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Short Communication

Aerobic fitness and metabolic health in children: A clinical validation of directly measured maximal oxygen consumption versus performance measures as markers of health

Eivind Aadland [a,*], Olav Martin Kvalheim [b,c], Tarja Rajalahti [d], Turid Skrede [a], Geir Kåre Resaland [a,e]

[a] Faculty of Teacher Education and Sports, Western Norway University of Applied Sciences, Campus Sogndal, Sogndal, Norway
[b] Faculty of Health Studies, Western Norway University of Applied Sciences, Campus Førde, Førde, Norway
[c] Department of Chemistry, University of Bergen, Bergen, Norway
[d] Fjordomics, Førde Health Trust, Førde, Norway
[e] Center for Health Research, Førde Central Hospital, Førde, Norway

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ABSTRACT

High aerobic fitness is consistently associated with a favorable metabolic health profile in children. However, measurement of oxygen uptake, regarded as the gold standard for evaluating aerobic fitness, is often not feasible. Thus, the aim of the present study was to perform a clinical validation of three measures of aerobic fitness (peak oxygen consumption [VO_{2peak}] and time to exhaustion [TTE] determined from a graded treadmill protocol to exhaustion, and the Andersen intermittent running test) with clustered metabolic health in 10-year-old children. We included 93 children (55 boys and 38 girls) from Norway during 2012–2013 in the study. Associations between aerobic fitness and three different composite metabolic health scores (including lipoprotein subgroup particle concentrations, triglyceride, glucose, systolic blood pressure, and waist-to-height ratio) were determined by regression analyses adjusting for sex. The relationships among the measures of aerobic fitness were $r = 0.78$ for VO_{2peak} vs. TTE, $r = 0.63$ for VO_{2peak} vs. the Andersen test, and $r = 0.67$ for TTE vs. the Andersen test. The Andersen test showed the strongest associations across all markers of metabolic health ($r = -0.45$ to -0.31, $p < 0.002$), followed by VO_{2peak} ($r = -0.35$ to -0.12, $p < 0.256$), and TTE ($r = -0.28$ to -0.10, $p < 0.334$). Our findings indicate that indirect measures of aerobic fitness do not stand back as markers of metabolic health status in children, compared to VO_{2peak}. This is of great importance as good field tests provide opportunities for measuring aerobic fitness in many settings where measuring VO_{2peak} are impossible.

1. Introduction

High aerobic fitness is consistently associated with longevity in adults (Barry et al., 2014; Kodama et al., 2009) and a favorable metabolic health profile in children (Andersen et al., 2008a, 2008b; Anderssen et al., 2007). In order to avoid misinforming the society regarding the impact of aerobic fitness on health, good measures of aerobic fitness are needed. Because direct measurement of maximal or peak oxygen consumption (VO_{2peak}) is time-consuming and requires expensive equipment and highly trained test personnel, it is often not feasible. Thus, indirect performance tests such as the 20 m multistage shuttle run test (Leger et al., 1988), the Andersen test (Andersen et al., 2008b), or time to exhaustion (TTE) on graded treadmill protocols (Aadland et al., 2014) are widely applied as substitutes or proxy measures of VO_{2peak}.

We have previously validated both the Andersen test and TTE on a graded treadmill protocol against VO_{2peak} in 10-year-old children (Aadland et al., 2014b; Aadland et al., 2014), and found that both measures performed well on a group level, but that care should be taken when attempting to use such measures on an individual level. However, this conclusion is only valid under the paradigm that VO_{2peak} reflect the "true" measure of aerobic fitness. As hypothesized previously (Aadland et al., 2014b), it might well be that the energy spent (VO_{2peak}) and the test duration (TTE) on the graded treadmill test, as well as the field performance (Andersen test), to a similar extent reflect the underlying latent variable "aerobic fitness". Studies that have shown similar prognostic value of directly measured maximal oxygen consumption and performance measures in terms of mortality rate in adults (Goel et al., 2011; Kavanagh et al., 2002), supports our hypothesis.

To the best of our knowledge, no "clinical validation" of different measures of aerobic fitness has been carried out in children. In lack of

* Corresponding author at: Faculty of Teacher Education and Sport, Western Norway University of Applied Sciences, Campus Sogndal, Box 133, 6851 Sogndal, Norway.
E-mail address: eivind.aadland@hvl.no (E. Aadland).

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hard endpoints in children, we used clustered metabolic health as an outcome variable, which is consistently associated with aerobic fitness in children (Andersen et al., 2011; Andersen et al., 2008a, 2008b; Anderssen et al., 2007; Artero et al., 2011; Bailey et al., 2012; Steene-Johannessen et al., 2009). Thus, the aim of this paper was to determine the associations for three measures of aerobic fitness (VO_{2peak} and TTE as obtained from a graded treadmill protocol to exhaustion, and the Andersen intermittent running test) with metabolic health in 10-year-old children.

2. Methods

The subjects and material underlying the present study has been outlined in detail previously (Aadland et al., 2014a, 2014b). Thus, only a brief overview of subjects and methods will be given herein.

2.1. Subjects

We recruited 118 10-year old children (67 boys and 51 girls) from Norway during 2012–2013 to participate in the study. Children and their parents were given thorough oral and written information regarding the study protocol, and written informed consent was obtained from each child's parent(s)/guardian(s) prior to the child's inclusion in the study. The study was approved by the Regional Committee for Medical Research Ethics (REC West) in Norway.

2.2. Procedures

Children performed three Andersen tests and one incremental treadmill test to exhaustion to measure their VO_{2peak} and TTE during four subsequent weeks. In the present study, the first Andersen test was used (test 2 or 3 were used if test 1 or 2 were missing), to avoid superior reliability compared to VO_{2peak} and TTE for which only one measure was available. The Andersen test was performed according to standard procedures (Aadland et al., 2014a). Children were informed about the procedures and performed a collective five-minute warm-up before the test. Then, they ran as long as possible in a to-and-fro movement on a 20-meter track, with 15-second work periods and 15-second breaks, for a total duration of 10 min. Each time the children turned around at an end line, they had to touch with one finger the floor behind the end line. The goal was to cover the longest possible distance during the 10-minute run, thus, the children ran to voluntary exhaustion. Adult test assistants, who subjectively judged whether the child completed a valid test, recorded the distance covered. We used an incremental treadmill protocol to measure VO_{2peak} (ml/kg/min), applying the Moxus Modular Metabolic System (AEI Technologies Inc., Pittsburgh, USA), and TTE (seconds), which has shown to be reliable and valid compared to the Douglas-bag technique (Medbø et al., 2012), to measure oxygen consumption. Children started to walk at 5 km/h for 5 min on a treadmill having a constant inclination of 5.3%. Thereafter, the speed increased by 1 km/h each minute until exhaustion.

Height and body mass were measured prior to the VO_{2peak}-test. For reporting of descriptive statistics, children were categorized as normal weight, overweight, or obese according to the criteria set by Cole et al. (2000). Waist circumference (WC) (mean of two measurements) was measured with a measuring tape 2 cm above the umbilicus with the child's abdomen relaxed at the end of a gentle expiration. Blood pressure (mean of three measurements) was measured with an appropriate cuff size on the upper right arm using the Omron HBP-1300 automated monitor (Omron Healthcare, Inc., IL, US) in a quiet room after at least 10 min of rest. Blood samples were drawn between 8 and 10 am after an overnight fast. Serum lipoprotein subclass particle concentrations and lipid was obtained according to a standardized protocol described previously (Lin et al., 2016). Samples were split into 0.5 ml aliquots before storage in cryo tubes at −80 °C until analyses. Glucose was measured using standard laboratory procedures.

2.3. Statistical analyses

Three different composite metabolic health scores were created: 1) A composite score calculated as the mean of four standardized variables (systolic blood pressure, triglyceride [TG], total cholesterol [TC]:high density lipoprotein cholesterol [HDL]-ratio, and glucose concentration) (*Composite score without WC*); 2) A composite score calculated as the mean of five standardized variables (adding WC:height-ratio to the four-component score) (*Composite score with WC*); 3) Principal component analysis was used to create a component (38.7% explained variance) including 23 lipoprotein and lipid variables (total concentrations of TG, TC, very low density lipoprotein [VLDL], low density lipoprotein [LDL], and HDL-particles [p], as well as 4 subgroups of VLDL-p, 4 subgroups of LDL-p, 5 subgroups of HDL-p, average size of VLDL-p, LDL-p and HDL-p, and Apo A_1 and B) (*Lipoprotein score*). A negative score indicated a more beneficial pattern for all scores.

The subject characteristics are presented as means and standard deviations (SD). Linear regression analyses were used to determine associations among the three measures of aerobic fitness as well as a composite score of these three measures (independent variables) and the three composite metabolic health scores (dependent variables), of which all variables were standardized to one SD prior to performing the analyses. All analyses were adjusted for sex. Analyses were performed using IBM SPSS v. 23 (IBM SPSS Inc., Armonk, New York, USA). A p-value < 0.05 indicated statistically significant findings.

3. Results

Of the 118 children recruited, 93 children (55 boys and 38 girls) had valid data on all variables relevant to the present study and were included in the analyses (Table 1).

The relationship among the three measures of aerobic fitness were $r = 0.78$ for VO_{2peak} vs. TTE, $r = 0.63$ for VO_{2peak} vs. Andersen, and $r = 0.67$ for TTE vs Andersen (all $p < 0.001$), after adjustment for sex.

As there was no significant moderating effect of sex for associations between aerobic fitness and metabolic health (aerobic fitness ∗ sex $p > 0.353$), all analyses were performed using the total sample adjusting for sex as a covariate. As shown in Table 2, all measures of aerobic fitness showed the strongest associations with the Composite score including WC. The Andersen test showed the strongest associations across all markers of metabolic health, followed by VO_{2peak} and TTE.

Table 1
The children's characteristics.

	Boys	Girls
Number (%)	59	41
Age (years)	10.3 (0.3)	10.3 (0.3)
Height (cm)	143.9 (6.4)	143.0 (5.1)
Body mass (kg)	38.8 (9.9)	37.9 (6.8)
Body mass index (kg/m^2)	18.6 (3.8)	18.4 (2.6)
Overweight/obese (%)	11/11	16/5
WC (cm)	65.4 (10.0)	63.5 (7.8)
WC:height (ratio)	0.45 (0.06)	0.44 (0.05)
Andersen test (m)	910 (134)	878 (80)
VO_{2peak} (ml/kg/min)	55.8 (9.4)	50.6 (7.8)
Time to exhaustion (s)	665 (97)	629 (66)
Systolic blood pressure (mm Hg)	108.9 (7.8)	110.3 (9.7)
TC (mmol/l)	4.68 (0.65)	4.65 (0.64)
VLDL-p (mmol/l)	1.34 (0.67)	1.53 (0.63)
LDL-p (mmol/l)	2.51 (0.45)	2.63 (0.50)
HDL-p (mmol/l)	1.80 (0.31)	1.71 (0.24)
TG (mmol/l)	0.60 (0.26)	0.69 (0.27)
TC:HDL (ratio)	2.5 (0.4)	2.6 (0.5)
Glucose (mmol/l)	5.0 (0.4)	4.9 (0.4)

Values are means (SD) or percentages. WC = waist circumference; VO_{2peak} = peak oxygen consumption; TC = total cholesterol; VLDL-p = very low density lipoprotein particles; LDL-p = low density lipoprotein particles; HDL-p = high density lipoprotein particles; TG = triglyceride. The study was conducted in Norway during 2012–2013.

Table 2
The associations (standardized regression coefficients (β)) for the three different measures of aerobic fitness versus the metabolic health scores, adjusted for sex.

	Lipoprotein score	Composite score with WC	Composite score without WC
VO_{2peak}	−0.28 (0.009)	−0.35 (0.001)	−0.12 (0.256)
TTE	−0.19 (0.073)	−0.28 (0.008)	−0.10 (0.334)
Andersen	−0.36 (<0.001)	−0.45 (<0.001)	−0.31 (0.002)
Fitness composite score	−0.31 (0.003)	−0.39 (<0.001)	−0.20 (0.059)

Lipoprotein score = a principal component explaining 38.7% of the variance among 23 lipoprotein variables; Composite scores = composite scores for systolic blood pressure, triglyceride, total cholesterol to high density lipoprotein ratio, and glucose concentration (Composite score without WC), and adding waist circumferences (WC)-to-height ratio (Composite score with WC); VO_{2peak} = peak oxygen consumption; TTE = time to exhaustion; Fitness composite score = composite score of the three measures for aerobic fitness. The study was conducted in Norway during 2012–2013.

4. Discussion

Our results indicate that the Andersen test performed better than VO_{2peak} as a measure of aerobic fitness in children, in relation to three different metabolic health scores. Thus, along with the hypothesis put forward by Aadland et al. (2014b), different measures of aerobic fitness might perform well as markers of metabolic health in children, although not showing a perfect relationship with VO_{2peak}. This finding is of great importance in settings where direct measurement of oxygen consumption is difficult (e.g., large-scale school interventions). The present findings seem to support studies in adults that have shown similar prognostic value of directly measured maximal oxygen consumption and performance measures in terms of mortality rate (Goel et al., 2011; Kavanagh et al., 2002), but contradict previous studies applying a similar risk score as the present in 9–18-year-olds. These studies have indicated somewhat stronger associations for directly measured VO_{2peak} ($r \sim -0.50$ to -0.40) (Andersen et al., 2011; Steene-Johannessen et al., 2009), than for the 20 m shuttle run test ($r = -0.31$) (Artero et al., 2011; Bailey et al., 2012).

Studies applying poor tests of aerobic fitness are prone to report erroneous results and may misinform the society regarding the level and importance of aerobic fitness to health, as noise in exposure variables leads to regression dilution bias which increase the probability of performing type II errors (Hutcheon et al., 2010). Yet, the less than perfect relationship between "indirect" measures and "directly" measured VO_{2peak}, rest on the assumption that VO_{2peak} is the "true" measure of aerobic fitness. As all other measures, however, VO_{2peak} are measured with error, probably larger error than performance measures (Hodges et al., 2005; Hopkins et al., 2001). Because measurement error is reduced, we would expect that the composite score of aerobic fitness would perform even better than each of the three original measures, but our results did not support this hypothesis. Nevertheless, our results indicate that all the three measures applied provided more or less the same picture of metabolic health. Therefore, moderate agreement with the gold standard measure of aerobic fitness (VO_{2peak}) does not necessarily mean a measure is poor, as the Andersen test performed at least as good as VO_{2peak} in regard to metabolic health, despite the two measures being only moderately correlated ($r = 0.63$).

A limitation to the current findings is the reliance on a small sample; the results should therefore be regarded as preliminary. Thus, similar comparisons in larger and more diverse samples are warranted. Still, patterns were similar across outcomes and for both boys and girls (i.e., in even smaller samples; results not shown), which might indicate stability.

In conclusion, our findings indicate that indirect measures of aerobic fitness not necessarily stand back as measures of health status in children, compared to direct measurement of VO_{2peak}. This is an important finding as good field tests provide opportunities for measuring aerobic fitness in many settings were measuring oxygen consumption is impossible.

Conflict of interest

The authors have nothing to disclose.

Transparency document

The Transparency document associated with this article can be found, in the online version.

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