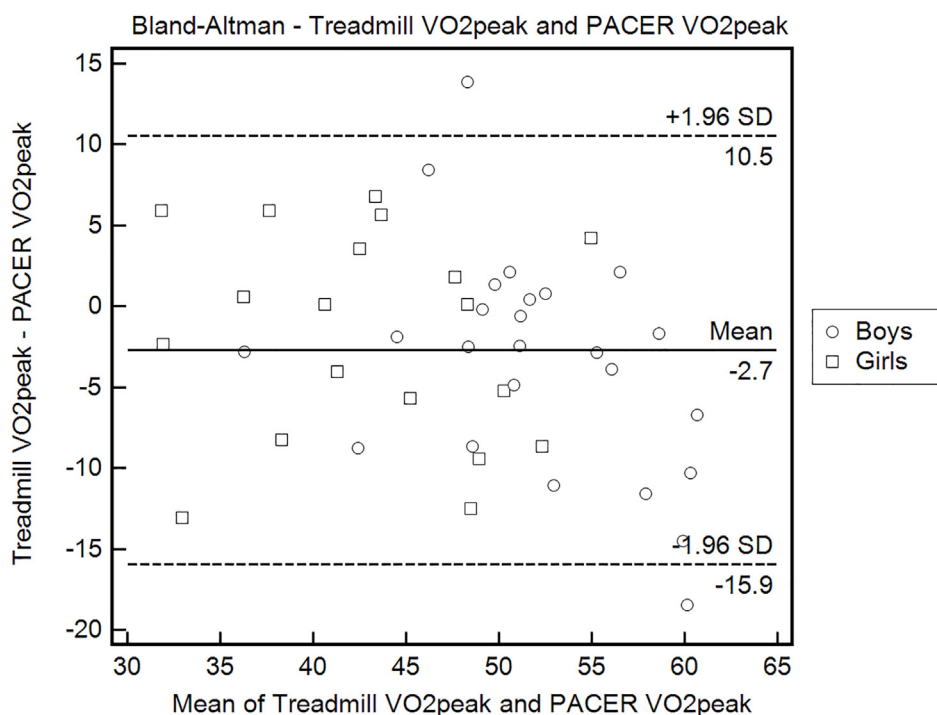
**Table 2**  
Exercise measures – mean (SD).

	All		Girls		Boys	
	Treadmill	PACER	Treadmill	PACER	Treadmill	PACER
VO <sub>2</sub> peak (ml·kg <sup>-1</sup> ·min <sup>-1</sup> )	46.7 (7.5)	49.4 (9.4) <sup>b</sup>	42.1 (7.3)	43.9 (8.0)	50.3 (5.6) <sup>a</sup>	53.7 (8.2) <sup>a,b</sup>
HR (bpm)	196.9 (9.3)	198.6 (8.8)	199.6 (6.6)	198.8 (5.7)	194.9 (10.5)	198.4 (10.7)
RER (VCO <sub>2</sub> /VO <sub>2</sub> )	1.07 (0.08)	1.14 (0.08) <sup>b</sup>	1.1 (0.1)	1.2 (0.08) <sup>b</sup>	1.03 (0.05) <sup>a</sup>	1.1 (0.07) <sup>a,b</sup>
RPE	8.1 (3.6)	7.6 (3.8) <sup>b</sup>	7.6 (3.1)	6.5 (3.2) <sup>b</sup>	8.4 (3.9)	8.4 (4.1)
Shuttle run laps	-	29.8 (12.9)	-	24.8 (8.9)	-	33.6 (14.4) <sup>a</sup>
Maximal shuttle run speed (km·h <sup>-1</sup> )	-	10.1 (0.7)	-	9.8 (0.6)	-	10.3 (0.8) <sup>a</sup>

HR = heart rate; RER = respiratory exchange ratio; RPE = rating of perceived exertion.

<sup>a</sup> Significant sex difference, *p* < 0.05.

<sup>b</sup> Significant test mode difference, *p* < 0.05.



**Fig. 1.** Bland-Altman comparing the mean difference between the measured treadmill VO<sub>2</sub>peak and measured PACER VO<sub>2</sub>peak.

2.7 ml. kg<sup>-1</sup>·min<sup>-1</sup> between PACER VO<sub>2</sub>peak and treadmill VO<sub>2</sub>peak was found to be significantly different in the current study. At the individual level, this mean difference could result in different fitness classifications as the aerobic capacity FITNESSGRAM® Performance Standards Needs Improvement category ranges from 2.3 to 3.1 ml. kg<sup>-1</sup>·min<sup>-1</sup> depending on sex and age.<sup>10</sup> We postulate several plausible explanations contributing to the higher VO<sub>2</sub>peak during the PACER compared to the treadmill test based on studies comparing physiological responses during shuttle running and forward running.

First, the progressive intensity nature of the PACER laps may simulate children’s normal exercise patterns, thus allowing children to exercise at a higher intensity, exhibit a greater VO<sub>2</sub>peak, and provide more effort during the PACER compared to the treadmill test. Additionally, blood lactate levels have been reported to be greater during shuttle running compared to straight line running suggesting a higher exercise intensity may be needed during shuttle running.<sup>22</sup> Previous research in this area used highly fit young adults accustomed to intermittent running and the current study used a sample of 7–14-year-old children who may have had

less developed anaerobic energy systems.<sup>42</sup> As a result, the higher blood lactate findings during intermittent running parallels the higher RER values the children experienced during the PACER in the present study. Interestingly, the HR values were not different between the PACER and treadmill test; however, the RPE was lower during the PACER than the treadmill test. The lower RPE value may suggest children perceived the PACER to be less challenging than the treadmill test, yet still intense enough to meet maximal cardiorespiratory fitness assessment criteria.

Secondly, the PACER requires children to frequently accelerate and decelerate throughout the test in order to run back and forth between the two end lines. Accelerating and decelerating the human body during the PACER is likely to elicit a greater physiological demand than continuous forward running.<sup>43,44</sup> Furthermore, the numerous changes of direction required throughout the PACER may pose a greater energy demand compared to forward running due to the increased energy cost of turning.<sup>22</sup> Turning frequency during the PACER begins with seven 180° changes of direction during the first minute and gradually increases as the test progresses. As a result, children repeatedly accelerate, decelerate, and change

direction throughout the PACER test. A linear relationship between turning frequency and  $\text{VO}_2$  has been reported; therefore, children may have elicited a greater  $\text{VO}_2$  peak during the PACER than the treadmill test due to reaching a higher intensity spurred by the numerous changes of direction during the PACER.<sup>23</sup>

Third, while children in the current study were given ample opportunity to become habituated with running on the treadmill and provided sufficient supervision, they may have been uncomfortable exerting themselves during the late stages of a vigorous treadmill protocol.<sup>45</sup> As a result, children may not have exerted themselves as much during the maximal treadmill test in fear of falling off the treadmill or due to being unaccustomed to treadmill running. The children may have been more familiar with the PACER as the test mimics children's traditional start-stop, spontaneous running and playing behavior, whereas the continuous running treadmill test may have been unfamiliar.<sup>46</sup> Subsequently, children may have viewed the treadmill test as a monotonous, less engaging test compared to the PACER.<sup>47</sup> Although child participants were strongly encouraged to continue running on the treadmill for as long as possible, they may have further exerted themselves during the vigorous phases of the PACER as they were accustomed to the running pattern and found the test to be more enjoyable.

While the current study was able to demonstrate the PACER results in a higher  $\text{VO}_2$  peak than a treadmill test, there are factors that limit our findings. The child participants were largely a homogenous sample inclined to participate in exercise. We had few participants ( $n = 8$ ) that were below the age and sex threshold for adequate cardiorespiratory fitness as unfit children may be less inclined to volunteer for a maximal exertion exercise study. Another potential limiting factor in this study could be the number of participants in each age category. Furthermore, we did not evaluate any specific differences in straight forward running versus shuttle running and can only hypothesize that change of direction, acceleration, deceleration, and greater muscular activation associated with balance and turning contributed to a higher intensity and greater  $\text{VO}_2$  peak during the PACER. Lastly, differences in the test setting may have contributed to differences in RPE between the two exercise tests as the PACER was completed in the gymnasium setting (where most children complete the PACER) while the treadmill test was completed in the laboratory setting. Future research is warranted to evaluate these hypotheses.

In conclusion, the PACER elicits a greater  $\text{VO}_2$  peak than a maximal treadmill test. We hypothesize the rationale for the greater  $\text{VO}_2$  peak during the PACER is that children obtain a higher intensity as a result of the need to accelerate, decelerate, and change direction often throughout the PACER. We support the use of the PACER to evaluate children's cardiorespiratory fitness but suggest future PACER equations attempt to predict  $\text{VO}_2$  peak from the objective assessment of  $\text{VO}_2$  during the PACER rather than treadmill  $\text{VO}_2$  peak.

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## Authors contributions

CAS, MDV, and JRM have given substantial contributions to the conception or the design of the manuscript and drafting the work or critically revising the intellectual content. All authors read and approved the final version of the manuscript.

## Declaration of competing interest

CAS, MDV, and JRM do not have any conflicts of interest. There are no professional relationships with companies or manufacturers who might benefit from the results of the present study. The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

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