Associations between cardiorespiratory fitness, motor competence, and adiposity in children

Short title: Fitness and motor competence in children

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ABSTRACT

We investigated the associations of motor competence (MC) with peak oxygen uptake ($\dot{V}O_{2peak}$), peak power output (W_{max}), and body fat percentage (BF%) and whether measures of CRF modify the associations between MC and BF%. Altogether 35 children (aged 7-11 years) in the CHIPASE Study and 297 in PANIC Study (aged 9-11 years) participated in the study. MC was assessed using KTK and modified Eurofit tests. $\dot{V}O_{2peak}$ and W_{max} were measured by maximal exercise test on a cycle ergometer and scaled by lean mass (LM) or body mass (BM). BF% was assessed either by bioimpedance (CHIPASE) or DXA (PANIC). MC was not associated with $\dot{V}O_{2peak}$ / LM (standardised regression coefficient β=0.073 to 0.188, p>0.083). $\dot{V}O_{2peak}$ / BM and W_{max} / LM and BM were positively associated with MC (β=0.158 to 0.610, p<0.05). MC (β=-0.186 to -0.665, p<0.01), but not $\dot{V}O_{2peak}$ / LM (β=-0.169 to 0.035, p>0.381), was inversely associated with BF%. Furthermore, the associations of MC with BF% were not modified by CRF. These results suggest that the positive associations between MC and CRF scaled by BM are a function of adiposity and not peak aerobic power and that CRF is not modifying factor in the associations of MC and BF%.

Key Words: children, motor skills, fitness, obesity, KTK

INTRODUCTION

The prevalence of overweight and obesity has increased during the past three decades[1,2]. Some evidence also suggests that motor competence (MC) and cardiorespiratory fitness (CRF) have declined making the current generation of children less able and fit to participate in various physical and daily life activities than previous generations[3,4]. These changes in MC and CRF in children have been suggested to lead to a negative circle leading to an increased risk of overweight and obesity[5]. Nevertheless, variable methods used to assess CRF and inappropriate scaling of the measures of CRF may have obscured our understanding on the associations between MC, CRF, and adiposity.

MC has been inversely associated with body mass index and body fat percentage (BF%) among children in cross-sectional and longitudinal studies[6–9]. Similarly, MC has been positively associated with CRF[6] and it has been suggested that CRF lies in the causal pathway mediating the association between MC and overweight and obesity possibly through physical activity in children[5,10]. However, the evidence on the positive associations between MC and CRF is mainly based on 20 metre shuttle run test as a measure of CRF[11]. Several studies have demonstrated that $\dot{V}O_{2peak}$ explains less than 50% of the 20 metre shuttle run test performance[12] limiting the validity of previous studies on the associations between CRF and MC[13]. Furthermore, some studies have showed a positive association between directly measured peak oxygen uptake ($\dot{V}O_{2peak}$), "a gold standard" in measuring cardiorespiratory fitness, scaled by body mass (BM) and MC[14,15]. Lima et al. also found that $\dot{V}O_{2peak}$ scaled by BM mediated the associations of MC and physical activity with adiposity in their 7-year follow-up study suggesting that $\dot{V}O_{2peak}$ could be an important factor influencing the associations between MC and adiposity[10]. Nevertheless, scaling $\dot{V}O_{2peak}$ by BM lacks physiological and statistical rationale and it does not remove the effect of body size and

composition on CRF[16–18]. BM includes also fat mass that does not contribute to $\dot{V}O_{2peak}$ or determinants of $\dot{V}O_{2peak}$ and therefore underestimates CRF in heavier individuals irrespective of their physiological cardiorespiratory capacity[16–18].

$\dot{V}O_{2peak}$ depends on the capacity of cardiovascular system to deliver oxygenated blood to the working muscle and the ability of muscle tissue to utilise oxygen to support mechanical work[13]. Maximal cardiac output has been found to be the strongest determinant of $\dot{V}O_{2peak}$ during exercise[19,20]. Muscle mass, that is an active tissue during exercise, is the main driver of absolute cardiac output and $\dot{V}O_{2peak}$[21] while fat mass, that is included in BM, does not contribute to cardiac output or $\dot{V}O_{2peak}$[18]. Therefore, $\dot{V}O_{2peak}$ scaled by lean mass (LM) using log-linear allometric modelling stands for the most appropriate measure of CRF[22]. Furthermore, peak power output (W_{max}) achieved in cycle ergometer test, which is an indirect laboratory measure of CRF, has been used as an alternative measure of CRF. While W_{max} has been suggested to serve a feasible indirect alternative to $\dot{V}O_{2peak}$[23], W_{max} does not describe only peak aerobic power but is supported by anaerobic metabolism and the ability to recruit and more fully use higher threshold motor units[24]. However, there are no previous studies comparing the associations of $\dot{V}O_{2peak}$ and W_{max} with MC and adiposity in children.

Previous studies have failed to provide valid information on the associations between MC and $\dot{V}O_{2peak}$ and whether $\dot{V}O_{2peak}$ modifies the magnitude of the associations between MC and adiposity in children. Therefore, u sing two separate data sets, we 1) investigated the associations of $\dot{V}O_{2peak}$ and W_{max} scaled by LM and BM with MC, 2) studied the associations between the measures of CRF and BF%, 3) explored the associations of MC with BF%, and 4) investigated whether the associations between MC and BF% are explained by CRF.

METHODS

Study design and study populations

The present cross-sectional data were derived from two separate studies conducted in Finland: The Children's Physical Activity Spectrum (CHIPASE)[25] Study and the 2-year follow-up assessments of the Physical Activity and Nutrition in Children (PANIC) Study[26]. The CHIPASE Study was designed to study the accuracy of different methods identify sedentary behaviour and physical activity and their variability in 7–11-year-old children[25]. Altogether 35 children were recruited from the schools in the City of Jyväskylä. The PANIC Study was physical activity and dietary intervention which continues as a follow-up study in a population sample of children from the city of Kuopio, Finland. Altogether 440 children (86% of those participating in baseline examinations) attended in the 2-year follow-up examinations. In the present analyses, we used 2-year follow-up data of the PANIC Study because $\dot{V}O_{2peak}$ was assessed only at the follow-up assessments. Complete data on variables used in the analyses on the associations of $\dot{V}O_{2peak}$, MC, and BF% at 2-year follow-up were available for 297 children (152 boys, 145 girls). Children who were included in the present analyses had a better 50m shuttle run test time than those who were excluded from the analyses (p=0.015) but there were no other differences in the participant characteristics between those who were included and those who were excluded. The study protocol of the CHIPASE Study was approved by the Research Ethics Committee of University of Jyväskylä and that of the PANIC Study was approved by the Research Ethics Committee of the Hospital District of Northern Savo. Both children and their parents gave their written informed consent.

Assessment of body size and composition

In the CHIPASE Study, body weight, LM, fat mass, and BF% were assessed after an overnight fast by a calibrated InBody® 770 bioelectrical impedance device (Biospace, Seoul, South

Korea). In the PANIC Study, body weight was measured after 12 hours fast by InBody® 720 bioelectrical impedance device (Biospace, Seoul, South Korea) and total fat mass, BF%, and LM were measured by the Lunar® dual-energy X-ray absorptiometry (GE Medical Systems, Madison, WI, USA) using standardised protocols[27]. Stature was measured the children standing head in the Frankfurt plane without shoes using a wall-mounted stadiometer to accuracy of 0.1 cm.

Assessment of motor competence

In the CHIPASE Study, MC was assessed by the Körperkoordination test für Kinder (KTK)[28]. During the assessment, children were asked to 1) walk backwards on balance beams with decreasing widths of 6.0cm, 4.5cm, and 3.0cm, 2) hop for height on one foot at a time, over a pile of soft mattresses (width 60 cm; depth 20 cm; height 5 cm each) with increasing height after each successful attempt, 3) jump sideways from side to side over a thin wooden lath (60 × 4 × 2 cm) on the jumping base (100 × 60 cm), and 4) move sideways with wooden plates (size 25 × 25 cm; height 5.7 cm) without stepping out as quickly as possible for 20 seconds. In each subtest, higher score indicates better MC. Raw scores from these tasks were used in the analyses.

In the PANIC Study, MC was assessed using 50 metre change of direction shuttle run test, standing long jump test, modified flamingo balance, and the box and block test[29]. In the 50 metre shuttle run test the children were asked to run 5 m from a starting line to another line as fast as possible, to turn on the line, to run back to the starting line, and to continue until five shuttles were completed. The test score was the running time in seconds, with a longer time indicating a poorer performance. In the standing long jump test the children were asked to stand the feet next to each other, to jump as far as possible, and to land on both feet. The test score

was the best result of three attempts in centimetres. In the modified flamingo balance test the children were asked to stand barefoot on one self-chosen leg with eyes closed for 30 s. The test score was the number of floor touches with a free foot or eye openings during 30 s, higher number of floor touches and eye openings indicating poorer static balance. In the box and block test the children were asked to pick up small wooden cubes (2.5 cm per side) one by one with the dominant hand from one side of a wooden box (53.7 cm × 25.4 cm × 8 cm) and to move as many cubes as possible to the other side of the box during 60 s and to repeat the same task with the non-dominant hand. The test score was the total number of cubes moved to the other side of the box during 120 seconds, a smaller number of cubes moved indicating poorer manual dexterity.

Assessment of cardiorespiratory fitness

In the CHIPASE and the PANIC Study, CRF was assessed using a maximal ramp exercise test with an electromagnetically braked Ergoline cycle ergometer (Ergoselect 200 K; Ergoline, Bitz, Germany). In the CHIPASE Study, the exercise protocol included 3-min warm-up at 20 Watts (W), an exercise period until exhaustion with a workload increase of 1 W every 3, 4, or 6 seconds depending on the stature of a child[30], and a 2–3 minute cooling down period without resistance. In the PANIC Study, the exercise test protocol included a 3-min warm-up period at 5 W, a 1-min steady-state period at 20 W, an exercise period with a workload increase of 1 W every 6 s until exhaustion and a 4-min cooling-down period at 5 W[31].

Respiratory gases were collected using paediatric masks (Hans–Rudolph, Shawnee, Kansas, USA) during the test. The respiratory gas analysers (CHIPASE: Jaeger Oxygon Mobile; PANIC: Jaeger Oxycon Pro, Hoechberg, Germany) were calibrated according to the manufacturer's instructions. Respiratory gases were measured directly by the breath-by-breath

method from the 2–2.5-min anticipatory period sitting on the ergometer to the post-exercise rest and were averaged over consecutive 15-s periods. The peak values of $\dot{V}O_2$, respiratory exchange ratio (RER) and $\dot{V}_E$ were defined as the highest 15-s average value recorded during the last minute of the test. Acknowledging the limitations of secondary indicators of true maximal oxygen uptake in children[32] and the lack of supramaximal validation test in the present studies, the exercise tests were considered maximal if primary and secondary physiological criteria indicated maximal effort and maximal cardiopulmonary capacity (e.g. plateau in $\dot{V}O_2$, RER ≥ 1.0) and the exercise specialist supervising the test considered the test maximal[31].

We scaled $\dot{V}O_{2peak}$ by LM^{-1} because $\dot{V}O_{2peak}$ (β=-0.097 to -0.075, p>0.200) and W_{max} (β=-0.069 to 0.228, p>0.202) scaled by LM^{-1} were not statistically significantly associated with LM suggesting the validity in scaling of CRF in both studies. We also scaled $\dot{V}O_{2peak}$ and W_{max} by BM^{-1} to investigate the associations of CRF with MC and BF% with conventional measure of CRF.

Other assessments

Maturity offset reflecting years from peak height velocity was used as an indicator of maturity. It was calculated separately for boys and girls using equations provided by Moore et al.[33]

Statistical methods

We performed all data analyses using SPSS Statistics, Version 24.0 (IBM Corp., Armonk, NY, USA). Basic characteristics between boys and girls were compared using the Student's t-test, the Mann–Whitney U-test, or the chi square-test. To reduce the number of MC variables, we performed principal component analyses to extract different MC components. After

principal component analyses, we computed population specific MC z-scores using the raw scorers from single MC tests. In the CHIPASE Study, all KTK variables loaded to same factor (0.245 to 0.304) explaining 78.3% of the variance and therefore we computed a total MC score from the z-scores of the KTK sub-test scores. Because balance assessed using walking backwards on a balance beam differs from other KTK tests as it is not time-dependent or jumping-related and it had the lowest correlation coefficient with other variables, we also analysed the associations of balance MC with CRF and BF% separately. In the PANIC Study, the first component explaining the highest proportion of variance (43.8%) was heavily loaded by 50-metre shuttle run (-0.897) and standing long jump (0.920). The second factor (27.8%) had high loadings with flamingo balance (0.790) and box and block (-0.761). Therefore, we created locomotor MC score from 50 metre shuttle run test and standing long jump z-scores and balance and manual dexterity MC score from the modified flamingo balance and box and block test z-scores based on the principal component analysis. The associations between the measures of CRF, the measures of MC, and BF% were analysed using linear regression analyses adjusted for age and sex. Whether $\dot{V}O_{2peak}$ or W_{max} scaled by LM^{-1} modify the magnitude of the association of MC with BF% was investigated using the three-step hierarchical linear regression analyses adjusted for age and sex. BF% was included as the depended variable and age and sex were included as covariates at the first step. At the second step, MC was included in the model as the primary independent variable. Finally, $\dot{V}O_{2peak}$ or W_{max} scaled by LM^{-1} was included in the model at step 3 as possible modifying factor. We found no evidence that sex modified the associations between the measures of CRF and the measures of MC in the PANIC Study and therefore we performed these analyses girls and boys combined. We found that sex modified the associations of BF% with balance and manual dexterity MC score (p=0.038 for interaction) and therefore we analysed the association of BF% with balance and manual dexterity MC score separately for

boys and girls. Statistical power was estimated using the G*Power software[34,35]. 395 to 55

observations were needed to observe small to medium effect size (f^2) and 55 to 25

observations to observe medium to large effect sizes in the linear regression analyses.

RESULTS

Basic characteristics

Boys had lower maturity offset, more lean mass, and higher absolute $\dot{V}O_{2peak}$ and W_{max} than

girls in both studies (Table 1). In the PANIC Study, boys also had less fat mass, lower BF%,

and higher LM and BM proportional $\dot{V}O_{2peak}$ and W_{max}. Boys also had faster 50 metre shuttle

run and better standing long jump performance but poorer box and block and flamingo

balance test performance than girls.

Associations of cardiorespiratory fitness with motor competence

$\dot{V}O_{2peak}$ scaled by LM^{-1} was not associated with MC in neither of the studies (Table 2). In the

CHIPASE Study, $\dot{V}O_{2peak}$ scaled by BM^{-1} was positively associated with total MC and

balance MC. In the PANIC Study, $\dot{V}O_{2peak}$ scaled by BM^{-1} was positively associated with

locomotor MC and balance and manual dexterity MC.

In the CHIPASE Study, W_{max} scaled by LM^{-1} and BM^{-1} were positively associated with total

MC and balance MC (Table 2). In the PANIC Study, W_{max} scaled by LM^{-1} and BM^{-1} were

positively associated with locomotor MC and balance and manual dexterity MC.

Associations of cardiorespiratory fitness with body fat percentage

In the CHIPASE Study, $\dot{V}O_{2peak}$ and W_{max} scaled by LM^{-1} were not associated with BF%

(Table 2). In the PANIC Study, $\dot{V}O_{2peak}$ scaled by LM^{-1} was not associated with BF%.

$\dot{V}O_{2peak}$ and W_{max} scaled by BM^{-1} were inversely associated with BF% in both studies. Furthermore, W_{max} scaled by LM^{-1} was inversely associated with BF% in the PANIC Study.

Associations of motor competence with body fat percentage

In the CHIPASE Study, total MC and balance MC were inversely associated with BF% (Table 2). In the PANIC Study, locomotor and balance and manual dexterity MC were inversely associated with BF%. However, balance and manual dexterity MC was inversely associated with BF% in boys (β=-0.265, p=0.001) but not in girls (β=-0.035, p=0.683).

Modifying effects of cardiorespiratory fitness in the associations of motor competence with body fat percentage

In the CHIPASE Study, total MC and balance MC were inversely associated with BF% (Table 2) and these associations remained statistically significant (β=-0.703 to -0.521, p$\leq$0.02) after including $\dot{V}O_{2peak}$ or W_{max} scaled by LM^{-1} to the regression model.

In the PANIC Study, locomotor MC was inversely associated with BF%. This association remained similar (β=-0.527 to -0.511, p<0.001) when $\dot{V}O_{2peak}$ or W_{max} scaled by LM^{-1} was included to the regression model. Similarly, balance and manual dexterity MC were inversely associated with BF% and including $\dot{V}O_{2peak}$ or W_{max} scaled by LM^{-1} had no effect on the magnitude of the association between balance and manual dexterity MC and BF% (β=-0.190 to -0.177, p=0.002 after including $\dot{V}O_{2peak}$ or W_{max} scaled by LM^{-1} to the model). The inverse association between W_{max} scaled by LM^{-1} and BF% was no longer statistically significant when locomotor MC (β=0.053, p=0.283) or balance and manual dexterity MC (β=-0.081, p=0.133) was entered into the model at the same time.

DISCUSSION

We showed, using two separate data sets, that children with lower and higher levels of MC had similar levels of CRF scaled by LM whereas children with poorer MC had lower levels of CRF scaled by BM. We also showed that MC, but not CRF, was inversely associated with BF%. Furthermore, we found that the associations of MC with BF% were not explained by CRF. These results suggest that the positive association between MC and CRF scaled by BM is a function of adiposity rather than peak aerobic power and that CRF is not a modifying factor in the associations between MC and BF%.

Our findings do not support previous findings on the positive associations of MC and CRF in children[6,36]. A reason for these divergent results is that previous studies have used body size and composition confounded measures of CRF[13,17,22,31], such as 20 metre shuttle run test[6,36] or $\dot{V}O_{2peak}$ scaled by BM[14,15], while we utilised $\dot{V}O_{2peak}$ scaled by LM that is the preferred method to normalise CRF for body size and composition[22]. Furthermore, we found a weak and statistically insignificant relationship of $\dot{V}O_{2peak}$ scaled by LM to BF% while we observed a strong inverse association between $\dot{V}O_{2peak}$ scaled by BM and BF%. These findings agree with previous studies and physiological observations that lean mass is the strongest determinant of $\dot{V}O_{2peak}$[21] and that fat mass does not contribute to $\dot{V}O_{2peak}$[18].

In line with the previous studies[6,36], we demonstrated an inverse association between MC and BF%. These findings suggest that MC is important determinant of body composition and that many tests used to assess MC are highly dependent on BF%. Therefore, it is not surprising that $\dot{V}O_{2peak}$, which is not influence by fat mass, does not play a role in the associations between MC and BF%. Nevertheless, we also showed that higher $\dot{V}O_{2peak}$ scaled by BM was

associated with better MC and lower BF% suggesting that the previous observations on the positive associations of MC with CRF and the modifying role of CRF in the associations between MC and BF% are largely influenced by body composition rather than peak aerobic power[13,22].

Although we found weak and statistically insignificant association between $\dot{V}O_{2peak}$ scaled by LM, MC, and BF%, we observed that W_{max} scaled either by LM or BM was positively associated with MC. We also found a weak inverse association between W_{max} scaled by LM and BF% in the PANIC Study, which is in contrast to the results with $\dot{V}O_{2peak}$. The reason for these partly contrasting findings between the measures of CRF may be that $\dot{V}O_{2peak}$ is a measure of peak aerobic power reflecting the integrated ability of cardiorespiratory system and skeletal muscles to deliver and extracting oxygen for energy production supporting muscle activity during exercise, and is mainly dependent on cardiac output, while W_{max} requires both aerobic and anaerobic metabolism and is more dependent on neuromuscular characteristic than $\dot{V}O_{2peak}$[24]. The reasons for the negative association between W_{max} and BF% may be reduced muscle quality[37,38], impaired motor unit activation[39], and reduced nerve amplitude[40] in children with higher BF%. These factors together may limit the ability to produce power per muscle cross-sectional area in children with higher BF% and therefore explain inverse association between W_{max} and BF%. Furthermore, MC explained the inverse association between W_{max} and BF% suggesting that one reason for this association maybe poorer ability to coordinate the neuromuscular system in cooperative fashion during the exercise test. These results are supported by previous findings showing that W_{max} is also a product of neuromuscular performance[41,42]. Therefore, our results suggest that $\dot{V}O_{2peak}$ and W_{max} should not be used interchangeably and the associations of different measures of CRF with MC should be interpreted cautiously.

The strengths of the present study include the use of two separate data set and valid and objective assessment of MC, $\dot{V}O_{2peak}$, W_{max}, and body composition. We also scaled the measures of CRF with LM instead on relying on traditional ratio scaling by BM. However, DXA, the reference method for body composition assessment, was not available in the CHIPASE Study. However, we utilised DXA in the PANIC Study to provide the best available evidence on the associations between CRF, MC, and adiposity. In addition, the measures of MC differed between the data sets and it would have been optimal to use the same methodology to allow direct comparison between studies. Nevertheless, the results were similar despite the different measures of MC strengthening the generalisability of our results. The sample size in the CHIPASE Study was also relatively small and within this study the associations were statistically significant mostly with large effect sizes. Therefore, further studies to investigate the associations between CRF, MC, and adiposity in larger populations are still warranted. Furthermore, it is possible that other measurers of fitness, such as muscle strength or anaerobic capacity, modify or mediate the associations between MC and BF%. However, we did not have comparable measures of muscle strength or anaerobic capacity in the CHIPASE Study and the PANIC Study. Finally, we did not include physical activity into our analyses although it is an important determinant of adiposity and MC in children[5,8,36,43]. While physical activity has been considered important factor mediating or moderating the associations between CRF, adiposity, and MC, we did not include physical activity into the present analyses because the current methodology used to assess physical activity and define cut-offs for light, moderate, and vigorous intensity physical activity may lead to large errors in the volume of physical activity at different intensities[44–46] and underestimate the true volume and intensity of physical activity especially in unfit and overweight or obese

individuals[45,47]. Therefore, including physical activity into our analyses would increase uncertainty to our results.

In conclusion, MC was not associated with $\dot{V}O_{2peak}$ in children whereas children with better MC also had higher W_{max}. Furthermore, CRF did not modify the association between MC and BF%. Therefore, different measures of CRF should not be used interchangeably and the interpretation of results should be adjusted accordingly. Our results highlight the need for further studies investigating the moderators and mediators of the association of MC and BF%, such as individually determined physical activity intensity and volume, sedentary behaviour, muscle strength and power, and other components of physical fitness instead of CRF.

PERSPECTIVES

Several cross-sectional and some longitudinal studies have demonstrated positive associations between MC and CRF and suggested that CRF mediate the associations of MC with BF%[14,36]. However, most of these previous studies have used methodology that prevents any firm conclusions on the role of peak aerobic power in MC and BF%. Our results suggest that the previous observations on the positive associations of MC with CRF and the modifying role of CRF in the associations between MC and BF% are largely influenced by body composition rather than peak aerobic power. Thus, to put our findings in perspective, our findings indicate that there are no remarkable differences in the functions of the cardiorespiratory system defined as $\dot{V}O_{2peak}$ between children with higher or lower levels of MC and adiposity. Therefore, our findings suggest that role of CRF in MC and BF% may have been overestimated and further studies with appropriate assessment and interpretation of CRF in relation to MC and BF% are highly warranted.

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