Definitive conclusions regarding the effects of PT on vertical jump performance cannot be drawn.

Several factors, including training programme design (type of exercises used, training duration, training frequency, volume and intensity of training), subject characteristics (age, gender, fitness level) and methods of testing different types of vertical jumps may be responsible for the discrepancy among PT literature. However, potentially the most important factor responsible for the observed conflicting findings is the sample size used in training interventions. For example, it is well known that sample size influences the power to detect real and significant effects. The typical sample size in almost all previous studies on PT ranged between 8 and 12 subjects per group, meaning that, by using statistical power of 80% and an r level of 0.05, these studies could detect only effect sizes (ESs) > 0.2. Evidently, most PT studies had insufficient statistical power to detect not only small to moderate, but even large treatment effects.

One method that allows us to overcome the problem of small sample size and low statistical power is the meta-analysis. Meta-analysis is a quantitative approach in which individual study findings addressing a common problem are statistically integrated and analysed. As meta-analysis effectively increases overall sample size, it can provide a more precise estimate of effect of PT on vertical jump height. In addition, meta-analysis can account for the factors partly responsible for the variability in treatment effects observed among different training studies (see previous text). Given the general importance of vertical jump ability in athletic performance, and in assessment of human muscle power capabilities, as well as...
METHODS

Literature search and study selection

The following databases were searched using CSA Ilumina search engine: MEDLINE (1966–Sep 2006), ERIC (1966–Sep 2006), Physical Education Index (1970–Sep 2006) and PsychINFO (1960–Sep 2006). We used the following combination of search terms and Booleans: plyometric OR pliometric OR stretch-shortening cycle OR drop jump OR depth jump OR jump training AND controlled trials. In addition, manual searches of relevant journals and reference lists obtained from articles were conducted. The present meta-analysis includes studies published in journals that have presented original research data on healthy human subjects. No age, gender or fitness level restrictions were imposed at the search stage.

Quality assessment

The PEDro Scale was used to assess methodological quality of the studies. It is an 11-item scale designed for rating methodological quality of randomised controlled trials. The answer to each criterion is a simple yes/no and each satisfied
item (except for item 1) contributes one point to the total PEDro Score (range: 0–10 points). The scale items are:
1. Eligibility criteria were specified.
2. Subjects were randomly allocated to groups (in a crossover study, subjects were randomly allocated an order in which treatments were received).
3. Allocation was concealed.
4. The groups were similar at baseline with respect to the most important prognostic indicators.
5. There was blinding of all subjects.
6. There was blinding of all therapists who administered the treatment.
7. There was blinding of all assessors who measured at least one key outcome.
8. Measurements of at least one key outcome were obtained from more than 85% of the subjects initially allocated to groups.
9. All subjects for whom the outcome measurements were available received the treatment or control condition as allocated, or where this was not the case, data for at least one key outcome were analysed by “intention to treat”.
10. The results of between-group statistical comparisons are reported for at least one key outcome.
11. The study provides both point measurements and measurements of variability for at least one key outcome.

Statistical analysis
The size of the effect of PT on vertical jump height ($\Delta_{\text{tot}}$) is given by the difference between the mean change in jump height of subjects in the plyometric group ($\Delta_{\text{plyo}}$) and the control group ($\Delta_{\text{con}}$). We used two approaches for pooling the data across studies. In the first approach, we expressed $\Delta_{\text{tot}}$ relative to the mean value of the control group—that is, in percentage values. In the second approach, we expressed the effect in standardised units quantified by calculating an ES. The ESs were calculated by dividing $\Delta_{\text{tot}}$ (ie, $\Delta_{\text{plyo}} - \Delta_{\text{con}}$) by the pooled SD of the change scores of the plyometric and control groups. This approach was adopted as some authors reported marked differences in the mean vertical jump height between the plyometric group and the control group at baseline.\textsuperscript{35–38} For the studies that did not report SD of the change scores, these were estimated from the SDs extracted before and after training by assuming a correlation of 0.75 between measures taken before and after training (details are given in Higgins and Green\textsuperscript{72}). The correlation of 0.75 was selected on the basis of the findings of Adams\textsuperscript{39} who showed, on six independent and relatively large subject samples, that the correlation between jump heights measured before and after 7 weeks of PT is mainly $>0.75$. This was further verified by calculating the correlation between jump heights before and after training for the 16 studies included in our analyses that reported SD for change scores.\textsuperscript{35–38} Median correlation of 0.81 and 0.84 was obtained for the plyometric and control groups, respectively. Thus, we believe that the selected correlation coefficient of 0.75 can be considered appropriate. The calculated ESs were then corrected for small-sample bias.\textsuperscript{73} According to Cohen,\textsuperscript{74} an ES of 0.2 is considered as a small effect, 0.5 as a moderate effect and 0.8 as a large effect.

Heterogeneity of effects for each vertical jump height test was assessed by using the quantity $I^2$, as suggested by Higgins et al.\textsuperscript{75} In brief, $I^2$ was calculated as follows: $I^2 = 100 \cdot \frac{(Q-\text{df})/Q}{Q}$, where $Q$ is Cochran's $\chi^2$ heterogeneity statistic and df the degrees of freedom. The Cochran's $Q$ is calculated by summing the squared deviations of each trial's estimate from the overall meta-analytical estimate. $I^2$ describes the percentage of variability in point estimates which is due to heterogeneity rather than sampling error. $I^2$ values of 25%, 50% and 75% represent low, moderate and high statistical heterogeneity, respectively.\textsuperscript{76} Although the heterogeneity of effects in our meta-analyses ranged from 0% to 33% (see Results section), we decided to apply a random-effects model of meta-analysis in all the cases. To test the robustness of these analyses, we also calculated and reported a fixed-effects model.

Publication bias, as well as evidence of outliers, was examined by funnel plots of the SEs of the estimate of the effect versus calculated ESs. Subsequently, three studies (two studies for the SJ and one study for the SJ) were excluded from the meta-analyses owing to unrealistically large positive effects (table 1). In addition, publication bias was also statistically evaluated by calculating rank correlations between effect estimates and their SEs (ie, Kendall's $t$ statistic\textsuperscript{77}). A significant result ($p<0.05$) was considered to be suggestive of publication bias.

It should also be noted that some studies reported $>1$ primary outcome owing to $>1$ plyometric groups and/or vertical jump tests measured. We treated these outcomes as independent data points. However, to examine the influence (sensitivity) of each study on the overall results, analyses were performed with each study deleted from the model. If the effect and CIs in the sensitivity analysis lead to the same conclusion as the primary meta-analysis value, the results are considered robust.

Subgroup analyses for each primary outcome included both subject’s fitness level (non-athletes vs athletes) and type of training programme applied (three different types of PT programmes), and were performed using analysis of variance-like procedures for meta-analysis.\textsuperscript{78} Meta-regression was used for analysing the relationship between the ES and the selected subject or training characteristics: subject's age, gender, duration of the training period, number of training sessions and number of foot contacts. Finally, pooled estimates were statistically compared by comparing the overlap of their CIs. The level of significance was set to $p<0.05$.

RESULTS
Descriptive statistics
Altogether, 26 published investigations were included in the meta-analyses. In all, 15 of the 26 investigations provided $\geq2$ primary outcomes (through multiple treatment groups and/or $>1$ vertical jump height tests) giving 13 ESs for the SJ, 19 ESs for the CMJ, 14 ESs for the CMJA and 7 ESs for the DJ. Table 1 summarises the characteristics of the included studies. Note that three ESs (one for the SJ and two for the DJ; table 1) from two studies were excluded from the meta-analyses owing to unrealistically large positive effects. Altogether, 1024 subjects (849 males and 175 females, or 83% males vs 17% females) were included in the meta-analyses. When distributed over particular primary outcomes, this number was 253 subjects for SJ, 405 subjects for CMJ, 297 subjects for CMJA and 69 subjects for DJ. The average sample size per group was 11 (range: 5–33) subjects. Mean age of the subjects included in this study ranged from 11 to 29 years, with $\sim55$% of the subjects being aged between 20 and 22 years.

Studies included in the meta-analyses had an intervention duration ranging from 4 to 24 weeks, a total number of training sessions ranging from 12 to 60 and a total number of foot contacts ranging from 468 to 7500.

Methodological quality
The median PEDro Quality Score assessing methodological quality of the included studies was 5 out of 10 (range 3–5; table 1). The results of PEDro Scale showed that two studies\textsuperscript{11,12} failed to randomise the subjects into groups. Note, however, that all studies failed to satisfy the following five methodological criteria: treatment allocation concealment, blinding of all subjects; blinding of all therapists, blinding of all assessors; and
Table 1. Chronological summary of investigations included in the meta-analyses of effects of plyometric training on vertical jump height

<table>
<thead>
<tr>
<th>Study</th>
<th>Author</th>
<th>Year</th>
<th>Age (years)</th>
<th>Fitness</th>
<th>Sample size</th>
<th>Duration (weeks)</th>
<th>Sessions (n)</th>
<th>Type of exercise</th>
<th>Foot contacts (n)</th>
<th>Effect size (SE)</th>
<th>95% CI</th>
<th>% change</th>
<th>95% CI</th>
<th>Quality score</th>
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<tbody>
<tr>
<td>SJ</td>
<td>Wilson</td>
<td>2006</td>
<td>13/0</td>
<td>14/0</td>
<td>10</td>
<td>20</td>
<td>DJT</td>
<td>720</td>
<td>0.48 (0.39)</td>
<td>-0.29 to 1.24</td>
<td>6.7 (5.4)</td>
<td>-3.9 to 17.3</td>
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<td></td>
<td>Holcomb</td>
<td>2006</td>
<td>23</td>
<td>9/0</td>
<td>8</td>
<td>24</td>
<td>DJT</td>
<td>1728</td>
<td>0.95 (0.48)</td>
<td>0.00 to 1.90</td>
<td>7.3 (3.5)</td>
<td>0.4 to 14.2</td>
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<td>Holcomb</td>
<td>2006</td>
<td>10</td>
<td>9/0</td>
<td>8</td>
<td>24</td>
<td>DJT</td>
<td>1728</td>
<td>0.38 (0.46)</td>
<td>-0.53 to 1.29</td>
<td>3.3 (4.0)</td>
<td>-4.5 to 11.1</td>
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<td></td>
<td>Gehl</td>
<td>2006</td>
<td>17</td>
<td>5/6</td>
<td>5/5</td>
<td>12</td>
<td>DJT</td>
<td>704</td>
<td>0.74 (0.48)</td>
<td>-0.19 to 1.67</td>
<td>6.4 (4.0)</td>
<td>-1.4 to 14.2</td>
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<td></td>
<td>Gehl</td>
<td>2006</td>
<td>20</td>
<td>5/6</td>
<td>5/5</td>
<td>12</td>
<td>CMJT</td>
<td>704</td>
<td>0.54 (0.44)</td>
<td>-0.33 to 1.41</td>
<td>10.8 (8.7)</td>
<td>-6.2 to 27.7</td>
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<td>Gehl</td>
<td>2006</td>
<td>20</td>
<td>4/3</td>
<td>5/5</td>
<td>12</td>
<td>CMJT</td>
<td>704</td>
<td>0.23 (0.49)</td>
<td>-0.74 to 1.20</td>
<td>5.1 (10.8)</td>
<td>-16.1 to 26.3</td>
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<td></td>
<td>Gehl</td>
<td>2006</td>
<td>26</td>
<td>5/9</td>
<td>9/0</td>
<td>6</td>
<td>DJT</td>
<td>468</td>
<td>-0.22 (0.56)</td>
<td>-1.31 to 0.88</td>
<td>-1.7 (4.4)</td>
<td>-10.2 to 6.9</td>
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<td>Gehl</td>
<td>2006</td>
<td>26</td>
<td>5/9</td>
<td>9/0</td>
<td>6</td>
<td>DJT</td>
<td>468</td>
<td>-0.43 (0.43)</td>
<td>-0.56 to 0.26</td>
<td>6.5 (4.3)</td>
<td>-11.2 to 6.7</td>
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<td>Dallal</td>
<td>2006</td>
<td>13</td>
<td>10</td>
<td>10/0</td>
<td>10</td>
<td>COMB</td>
<td>7500</td>
<td>1.14 (0.48)</td>
<td>0.19 to 2.09</td>
<td>14.3 (4.9)</td>
<td>4.7 to 23.9</td>
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<td>Turner</td>
<td>2006</td>
<td>29</td>
<td>4/6</td>
<td>4/4</td>
<td>6</td>
<td>COMB</td>
<td>1599</td>
<td>0.00 (0.47)</td>
<td>-0.93 to 0.93</td>
<td>0.0 (6.3)</td>
<td>-12.3 to 12.3</td>
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<td></td>
<td>Tricoli</td>
<td>2006</td>
<td>20</td>
<td>8/0</td>
<td>17/0</td>
<td>12</td>
<td>DJT</td>
<td>2028</td>
<td>0.46 (0.52)</td>
<td>-0.57 to 1.49</td>
<td>3.6 (4.1)</td>
<td>-4.3 to 11.4</td>
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<td>Herrero</td>
<td>2006</td>
<td>21</td>
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<td>10/0</td>
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<td>COMB</td>
<td>1580</td>
<td>-0.31 (0.46)</td>
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<td>Čotamanidis</td>
<td>2006</td>
<td>11</td>
<td>15/0</td>
<td>15/0</td>
<td>10</td>
<td>COMB</td>
<td>1520</td>
<td>2.77 (0.31)</td>
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<td>29.2 to 49.4</td>
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<td>Markovic</td>
<td>2006</td>
<td>20</td>
<td>30/3</td>
<td>33/0</td>
<td>4</td>
<td>CMJT</td>
<td>1580</td>
<td>1.03 (0.27)</td>
<td>0.50 to 1.55</td>
<td>7.1 (1.8)</td>
<td>3.7 to 10.6</td>
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<td></td>
<td>Overall</td>
<td>2006</td>
<td>21</td>
<td>-10/2</td>
<td>-11/1</td>
<td>8</td>
<td>NA</td>
<td>1718</td>
<td>0.44 (0.15)</td>
<td>0.15 to 0.72</td>
<td>4.7 (1.5)</td>
<td>1.8 to 7.6</td>
<td>NA</td>
<td></td>
</tr>
</tbody>
</table>

Sample size: M/F = males/females; N-A = non-athletes; NA = not applicable; PLYO = plyometric group; SJ = squat jump.

Samples are presented in chronological order of their publication.

*Total score of each study on the PEDro 11-point quality scale.

A, athletes; CMJ, countermovement jump; OMJ, countermovement jump with the arms swinging; CMAT, countermovement jump exercise; COMB, combination of various jump exercises; CON, control group; DJ, drop jump; DJT, drop jump exercise; F, females; M, males; N-A, non-athletes; NA, not applicable; PLYO, plyometric group; SJ, squat jump.

A total score of each study on the PEDro 11-point quality scale.

Studies excluded from meta-analysis as outliers.

A, athletes; CMJ, countermovement jump; OMJ, countermovement jump with the arms swinging; CMAT, countermovement jump exercise; COMB, combination of various jump exercises; CON, control group; DJ, drop jump; DJT, drop jump exercise; F, females; M, males; N-A, non-athletes; NA, not applicable; PLYO, plyometric group; SJ, squat jump.

A total score of each study on the PEDro 11-point quality scale.

Studies excluded from meta-analysis as outliers.
intention to treat analyses (ie, items 3, 5, 6, 7 and 9, respectively).

**Primary outcomes**

Table 1 reports the individual percentage and changes in ES in the primary outcomes and summarises the pooled estimates of the effects of PT on vertical jump height.

**Squat jump**

For the SJ, pooled estimate of the effect of PT was 4.7% (95% CI 1.8 to 7.6%). When expressed in standardised units, this effect was rather small (ES = 0.44, 95% CI 0.15 to 0.72). A somewhat higher pooled estimate was observed when a fixed-effect model was used (ES = 0.47, 95% CI 0.21 to 0.72). The statistical heterogeneity of effects of PT on the SJ was moderate ($I^2 = 33\%$). When each study was removed from the model once, the ES ranged from 0.35 (95% CI 0.10 to 0.62) to 0.55 (95% CI 0.31 to 0.80). Both funnel plot and Kendall’s $\tau$ statistic ($\tau = 0.05; p = 0.86$) showed no evidence of publication bias for the SJ.

**Countermovement jump**

Pooled estimate of the effect of PT on CMJ was 8.7% (95% CI 7.0 to 10.4%). Expressing the data as ES indicated the large effect (ES = 0.88, 95% CI: 0.64 to 1.11). Almost identical pooled estimate was obtained with a fixed-effect model (ES = 0.87, 95% CI 0.67 to 1.06). We also observed low statistical heterogeneity of effects for the CMJ ($I^2 = 11.4\%$). Finally, when each study was removed from the model once, the ES ranged from 0.83 (95% CI 0.63 to 1.03) to 0.89 (95% CI 0.69 to 1.09). Note, however, that an inspection of the funnel plot as well as Kendall’s $\tau$ statistic ($\tau = 0.42; p = 0.012$) suggest the presence of publication bias in the CMJ.

**Countermovement jump with the arm swing**

Overall, PT resulted in improvement in the CMJA of 7.5% (95% CI 4.2 to 10.8%). Pooled ES value of 0.74 (95% CI 0.47 to 1.02) suggests that this effect was moderate to large. A somewhat lower pooled estimate was observed when a fixed-effect model was used (ES = 0.71, 95% CI 0.49 to 0.93). Heterogeneity of effect for the CMJA was moderate ($I^2 = 29.6\%$). When each study was removed from the model once, changes in ES ranged from 0.67 (95% CI 0.42 to 0.93) to 0.79 (95% CI 0.51 to 1.08). Similar to the CMJ, both funnel plot and Kendall’s $\tau$ statistic ($\tau = 0.49; p = 0.016$) suggest the presence of publication bias in the CMJA.

**Drop jump**

For the DJ, pooled estimate of the effect of PT was 4.7% (95% CI 0.8 to 8.6%), similar to the one observed for the SJ. Expressing the data as ES indicated moderate effect (ES = 0.62) with relatively large CI (95% CI 0.18 to 1.05) probably owing to the small number of studies analysed. Identical pooled estimate was obtained with a fixed-effect model (ES = 0.62, 95% CI 0.18 to 1.05). This is not surprising, as the heterogeneity measure $I^2$ was equal to zero. When each study was removed from the model once, changes in ES ranged from 0.57 (95% CI 0.09 to 1.09) to 0.66 (95% CI 0.18 to 1.14). No qualitative (funnel plot) or quantitative ($\tau = 0.18; p = 0.82$) evidence of publication bias was found in the DJ.

There were no significant differences in the pooled effects between four vertical jump tests. However, it should be stressed that the effect of PT was nearly twice as high in the CMJ than that in the SJ.

**Subgroup analyses**

No significant differences in the ES (all $p>0.05$) were found between non-athletes and athletes for each of the four vertical jumps. Moreover, there were no significant differences (all $p>0.05$) in treatment effects between different PT programmes.

**Meta regressions**

A significant positive relationship was found between the total number of training sessions and the ES in SJ (p = 0.002; fig 1A) and CMJA (p = 0.004; fig 1B). In all the remaining metaregressions, no significant relationships were observed (all $p>0.05$).

**DISCUSSION**

This study uses a meta-analytical approach and provides a precise estimate of the effect of PT on vertical jump height based on a significant sample size, which, otherwise, may be difficult to achieve. In this study, the results of this study suggest that the PT significantly improves vertical jump height and that the mean effect ranges from 4.7% (ES = 0.44; ie, small effect) to 8.7% (ES = 0.88; ie, large effect) depending on the type of vertical jump measured. There was very low to moderate heterogeneity of effects within each meta-analysis, suggesting that all trials examined the same effect. Moreover, sensitivity analyses using (1) a fixed-effects model, and (2) excluding each study from the model once, did not substantially change the mean effects or their CIs, providing evidence that the results of the meta-analyses were robust. Note, however, that we observed a publication bias in two primary outcomes (ie, CMJ and CMJA). As we meta-analysed only PT studies published in peer-reviewed journals, there is a likelihood that some smaller studies without significant effects remain unpublished. Therefore, some caution is warranted regarding the precise estimates of the effects of PT on jump height in these two vertical jumps.

Besides being statistically significant, the estimated improvements in vertical jump height as a result of PT could also be considered as practically relevant—for example, an improvement in vertical jump height of ~5–10% (ie, ~2–6 cm, depending on the type of vertical jump) could be of high importance for trained athletes in sports relying on jumping performance, like basketball, volleyball and high jump. In addition, several studies on PT have demonstrated that a significant increase in vertical jump height of ~10% was accompanied with similar increase in sport-specific jumping.12 13 25 26 51 A cycling25 and distance-running performance.24 25 51 These exceptions, no significant relationships were observed (all $p>0.05$) in treatment effects between different PT programmes.
vertical jump ability. However, this study offers robust quantitative evidence to this conclusion, together with a precise estimate of the effect of PT on jump height in particular types of vertical jumps. Although the results of this review provide some valuable information, certain potential limitations of this study should be outlined. First, the PEDro Scores of the studies included in the meta-analyses suggest that most studies could be classified as low-quality studies. However, we should bear in mind that blinding of participants and therapists is impossible in exercise interventions. If these two items were deleted from the PEDro Scale, quality ratings of all included studies would have changed substantially. Nonetheless, it is recommended that the future studies on PT have to improve their quality by blinding the assessor, as well as by ensuring that treatment allocation concealment and intention to treat analyses are performed.

Another potential limitation of this study is related to the observed publication bias in the CMJ and CMJA. We therefore acknowledge the possibility that a precise effect of PT on these two vertical jumps could be somewhat smaller than that estimated in our study. Finally, a potential weakness of this investigation was the small number of ES available for some subgroup analyses (eg, athletes vs non-athletes) and metaregressions (eg, age, gender). This prevented us from generalising the effects of subjects and/or training characteristics.

In conclusion, the present study demonstrates that PT significantly improves vertical jump height in all four types of standard vertical jumps. The observed mean effect in jump height ranged between 4.7% and 8.7% and could also be considered as practically relevant. From this perspective, PT can be recommended as an effective form of physical conditioning for augmenting the vertical jump performance of healthy individuals.

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Plyometric training improves vertical jump height


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Meta-analyses such as this are useful as they combine the efforts of many researchers and projects to provide greater insight into the research problem. Given the widespread application of plyometric training, it is important to know that, on balance, the research supports the efficacy of plyometric training for the improvement of jumping performance.

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