A meta-analysis on the effects of exercise training on the VO$_2$max in children and adolescents

Meta análisis de los efectos del entrenamiento en el VO$_2$máx en niños y adolescentes

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Abstract. The chronic adaptations of the cardiovascular system to exercise training in children and adolescents yield inconclusive results, in spite of previous meta-analytic evidence. The aim of this meta-analysis was to determine the effectiveness of exercise training on the VO$_2$max of children and adolescents. The studies meta-analyzed met the following inclusion criteria: a) healthy individuals, b) participants between 10 and 18 years old, c) being trained in some type of supervised exercise program, d) VO$_2$max reported in ml·kg$^{-1}$·min$^{-1}$, e) the study reported before and after mean and standard deviation, f) pre-test post-test research designs, and g) the study was published in a peer-reviewed journal up to February, 2013. Thirty-four studies and 96 effect sizes (ES) were obtained. Compared to controls, experimental groups showed a significant improvement in VO$_2$max (p < 0.01) following exercise training. The increase in VO$_2$max was maintained regardless of the sample size characteristics and the exercise protocol. Based on the findings of this study, in order for children and adolescents to improve their VO$_2$max, exercise training should include at least two sessions per week of > 20 minutes duration per session, performed at a moderate intensity. In summary, planned exercise training improves VO$_2$max in children and adolescents.

Key words. VO$_2$max, aerobic power, training, children, adolescents, meta-analysis.

Introduction

Training programs designed to improve the cardiovascular system in children and adolescents date from the 70's and 80's (Kobayashi et al., 1978; Mirwald, Bailey, Cameron, & Rasmussen, 1981). Equivocal findings were found, with most of the studies concluding that exercise training did not produce significant changes in VO$_2$max before the age of 12. These conclusions were subsequently supported by two narrative reviews of literature (Bar-Or, 1989; Borns, 1986).

However, these previous findings have been challenged by recent studies (Breel, Weber, Koller, Hoppeker, & Vagt, 2010; McMillan, Helgerud, Macdonald, & Hoff, 2005; Perini et al., 2006), where significant improvements in VO$_2$max have been found in these age groups following physical training. In general, it is concluded that a sufficient training stimulus must be provided for a significant enhancement of the VO$_2$max in children and adolescents to occur. In practical terms, new directions regarding the frequency, intensity and duration of the exercise programs are needed.

Meta-analytic research on the subject was published in the 90's (LeMura, Von Duivillard, Carlonas, & Andreacci, 1999; Payne & Morrow, 1993), allowing for a better understanding of the state of the knowledge at that time. The first meta-analysis published on the subject (Payne & Morrow, 1993) included 28 studies, and 70 effect sizes (ES) were computed from a pooled sample of 420 participants. The mean VO$_2$max before starting an exercise program was 46.22 ml·kg$^{-1}$·min$^{-1}$ and 48.39 ml·kg$^{-1}$·min$^{-1}$ after the training period. The researchers concluded that exercise training improved aerobic power in children by nearly 5%, with cross-sectional studies producing larger ES than studies using repeated measures designs (i.e., the participant as its own control) (ES = 1.1 ± 0.1 vs. ES = 0.32 ± 0.2, respectively). Also, children between the ages of 11 and 13 reported significantly larger improvements in VO$_2$max (ES = 1.1 ± 0.7) than children between 8 and 10 years old (ES = 0.47 ± 0.4). No significant differences were found between males (ES = 0.64 ± 0.6) and females (ES = 1.0 ± 0.6), or between treadmill (ES = 0.75 ± 0.7) and cycle ergometer (ES = 0.94 ± 0.7) testing modalities.

The authors were unable to extract information from the articles to fully characterize the exercise protocol (LeMura et al., 1999). Exercise programs were categorized as having «adequate» (i.e., a minimum of three sessions per week for six weeks at an intensity equal to or greater 70% maximal heart rate) or «inadequate» training based on recommendations from professional organizations (American College of Sports Medicine, 1995). Statistical analysis showed that an appropriate training (ES = 1.2 ± 0.5) improved VO$_2$max more than an inadequate training (ES = 0.3 ± 0.2).

The meta-analytic evidence suggests a direct association between children’s age and VO$_2$max resulting from exercise training. It also shows that male and females benefit similarly from their participation in exercise training programs, with a trend towards larger improvements in females compared to males. However, this finding must be cautiously interpreted since only few studies with female groups were analyzed and greater benefits are expected due to their initial lower fitness level. A proper exercise prescription is critical to enhance VO$_2$max, since insufficient
training on VO2max in children and adolescents were divided into four categories: a) general characteristics of the study, b) general information about participants, c) exercise program characteristics, and d) testing modalities (Table 1).

Inclusion Criteria
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Variable Coding
Moderator variables that might influence the effect of exercise training on VO2max in children and adolescents were divided into four categories: a) general characteristics of the study, b) general information about participants, c) exercise program characteristics, and d) testing modalities (Table 1).

Methodology
A systematic search was conducted of Academic Search Complete, Educational Resource Information Center (ERIC), MEDLINE, SPORTDiscus, Arts and Humanities Citation Index, Physical Education Index, Science Citation Index Expanded, Social Sciences Citation Index, and the Spanish database Dialnet for the period October, 2012 until February, 2013. The search strategy included a mix of subject headings and free text terms for the key words aerobic, endurance, exercise, training, children, teenagers, adolescents, adolescence, VO2, VO2max, aerobic power, and their combination. Reference lists of articles found were scrutinized for new references. No language limits were imposed.

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Analyze
All meta-analyses were performed using the Statistical Package for the Social Sciences (SPSS), version 20.0. The outcome measure was VO2max. Descriptive data are reported as the mean ± SD unless otherwise noted. Effect sizes (ES) for each study group were calculated by subtracting the pre-test value from the post-test value for both, the experimental and control groups (Thomas & French, 1986). ES were corrected to avoid estimate overestimation due to different sample sizes between true, quasi-, and pre-experimental research designs on the mean VO2max ES (F = 1.016, p = 0.369). Since ES were similar between research designs (Table 2), we pooled the ES from all the studies for further analysis.

Effect size according to the research design

\[
\text{Table 2. Effect size according to the research design}
\]

<table>
<thead>
<tr>
<th>Research design</th>
<th>ES</th>
<th>z</th>
<th>p</th>
<th>zp</th>
</tr>
</thead>
<tbody>
<tr>
<td>True experimental</td>
<td>0.40</td>
<td>0.59</td>
<td>0.39</td>
<td>0.03</td>
</tr>
<tr>
<td>Quasi-experimental</td>
<td>0.58</td>
<td>0.50</td>
<td>0.41</td>
<td>0.05</td>
</tr>
<tr>
<td>Pre-experimental</td>
<td>0.31</td>
<td>0.50</td>
<td>0.57</td>
<td>0.24</td>
</tr>
</tbody>
</table>

* zp different 0, p < 0.05

** zp different 0, p < 0.01

Effect size according to the characteristics of the sample

\[
\text{Table 3. Characteristics of the sample}
\]

<table>
<thead>
<tr>
<th>Characteristics of the sample</th>
<th>ES</th>
<th>z</th>
<th>p</th>
<th>zp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>0.54</td>
<td>0.63</td>
<td>0.36</td>
<td>0.02</td>
</tr>
<tr>
<td>Female</td>
<td>0.49</td>
<td>0.55</td>
<td>0.30</td>
<td>0.05</td>
</tr>
<tr>
<td>Missed groups</td>
<td>0.53</td>
<td>0.51</td>
<td>0.31</td>
<td>0.01</td>
</tr>
<tr>
<td>Age (years)</td>
<td>0.45</td>
<td>0.53</td>
<td>0.40</td>
<td>0.12</td>
</tr>
<tr>
<td>Type of participant</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Athlete</td>
<td>0.60</td>
<td>0.42</td>
<td>0.30</td>
<td>0.00</td>
</tr>
<tr>
<td>Non-athlete</td>
<td>0.44</td>
<td>0.39</td>
<td>0.13</td>
<td>0.00</td>
</tr>
<tr>
<td>Type of activity</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Agility</td>
<td>0.48</td>
<td>0.56</td>
<td>0.49</td>
<td>0.07</td>
</tr>
<tr>
<td>Swimming</td>
<td>0.46</td>
<td>0.56</td>
<td>0.12</td>
<td>0.02</td>
</tr>
<tr>
<td>Running</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Endurance</td>
<td>0.48</td>
<td>0.56</td>
<td>0.11</td>
<td>0.02</td>
</tr>
<tr>
<td>Other</td>
<td>0.48</td>
<td>0.56</td>
<td>0.10</td>
<td>0.01</td>
</tr>
</tbody>
</table>

* zp different 0, p < 0.05

![Figure 1: Effect size (ES) magnitude of the training interventions on the VO2max in children and adolescents.](image)

- a < b, p < 0.05

Results
Thirty-four studies were included in the meta-analysis, and 96 ES were computed from 2113 participants. Cochran’s Q showed heterogeneity among ES (Q = 149.17, p < 0.01); therefore, the moderator variables were scrutinized. One-way ANOVA showed no significant differences between true, quasi-, and pre-experimental research designs on the mean VO2max ES (F = 1.016, p = 0.369). Since ES were similar between research designs (Table 2), we pooled the ES from all the studies for further analysis.

Subjects participating in exercise training programs significantly improved their VO2max (ES = 0.47 ± 0.56, z = 2.89, p < 0.05) compared to their control counterparts (ES = 0.05 ± 0.31, z = 0.25, p > 0.05). One-way ANOVA for exercise training characteristics as a moderator variable showed significant differences between the types of activities (F = 5.956, p < 0.0001). Tukey’s post hoc analysis revealed differences (p < 0.05) between control groups and running and other aerobic activities (e.g., dancing, climbing stairs, practicing taekwondo or combined aerobic and resistance exercise) (Figure 1).

Differences between categories were determined by on-way analysis of variance (ANOVA), followed by Tukey’s post hoc comparisons. Pearson product-moment correlations were used to test associations between continuous variables. In this study, ES magnitude was considered small (ES < 0.40), moderate (ES 0.41 to 0.70), and large (ES > 0.71) based on previous literature (Thomas, Salazar, & Landers, 1991).
One-way ANOVA for the sample characteristics as a moderator variable showed no significant differences for gender ($F = 0.732, p = 0.486$), age ($r = 0.14, p = 0.152$) and type of participant ($F = 0.448, p = 0.508$). In general, all participants improved their VO$_{2\text{max}}$ when participating in an exercise training program (Table 3).

One-way ANOVA for the characteristics of the exercise training interventions as a moderator variable showed no significant differences for exercise intensity ($F = 0.216, p = 0.885$), weekly frequency ($r = 0.12, p = 0.409$), session duration ($r = 0.11, p = 0.496$), and program length ($r = -0.10, p = 0.442$) (Table 4).

One-way ANOVA for VO$_{2\text{max}}$ testing characteristics as a moderator variable showed significant differences between cycle ergometer ($ES = 0.50 \pm 0.57, z = 5.82, p < 0.05$) and treadmill ($ES = 0.49 \pm 0.63, z = 4.70, p < 0.05$) compared to 20-m interval running ($ES = 0.25 \pm 0.12, p > 0.05$).

**Discussion**

The aim of the study was to determine the effect of exercise training on the VO$_{2\text{max}}$ of children and adolescents and to detect relevant moderator variables. The main finding of this study was a confirmation of the human body’s ability to chronically adapt to exercise training, leading to an improvement in the aerobic power (i.e., VO$_{2\text{max}}$) from childhood to adolescence. A moderate ES was found for VO$_{2\text{max}}$ regardless of the sample and training program characteristics. The increase in 6.53% in VO$_{2\text{max}}$ resulting from exercise training found in the present study is at the higher range of the 5% to 6.14% reported in previous meta-analyses (LeMura et al., 1999; Payne & Morrow, 1993) (Figure 2).

No significant gender differences in VO2max following training were found in this study. Others (LeMura et al., 1999; Payne & Morrow, 1993) suggested that females might benefit more than males from an exercise program. However, with the similar number of ES computed in the present study that trend is no longer supported.

We found improvements in VO$_{2\text{max}}$ in children and adolescents from 10 to 18 years by increasing the age range. Others (LeMura et al., 1999; Payne & Morrow, 1993) reported ES differences by age group; however, these authors only included participants with a limited age range (i.e., 8 to 10 and 11 to 13 yrs). In agreement with previous reports (Baquet, van Praagh, & Berthoin, 2003), no significant ES differences in the VO$_{2\text{max}}$ were found between athletes and non-athletes.

In this study, similar ES were found for moderator variables exercise frequency, duration and the training program length. In opposition, others (Armstrong, Barrett, & Welsman, 2007), suggested a minimum of three to four sessions per week, for 40-60 min/session, for at least 12 weeks to obtain aerobic power benefits. Our evidence suggests that an exercise program characteristic is not a strong moderator for the effects on VO$_{2\text{max}}$. We found that at least two exercise sessions/week of a minimum of 20 min/session, executed at a moderate intensity for at least 11 days, provide significant benefits to children and adolescents.

Exercise intensity is a key element in a training program. This feature is difficult to meta-analyze since some authors do not report the training intensity used in their studies. Another limitation is that for those authors reporting exercise intensities, maximal heart rate (HRmax) and VO$_{2\text{max}}$ percentage were used interchangeably. In the present study we categorized the high intensity exercise as 80-100%, moderate intensity as 60-79%, and low intensity as > 59%.

We found that a moderate exercise intensity of (e.g., ~60% of an individual’s HRmax) provided enough stimuli for a VO$_{2\text{max}}$ improvement. This contrasts previous findings (Armstrong et al., 2007; Baquet et al., 2003), suggesting a higher exercise intensity (e.g., > 80% HRmax) necessary to achieve aerobic power benefits.

There were changes in the initial characteristics of the exercise protocol in several studies. This is an expected finding that follows the principle of exercise progression, which states the need of adjusting the workload for optimal results; however, modifying the original protocol (and not reporting it) precludes from studying a cause-effect association and potential physiological mechanisms responsible for the observed outcomes. A methodological sound suggestion for future studies would be to test participants in all dependent variables any time a change in the program workload is done.

In this study, 20-m interval running tests did not result in ES statistically different from zero. Although this test is easier to administer and is inexpensive compared to laboratory equipment such as cycle ergometers, metabolic carts and treadmills, the validity and reliability of data derived from this field test is not always reported or known. Therefore, in order to obtain valid and reliable VO$_{2\text{max}}$ estimates, direct measurement of aerobic power must be used when studying the effects of exercise interventions in children and adolescents.

We agreed with others (Payne & Morrow, 1993), who found similar ES when participants were tested in treadmill and cycle ergometers. Undoubtedly, the children and adolescents’ ability to improve their aerobic capacity by exercise training is demonstrated. Empirical evidence suggests similar benefits regardless of the characteristics of exercise program; however, further experimental research is needed that address proper and quantifiable exercise frequency, intensity and duration.

In conclusion, in order for children and adolescents to improve their VO$_{2\text{max}}$, exercise training should include at least two sessions per week, for > 20 minutes duration per session, performed at a moderate intensity.

**References**


Studies meta-analysed


