Development of Cardiorespiratory Fitness Standards for Working Memory Using Receiver Operating Curves In 15-Year-Old Adolescents

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Research article

Keywords: Executive Functions, Cognitive Control, Physical Fitness, Development

DOI: https://doi.org/10.21203/rs.3.rs-88014/v1

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Abstract

Working memory performance is associated with better academic achievements in children and adolescents, and it is positively related to CRF. However, what level of cardiorespiratory fitness (CRF) discriminates higher working memory performance is not known. The purpose of this study was to identify thresholds of CRF linked to working memory in adolescents. Data of 141 adolescents (53.2% girls) were collected (14.9 years) from a cross-sectional study during the year 2019. CRF was assessed by the 20-m shuttle run test, and maximal oxygen uptake were calculated by Mahar’s equation. Working memory was evaluated by the Corsi blocks test and the performance was classified by percentiles. Receiver operating characteristic (ROC) curve analysis was used to identify CRF thresholds. The results of ROC analysis indicated that CRF could be used to discriminate working memory in adolescents. CRF thresholds of ≥45.03 ml.kg\(^{-1}\).min\(^{-1}\) for boys and ≥36.63 ml.kg\(^{-1}\).min\(^{-1}\) for girls were found to be indicative of “normal” performance in working memory.

Conclusion

CRF could discriminate low and normal working memory performance in 14-16 years old adolescents. These thresholds could allow for earlier identification and intervention of low working memory performance by the CRF.

Introduction

Cardiorespiratory fitness (CRF) and physical activity (PA) have shown positive effects on young people's cognition [1]. Several systematic reviews have suggested that CRF and PA promote benefits in academic [2, 3] and cognitive performance [1, 3, 4] of children and adolescents. In this way, PA has the potential to improve or maintain CRF, which in turn can affect brain plasticity [5], leading to improvements in both academic performance and executive functions [6].

Well-developed executive functions are necessary requirements for good academic performance [7]. Among executive functions, working memory stands out, which is a highly important function in the learning and academic performance of children and adolescents [8]. Working memory is responsible for monitoring and coding the information received in order to review and replace information that is no longer relevant due to new and more useful information [7].

Working memory has been associated with CRF [9, 10] in children and adolescents, and it has been suggested that PA promotes improvements in physical fitness and improvements in brain structures that support executive functions and memory [1, 10]. Bruijn et al. [10], found that among executive functions analyzed, visuospatial working memory mediated associations between academic achievements and physical fitness. Hansen et al. [11] observed that CRF had significant quadratic association with academic performance (spelling and mathematics), indicating that 22 to 27 PACER laps were key to significant increases in academic performance of children.
It is known that CRF is used as an important discriminator for health factors in young people [12, 13]. Studies have used CRF levels to discriminate metabolic syndrome [14] and cardiovascular health [15] in adolescents. In addition, many studies have demonstrated the importance of CRF for executive functions in children and adolescents. These studies have created groups of high and low maximal oxygen uptake (\(VO_2\max\)), in children and adolescents by the percentile, and compared these groups for performance in cognitive functions [16–19]; and most of these studies excluded individuals classified in middle percentiles. However, little is known about how much CRF is necessary to be classified with good working memory. In this case, a specific threshold could provide the ideal cut-off for a better performance in working memory for adolescents.

Therefore, the objective of the present study was to create cut-off points of CRF in order to discriminate the working memory performance using receiver operating characteristic (ROC) analysis in adolescents.

**Methods**

**Sample and Study Design**

This was a cross-sectional study involving students from public schools of Londrina-PR, Brazil. The sample was composed of 141 adolescents (75 girls), aged 14.9 years old and enrolled in secondary education. Adolescents who did not return the consent form signed by parents/guardians and declared withdrawal during or after data collection were excluded from the study.

The data collection process involved obtaining anthropometric measurements, CRF, and working memory. Measurements were performed on two days on the school settings. The working memory and the CRF tests were applied on different days to avoid possible interferences. The data was collected during the year 2019.

**Anthropometric measurements**

Body mass was measured using a portable digital scale, with precision of 0.1 kg (Seca, Hamburg, Germany) and height with a portable stadiometer, with precision of 0.1 cm (Harpenden Holtain Ltd, Crymych, Dyfed, UK). From this, Body Mass Index (BMI) was estimated (kg/m\(^2\)). Sum of skinfolds was collected through subscapular and tricipital skinfold thickness, which were measured using a scientific adipometer (Lange, Cambridge Scientific Instruments, Cambridge, MD) and performed by an experienced evaluator; in accordance to the techniques established by Harrison et al. [20]. The absolute technical error of height was 0.4 cm and 1.3 mm for tricipital and 0.96 mm for subscapular skinfolds.

**Cardiorespiratory Fitness**

CRF was evaluated by the 20-m shuttle-run test. This test was conducted on a sports court and the criteria for conduction and completing the test followed procedures described by Léger and Lambert [21]. The test started at velocity of 8.5 km/h and had increment of 0.5 km/h every minute. The end of the test was determined by voluntary exhaustion or failure to maintain the velocity determined by each stage in
three consecutive signals. $V_{O_{2} \text{max}}$ was calculated in $\text{ml.kg}^{-1}.\text{min}^{-1}$, using the quadratic equation suggested by Mahar et al. [22], and recommended by the FITNESSGRAM.

**Working Memory**

To verify the working memory, the Corsi block-tapping task (CB) was used. The Corsi Block Test is widely used both in clinical practice and research, and specifically evaluates short-term visuospatial working memory [23]. Originally developed by Corsi [24], this test involves simple measurements that can be quickly and easily administered, requiring the subject to maintain the sequence of information [23]. This test have good reliability for 15-year-old adolescents ($r = 0.79$) and moderate validity ($r = 0.66$) [25].

According to the normative standardization of the Corsi block test, 20% of individuals with the worst test results can be considered as borderlines [23]. In addition, subjects classified with 0.6 z-score below the group that they belong are identified with low neuropsychological ability. In the same way, if the test is easy, 80% could be classified as middle score [26].

The test consists in memorizing a sequence in which cubes flash on a computer screen. The test starts with two cubes flashing in the middle of nine cubes disposed on the screen, in which the participant tries to reproduce the sequence in the same order (forward condition) in which cubes appears. The order in which cubes flash increases progressively until maximum limit is reached. The test was interrupted when the participant misses the order of the sequence twice at the same level. Block Span (CB extension) and total score (block span x number of correct responses until the test was interrupted) were adopted as performance indicators. Adolescents had one execution in the test for adaptation.

For classification into normal and borderline performance, 20 percentiles as describe by Kessels et al. [23] was used. Adolescents who obtained the 20% lowest scores were classified as borderline. Classification was performed according to sex.

**Statistical analyses**

Median and interquartile range were used for sample description. Mann Whitney U was adopted for the comparison of variables between groups. ROC analysis was used to discriminate adolescents with normal performance from borderlines for working memory with $V_{O_{2} \text{max}}$. For ROC analysis, the area under the curve (AUC) was used for analysis of the accuracy of cut-off points. Better ROC analysis results are found for sensitivity and specificity close to 100, in this case indicating high positive cases and low false-positive cases.

After identifying the cutoff values, two groups were created, high CRF (Boys $\geq 45.03$; Girls $\geq 36.63$) and Low CRF (Boys $< 45.03$; Girls $< 36.63$) in order to compare groups; the comparison was performed by the generalized estimating equation and values were expressed in estimated means and confidence intervals; analysis were controlled by sex and $\sum$ of tricipital and subscapular skinfolds. Significance was set at 5%. All analyses were conducted using statistical software SPSS version 26.0 and MedCalc version 19.1.2.
**Results**

Table 1 shows the sample characterization between subjects classified as normal or borderlines and stratified by sex. Results demonstrate significant differences for VO\(_2\text{max}\) (Girls: \(P = 0.023\); Boys: \(P = 0.037\)) and for working memory variables (Block Span and Total Score, \(P < 0.001\)). Higher CRF values and working memory performance were found for adolescents classified as normal cognitive performance.

|                       | Girls (n = 75) | Normal | P   | Boys (n = 66) | Normal | P   |
|-----------------------|----------------|--------|-----|---------------|--------|-----|
| **Age (years)**       |                |        |     |               |        |     |
| Borderline            | 15.01 (14.54–15.19) | 14.96 (14.54–15.42) | 0.822 | 14.82 (14.09–15.99) | 15.05 (14.55–15.47) | 0.587 |
| Normal                |                |        |     |               |        |     |
| **Body Mass (Kg)**    |                |        |     |               |        |     |
| Borderline            | 55.9 (53.0–67.65) | 55.25 (50.92–65.95) | 0.455 | 64.80 (53.15–82.35) | 59.6 (54.75–69.8) | 0.232 |
| Normal                |                |        |     |               |        |     |
| **Height (cm)**       |                |        |     |               |        |     |
| Borderline            | 161.5 (156.85–169.55) | 163.55 (158.12–168.52) | 0.728 | 172.4 (164.5–176.15) | 171.7 (167.7–175.65) | 0.764 |
| Normal                |                |        |     |               |        |     |
| **BMI (Kg/m\(^2\))** |                |        |     |               |        |     |
| Borderline            | 21.85 (20.29–25.56) | 21.15 (19.09–24.97) | 0.351 | 22.13 (17.55–27.47) | 20.35 (18.20–22.70) | 0.210 |
| Normal                |                |        |     |               |        |     |
| **∑ skinfold (mm)**   |                |        |     |               |        |     |
| Borderline            | 42 (32.50–59.5) | 39.75 (31.0–54.5) | 0.441 | 37.0 (18.25–51.0) | 26.0 (19.0–37.75) | 0.278 |
| Normal                |                |        |     |               |        |     |
| **Vo\(_2\text{max}\) (ml.kg\(^{-1}\).min\(^{-1}\))** | | | | | | |
| Borderline            | 35.71 (33.19–39.60) | 40.01 (34.19–42.82) | 0.023 | 47.39 (39.38–52.52) | 50.09 (46.79–54.28) | 0.037 |
| Normal                |                |        |     |               |        |     |
| **Corsi Blocks**      |                |        |     |               |        |     |
| Block Span            | 5 (5–5) | 6 (5–7) | \(<\) 0.001 | 5 (5–5) | 6 (6–7) | \(<\) 0.001 |
| Total Score           | 35 (27.5–35) | 54.0 (40–70) | \(<\) 0.001 | 35 (30–35) | 54 (45–70) | \(<\) 0.001 |

BMI: Body mass index; ∑ skinfold: sum of skinfold; Values expressed in median and interquartile range; Significant values for \(P < 0.05\)

Figure 1 presents the ROC Curves analysis for VO\(_2\text{max}\) and working memory classification (borderline or normal). In both sexes, VO\(_2\text{max}\) was able to discriminate subjects with low and normal working memory ability (\(P < 0.05\)). For boys, the cut-off value to be classified as “normal” was of \(≥ 45.03\) ml.kg\(^{-1}\).min\(^{-1}\) (Sensitivity 47.1; Specificity 91.8); VO\(_2\text{max}\) was able to discriminate cases with accuracy of 67.1% (AUC = 0.671; CI95%: 0.544–0.782). For girls, the value was of \(≥ 36.63\) ml.kg\(^{-1}\).min\(^{-1}\) (Sensitivity 72; Specificity
70) and discriminate normal or borderline subjects with accuracy of 66.2% (AUC = 0.662; CI95%: 0.543–0.767).
Comparisons between high and low CRF are shown in Table 2. Significant differences were found for VO$_{2\text{max}}$ and total score in Corsi Blocks test for all boys, demonstrating that boys classified as high CRF presented higher working memory values if compared to low CRF individuals (df:16.22; $P = 0.001$).

### Table 2
- Comparison of cardiorespiratory fitness groups for VO$_{2\text{max}}$ and working memory performance in adolescents

|       | N  | VO$_{2\text{max}}$ (ml.kg$^{-1}$.min$^{-1}$) | Total Score |       |
|-------|----|------------------------------------------|-------------|-------|
|       |    | Estimated means (95% CI) | Estimated means (95% CI) |       |
| All   | 45 | 34.3 (33.0–35.7) | < 0.001 | 43.7 (38.7–49.4) | 0.005 |
| Low CRF | 96 | 47.1 (46.0–48.3) | 53.2 (49.5–57.35) |       |
| High CRF |       |       |       |       |
| Boys  | 12 | 39.5 (37.5–41.5) | < 0.001 | 39.5 (32.5–47.9) | 0.001 |
| Low CRF | 54 | 51.1 (50.2–52.1) | 55.7 (50.6–61.3) |       |
| High CRF |       |       |       |       |
| Girls | 33 | 32.4 (31.2–33.6) | < 0.001 | 45.3 (39.1–52.4) | 0.280 |
| Low CRF | 42 | 41.9 (41.0–42.9) | 50.1 (44.7–56.1) |       |
| High CRF |       |       |       |       |

CRF: Cardiorespiratory fitness; 95% CI: Confidence interval of 95%; Significant values for $P < 0.05$.  

### Discussion
The main objective of the present study was to verify the level of CRF (VO$_{2\text{max}}$) that discriminates working memory in adolescents. Results showed that boys need minimum of 45.03 ml.kg$^{-1}$.min$^{-1}$ and girls 36.63 ml.kg$^{-1}$.min$^{-1}$ to be classified as “normal”. Additionally, thresholds for VO$_{2\text{max}}$ presented significant differences for working memory, which demonstrated higher values of working memory for group with high CRF.

Comparing CRF groups with academic achievement, adolescents classified in the Health Fitness Zone (HFZ), FITNESSGRAM®, presented higher academic grades [1, 27]. When the relationship between CRF and academic achievement in children was evaluated, Hansen et al. [11] found non-linear relationship, in which increases in academic performance occur up to 22 laps (~47.5 ml.kg$^{-1}$.min$^{-1}$) for spelling and 27 (~49.7 ml.kg$^{-1}$.min$^{-1}$) laps for math scores, after that, performance reached a plateau.
The relationship between CRF (pacer laps) and working memory performance, in children, presented significance, analyzing the reaction time ($r = -0.13$), and working memory accuracy ($r = 0.14$) [28]. Analyzing relationships longitudinally and controlling other variables (grade, sex, maternal education, BMI), CRF can explain by 7.5% the working memory accuracy [29]. In addition, improvements in CRF are associated with improvements in the cognitive control of the working memory of preadolescents [30]. According to results of the present study, higher CRF values, classified by the created threshold, indicated better working memory for boys.

The threshold values for VO$_{2\text{max}}$ to discriminate low and normal working memory in the present study are similar to that used by FITNESSGRAM®, developed by Welk et al. [14], which determined the presence of metabolic syndrome through VO$_{2\text{max}}$ measured by submaximal treadmill test. For boys, the HFZ value was $\geq 43.6 \text{ ml.kg}^{-1}.\text{min}^{-1}$, a difference of 1.7 ml.kg$^{-1}$.min$^{-1}$ from the present study; for girls, the HFZ value was $\geq 39.1 \text{ ml.kg}^{-1}.\text{min}^{-1}$, a difference of 2.47 ml.kg$^{-1}$.min$^{-1}$.

Ruiz et al. [15], established CRF cut-off points to determine a cardiovascular health profile in adolescents, finding values of $43.8 \text{ ml.kg}^{-1}.\text{min}^{-1}$ for boys and $34.6 \text{ ml.kg}^{-1}.\text{min}^{-1}$ for girls. Likewise, these values are similar to those found in the present study, demonstrating that cardiovascular health and mental functions are affected in similar CRF intensities in adolescents.

The low sensitivity and high specificity found for boys can be explained by the number of boys with high CRF in this sample. Borderline adolescents showed median VO$_{2\text{max}}$ value of $47.39 \text{ ml.kg}^{-1}.\text{min}^{-1}$ (39.38–52.52). Using the classification proposed by an international normative [31], the borderline group had subjects in the 50th percentile but some individuals could reach the 90th percentile. On the other hand, the high specificity of created cut-off points (91.8%), implies that individual with low CRF have high probably to be classified as borderline. This pattern was not found for girls, in which the similar sensitivity and specificity could be justified by the homogeneous VO$_{2\text{max}}$ distribution.

It is important to highlight the changes that CRF can cause in the cerebral morphology, and these changes are related to the working memory performance. It is noteworthy that well-developed prefrontal cortex [32, 33] and greater hippocampal volume [34] are associated with better working memory. In addition, children with higher CRF have greater hippocampal volume [34, 35].

Neuroelectric indexes are also related to working memory, and evidence suggests that higher P3 amplitude, an event related to the neuronal activity and linked to attentional processing, is associated with better working memory [6]. Comparing to individuals with high and low CRF by Event-Related Potentials, the results demonstrated better P3 indexes for children with high CRF [36]; and higher functional connectivity [19].

This study has some limitations such as the relatively small sample and the creation of thresholds only for adolescents aged 14–16 years. Another limitation was not using academic achievements for the development of thresholds to compare the working memory. However, a strong point is the creation of
thresholds for working memory, which is possibly one of the first studies with this objective. In addition, this study used a sample composed of adolescents, and many of studies used children in the second infancy [37].

In summary, VO\textsubscript{2max} can be used to discriminate adolescents classified as borderline or normal working memory. In this sense, these results can complement normative health data or be useful in school programs, since working memory can improve academic performance.

**Abbreviations**

CRF  
Cardiorespiratory fitness  
PA  
Physical activity  
VO\textsubscript{2max}  
Maximal oxygen uptake  
ROC  
Receiver operating characteristic  
BMI  
Body mass index  
AUC  
Area under curve  
HFZ  
Health fitness zone

**Declarations**

**AUTHOR CONTRIBUTION**

VW: Conception and Design, methodology, data collection, analysis and interpretation of data, drafting the article, final approval.

DF: Conception and Design; analysis of data, data collection, drafting the article, final approval.

LV: Methodology, data collection, drafting the article, final approval.

MB: Methodology, data collection, drafting the article, final approval

MR: Revising it critically, supervision, final approval

JC: Revising it critically, editing, analysis and interpretation, final approval

ER: Conception and Design, methodology, drafting the article, supervision, final approval.
COMPLIANCE WITH ETHICAL STATEMENTS

Conflict of interest

Author VW and DF received master’s grant from Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES). Author ER received research productivity grant from the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq).

Funding

There is no funding source

Ethical approval

The local ethics committee (Ethics Committee in Research with Human Beings of the State University of Londrina) approved all the procedures of the present study according to norms of resolution No. 466/2012 of the National Health Council on research involving human beings under protocol No. 3.679.195.

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