

**Floría, P., & Harrison, A. J. (2013). The effect of arm action on the vertical jump performance in children and adult females. Journal of Applied Biomechanics, 29(6), 655–661. <https://doi.org/10.1123/jab.29.6.655>**

## **Abstract**

The aim of this study was to evaluate the effect of age on the use of arm swing in the vertical jump. Counter-movement jumps with arms and without arms performed by 36 girls aged between five to eight years and 20 adult females were examined using force platform analysis. The data were analyzed using Mann-Whitney and Wilcoxon signed-rank tests to determine differences between groups and between types of jump. The analysis of the data indicated that the arm action increased the jump performance in both groups, although the increase was relatively greater in children than adults. This difference in jump height was due to a combination of greater height at take-off in children compared to adults with no differences in the flight height. This increase in height of take-off was accompanied by an increase in the distance of propulsion. The results suggested that children take advantage of the action of the arms in vertical jump differently than adults. The children improved their performance by increasing height at take-off whereas the adults improved by increasing the flight height.

Keywords: age differences, force plate, child, development

## Introduction

In children, the vertical jump is one of the most common skills in sports and games. It is normally acquired during the fundamental movement phase of development which occurs at approximately four to seven years.<sup>1</sup> Numerous studies have shown progressive increases in jumping height from childhood to adolescence.<sup>2,3</sup> Most of these studies analyzed the jump with the arms in the akimbo position (i.e. hands on hips) and contrasted this with the jump using a vigorous arm action and found that the arms increased the height jumped compared to a jump without arm action.<sup>4-6</sup> The most likely causes of this increase are firstly, the increased height of center of mass at take-off ( $h_{TO}$ ) due to the raising of arms and secondly, a higher flight height ( $h_{flight}$ ) attributed to increased vertical velocity at take-off.<sup>4,5,7</sup> From the literature, several mechanisms have been proposed to explain how the vertical velocity can be increased by the action of the arms. Firstly, an opposite movement of the arms with respect to the legs may increase muscle force in the legs by allowing a slower muscle contraction and thus generate a higher amount of force.<sup>4,6,8</sup> Second, the arms may cause an increase in the transfer of energy generated by the swinging arms in the early phase of the movement to the rest of the body in the later phase.<sup>5</sup> Recent studies have shown that both proposed mechanisms may contribute to  $h_{flight}$ .<sup>7,9</sup>

In adults, it is estimated that the increased height of the jump due to the action of the arms is 10% or more.<sup>4,6,8</sup> Approximately 42% of this is attributed to a higher  $h_{TO}$  while the remainder is a result of increasing the  $h_{flight}$ .<sup>4,5,8</sup> From our knowledge, only one study (Gerondimos et al.<sup>10</sup>) has reported the contribution of the arms in vertical jump in children. The authors observed that the contribution of arm swing was about 16% in boys of 12 years old and this remained unchanged during the maturation process. Gerondimos et al.<sup>10</sup> calculated the contribution of arm swing by measuring

only differences in  $h_{\text{flight}}$ , therefore, the contribution of the arms to a higher  $h_{\text{TO}}$  in children is unknown. On the other hand, an increase in  $h_{\text{flight}}$  is related to the capacity of produce work,<sup>11</sup> so a jump with arm swing produces more work than another without it.<sup>5,12,13</sup> However, it is not known whether the increase will be accompanied by similar changes in the application of force and displacement in children than adults. This could be important since it has been observed that in children, the distance of propulsion has more influence on the height jumped compared with other parameters related to strength (i.e. force generation).<sup>14</sup>

In order to improve the understanding of motor development, it is important to know how the action of the arms affects the performance of the jump in children compared with adults with specific reference to differences between adults and children in the relative contributions of  $h_{\text{TO}}$  and  $h_{\text{flight}}$  to height jumped. Consequently, the aim of this study was to evaluate the effect of age on the use of arm swing in the vertical jump. Therefore, this study compared the  $h_{\text{TO}}$  and  $h_{\text{flight}}$  between girls and adult females as well as the parameters related to the distance and the application of force during the propulsive phase of the vertical jump. It was hypothesized that there would be differences in the way in which the children and adults take advantage of the action of the arms in vertical jump.

## Methods

The participants (N= 56) were divided into two groups: adults ( $n_1= 20$ ) and children ( $n_2= 36$ ). The adult group consisted of 20 females aged  $22.3 \pm 3.1$  years (mean  $\pm$  SD), with a mass of  $61.2 \pm 7.4$  kg and, a height of  $1.63 \pm 0.06$  m. The children's group consisted of 36 girls aged five to eight years old ( $6.8 \pm 1.3$  years-old), with a mass of  $23.1 \pm 5.3$  kg and, a height of  $1.19 \pm 0.09$  m. The children were chosen in this age range, since this approximates the fundamental movement phase where the development of a mature vertical jumping sequence is normally achieved.<sup>1</sup> The adults recruited were physically active and the girls trained in acrobatic gymnastics twice per week. No participants had any past history of nervous system or muscular dysfunction. The study obtained ethical approval from the University Research Ethics Committee. All adult participants and parents/guardians of children participants signed informed consent forms before participating in the study.

Participants were instructed to perform counter-movement jumps (CMJ) and counter-movement jumps with arms (CMJA) on a portable force platform (Quattro Jump®, Kistler Instrument AG, Winterthur, Switzerland). Before each test, the participants performed 10 minutes of warm-up activity which included a brief period of low-intensity aerobic exercise, some short duration static stretching exercises and, one set of five sub-maximal jumps. Since all participants were physically active and regularly performed activities including jumping, a short familiarization session of was sufficient to ensure the participants could complete the jumping tasks to a satisfactory level. Force data were sampled at 500 Hz and the duration of data collection was five seconds. The instructions for each participant were standardized. They included a detailed verbal explanation and a physical demonstration by the experimenter. The importance of jumping as high as possible was

emphasized. Before each jump, the participants stood upright and stationary for at least two seconds during which body weight was recorded. The participants then squatted to a self-selected depth and jumped immediately as high as possible without pausing. For the CMJ, participants retained the arms akimbo position until the landing phase. For CMJA, participants were allowed to swing their arms backward, and then forward and upwards. Three successful jumps were recorded for each participant and for each type of jump, with at least two minutes of rest between jumps. The average of the three successful trials for each type of jump was used for analysis.<sup>15</sup>

The vertical component of center of mass (CoM) velocity was estimated using the impulse method.<sup>16</sup> Net impulse was obtained by integrating the net vertical ground reaction force, from two seconds prior to the first movement of the participant,<sup>17</sup> using the trapezoid method.<sup>18</sup> Subsequently, vertical CoM velocity was calculated by dividing the net impulse by the participant's body mass. Vertical CoM displacement was derived by numerically integrating the vertical CoM velocity. Finally, the total body work throughout the motion was calculated by integrating the force with respect to displacement.

Several performance parameters were determined during the jumps. The parameters were calculated in both the downward and upward phases which were defined as follows: downward phase from the start of the movement to instant of zero velocity of the CoM; the upward phase, from instant of zero velocity of the CoM to take-off. The start of the movement was identified on the recommendations of Street et al.<sup>17</sup> by inspecting the force-time records to identify the first instant where the vertical ground reaction force deviated above or below body weight (BW) by more than one threshold. The threshold was defined as 1.75 times the peak residual found in the two seconds of the BW averaging period. A backward search was then performed until vertical

ground reaction force passed through BW. The instant of take-off was defined as the first intersection of vertical ground reaction force with an offset threshold where, the threshold was determined by adding the average flight time (i.e., 0.4 seconds) and the peak residual to the offset.<sup>17</sup> Maximal height ( $h_{\max}$ ),  $h_{\text{flight}}$  and,  $h_{\text{TO}}$  were identified from the displacement records. Downward and upward displacements were calculated from their respective phases. Initial force ( $F_{\text{initial}}$ ) was identified at the start upward phase. Peak force ( $F_{\max}$ ) was measured as the maximum force reached during the upward phase. Average propulsive force ( $F_{\text{ave}}$ ) was calculated during the upward phase. The force variables were normalized to BW while the CoM displacement variables were normalized to body height (BH).

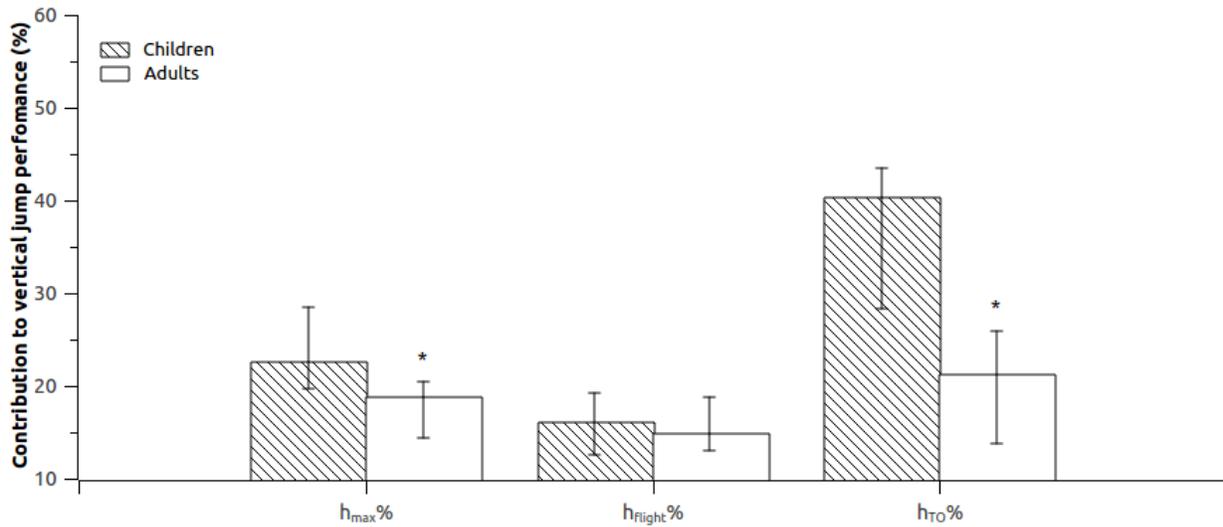
Statistical analyses were conducted using SPSS version 18.0. Tests of normality revealed several violations of this assumption therefore non-parametric statistics were used. Medians and 95% confidence limits of each participant group were computed for all the measured variables. The Mann-Whitney test was used to evaluate the differences between adults and children. The Wilcoxon signed-rank test was used to gauge differences within the children or adults groups between CMJ – CMJA. Significance level was set at  $P < 0.05$ . Statistical analysis was completed by the estimation of the effect size using Cohen's to evaluate the magnitude of differences. The criteria to interpret the effect size were trivial = 0.00 – 0.19, small = 0.20 – 0.59, moderate = 0.60 – 1.20, and, large  $> 1.20$ .<sup>19</sup>

## Results

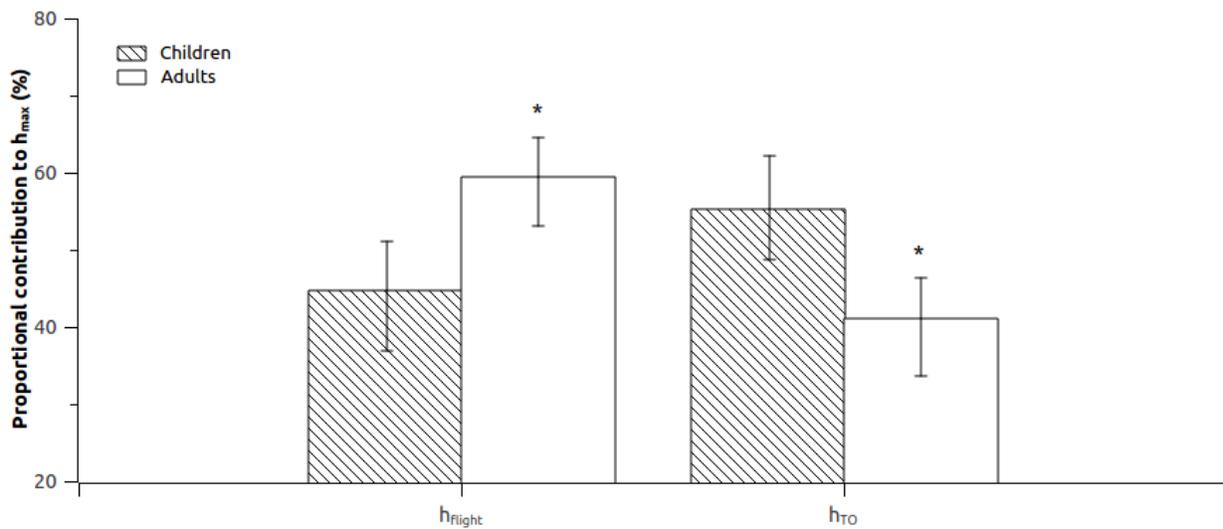
The arm action had a significant effect on jump performance in both groups, although the effect was relatively greater in children than adults (Figure 1). In children, the rate of increase in  $h_{\max}$  was 22.6% (95% confidence interval, 19.6% to 28.5%), while in adults was 18.7% (95% confidence interval, 14.4% to 20.5%). The  $h_{\max}$  was determined by summation of  $h_{\text{flight}}$  and  $h_{\text{TO}}$ . Both parameters were higher in the CMJ than CMJA in children and adults, although there were differences between the two groups in the contributions of  $h_{\text{flight}}$  and  $h_{\text{TO}}$  to the jump performance. In children,  $h_{\text{TO}}$  was higher in the CMJA compared to CMJ, the increase was 40.3% (95% confidence interval, 28.3% to 43.5%), while in adults the rate of increase was significantly lower 21.2% (95% confidence interval, 13.8% to 25.9%). In contrast, the increase in the  $h_{\text{flight}}$  produced by the arm action was similar in both groups. In children the major contribution to  $h_{\max}$  was  $h_{\text{TO}}$  (55.2%, 95% confidence interval, 48.7% to 62.2%) whereas in adults the major contribution was  $h_{\text{flight}}$  (58.9%, 95% confidence interval, 52.4% to 63.2%) (Figure 2).

Additionally,  $h_{\max}$ ,  $h_{\text{flight}}$  and, work were higher in adults compared with children in both types of jump and also when the CMJ was compared with the CMJA (Table 1).  $h_{\text{TO}}$  was higher in CMJA compared with CMJ in both groups but when children were compared with adults, there was differences in the CMJA nevertheless there was no differences in the CMJ. There were no significant differences between adults and children for the remaining parameters related to application of force and displacement in none of the two types of jumps. Similarly, no differences were found with respect to these variables when CMJA was compared with CMJ in adults. In children, the upward displacement was significantly higher in CMJA than in CMJ whereas there was no significant difference in the rest of parameters related to application of force and

displacement.



**Figure 1** – Medians  $\pm$  95% confidence interval for relative (%) contribution of arm swings to vertical jump performance in children and adults. \* denotes significant difference children and adult groups ( $P < 0.05$ ).  $h_{flight}$ : flight height;  $h_{max}$ : maximum height;  $h_{TO}$ : height at take-off.



**Figure 2** – Medians  $\pm$  95% confidence interval for relative (%) contribution of arm swings to vertical jump performance in children and adults. \* denotes significant difference children and adult groups ( $P < 0.05$ ).  $h_{flight}$ : flight height;  $h_{TO}$ : height at take-off

A large effect size was calculated for children and adults in  $h_{\max}$ ,  $h_{\text{flight}}$ ,  $h_{\text{TO}}$  and, work as well as moderate differences in upward displacement in children when the CMJ was compared with the CMJA (Table 1). Similar results were reported when calculating the effect sizes between groups. The value of Cohen's  $d$  was higher for work and moderate for  $h_{\max}$  and  $h_{\text{flight}}$  when comparing adults with children in CMJ and CMJA.

## Tables

**Table 1** Medians and 95% confidence limits of the variables studied in the counter-movement jump (CMJ) and counter-movement jump with arms (CMJA).

	Children			Adult			ES for group	
	CMJ	CMJA	ES for jump	CMJ	CMJA	ES for jump	CMJ	CMJA
$h_{\max}$ (BH)	0.19 (0.18-0.21)	0.25 (0.23-0.26) <sup>a</sup>	2.1	0.22 (0.20-0.24) <sup>b</sup>	0.26 (0.25-0.27) <sup>a,c</sup>	2.5	-1.1	-0.7
$h_{\text{flight}}$ (BH)	0.12 (0.11-0.13)	0.15 (0.13-0.15) <sup>a</sup>	1.4	0.15 (0.13-0.16) <sup>b</sup>	0.17 (0.15-0.18) <sup>a,c</sup>	1.8	-1.1	-1.0
$h_{\text{TO}}$ (BH)	0.07 (0.07-0.08)	0.10 (0.09-0.11) <sup>a</sup>	2.0	0.08 (0.07-0.08)	0.09 (0.09-0.10) <sup>a,c</sup>	2.7	-0.5	0.5
W (J·kg <sup>-1</sup> )	1.52 (1.37-1.70)	1.86 (1.62-1.95) <sup>a</sup>	1.5	2.50 (2.25-2.82) <sup>b</sup>	2.96 (2.60-3.17) <sup>a,c</sup>	1.7	-2.5	-2.7
$L_{\text{up}}$ (BH)	0.23 (0.21-0.24)	0.25 (0.24-0.26) <sup>a</sup>	0.7	0.25 (0.23-0.26)	0.25(0.23-0.27)	0.3	-0.3	0.0
$L_{\text{down}}$ (BH)	0.16 (0.13-0.17)	0.15 (0.13-0.17)	-0.2	0.17 (0.16-0.19)	0.16 (0.14-0.18)	-0.4	-0.2	-0.1
$F_{\text{ave}}$ (BW)	1.92 (1.88-2.10)	1.97 (1.89-2.04)	0.1	1.89 (1.82-2.01)	1.96 (1.81-2.03)	0.1	0.2	0.2
$F_{\text{initial}}$ (BW)	2.07 (1.77-2.22)	1.92 (1.75-2.10)	-0.1	2.12 (1.91-2.17)	1.92 (1.86-1.99)	-0.5	-0.1	0.2
$F_{\text{max}}$ (BW)	2.21 (2.15-2.35)	2.30 (2.19-2.36)	0.1	2.15 (2.09-2.26)	2.23 (2.12-2.31)	0.3	0.3	0.2

*Note.* ES: effect size;  $F_{\text{ave}}$ : average propulsive force during upward phase;  $F_{\text{initial}}$ : force at initial of upward phase;  $F_{\text{max}}$ : maximum force;  $h_{\text{flight}}$ : flight height;  $h_{\text{max}}$ : maximum height;  $h_{\text{TO}}$ : height at take-off;  $L_{\text{up}}$ : upward displacement;  $L_{\text{down}}$ : downward displacement; W: work.

<sup>a</sup> Differences between type of jump  $P < 0.05$

<sup>b</sup> Differences between group within CMJ  $P < 0.05$

<sup>c</sup> Differences between group within CMJA  $P < 0.05$

## Discussion

This study was performed to examine how children use the arm swing to increase vertical jump performance in comparison to adults. The results showed that both children and adults improved vertical jump performance due to the action of the arms, although adults were able to reach higher heights in both types of jumps. However, the effect size for the influence of the age on performance was relatively greater in the CMJ ( $d = 1.1$ ) than the CMJA ( $d = 0.7$ ). In children's activities, jumps with arm action are probably more common than without arm swing, so this suggests greater levels of practice in CMJA in children. A non-optimal coordination due to less practice in CMJ could explain the greater difference between children and adults in this type of jump. Although both groups increased  $h_{\max}$ , the improvement in children was relatively greater compared with adults: 23% and 19%, respectively. These results are in general agreement with previous studies on adults, which reported increases in  $h_{\max}$  of approximately 17%.<sup>4,5,8</sup> Although the difference found between groups contrasts with Gerodimos et al.,<sup>10</sup> who concluded that the contribution of arms remains relatively unchanged throughout the maturation process. The reason for the contrasting results, however, appears to be more related to methodological differences rather than conflicting results. In this investigation, the vertical jump performance was assessed by  $h_{\max}$ , while Gerodimos et al.<sup>10</sup> used only  $h_{\text{flight}}$ . The  $h_{\text{flight}}$  increases of 15% in children and 16% in adults in this study are similar to the 20% increases reported by previous studies.<sup>4,5,10</sup> Consequently, it appears that both children and adults utilized the arm action equally well to enhance their  $h_{\text{flight}}$  in the vertical jump. The results also support the efficacy of the two most common strategies to increase the  $h_{\text{flight}}$  in the vertical jump in childhood (i.e. that arm action and counter-movement remains unchanged during development<sup>10,20</sup>). This suggests that while the contribution of the arm action to  $h_{\max}$  changed from

childhood to adulthood, it was not accompanied by changes in the  $h_{\text{flight}}$ ; therefore, the differences might be explained analyzing the  $h_{\text{TO}}$ .

The results of this study showed that both children and adults were able to elevate their CoM position at take-off higher with the use of arms than without them in both types jumps. Although the relative increase between CMJ and CMJA was greater in children (41%) than in adults (22%) but this relative increase in adults is in approximate agreement with the 18% reported by previous studies on adult populations.<sup>4,5,8</sup> This relative difference between children and adults in  $h_{\text{TO}}$  could explain the overall difference found in the contribution of the arms to increase the  $h_{\text{max}}$ .

This suggests that there are differences in the mechanisms that children and adults use to increase the jump height with arm action. Careful scrutiny of the data shows that the main factor influencing  $h_{\text{max}}$  in children was the  $h_{\text{TO}}$  while in adults the major influence was  $h_{\text{flight}}$ . A higher  $h_{\text{TO}}$  can improve vertical jump performance in two ways. Firstly, starting from a high initial position could enable to achieve better performance in a vertical jump. Previous studies have also shown that master of a higher position at take-off could enhance the performance in the high jump in athletics.<sup>21</sup> Secondly, increasing the distance over which force is applied and this will lead to increases in the work and performance. Previous studies have showed that performance may improve by increasing the distance over which force is generated.<sup>11,22,23</sup> In this study, the childhood increases in work between CMJA to CMJ were accompanied by significant increases in the upward displacement of the CoM whereas the rest of variables related to the application of force and displacement remained unchanged. Since there was no difference in the downward displacement of the CoM, the increase in the range of motion could be due to a higher  $h_{\text{TO}}$  in CMJA with respect to CMJ. Therefore, during childhood an optimal arm action could raise the take-off position,

extend the range of motion and thereby enhance the performance in vertical jump. Previous studies have indicated the importance of increasing the range of motion in the vertical jump of children to improve their performance.<sup>14,24</sup> Wang et al.<sup>24</sup> observed that the greatest jump height of adults compared with children could be due to a greater range of motion. Similarly, Floria and Harrison<sup>14</sup> found that the parameters related to the range of movement had more influence on the jumped height than those related to the application of force.

In contrast, in adults there was no difference between CMJ and CMJA in variables related to the application of force and displacement, despite the increased work. The results of this study contrast with the theory joint torque augmentation, which suggests that the arm action facilitates a slower muscle contraction and thus generates a higher amount of force.<sup>4,6,8</sup> Feltner et al.<sup>4,8</sup> observed that the arm action caused an increase in force in the final section of the upward movement although in the initial force values were smaller compared with a jump without arms action. In the present study,  $F_{\text{initial}}$  and  $F_{\text{max}}$  variables were more related to the application of force in the first part of the upward phase thus no differences could be expected. Instead, the performance of  $F_{\text{ave}}$  in a jump with arm action remains inconsistent within the literature. Feltner et al.<sup>8</sup> found that the  $F_{\text{ave}}$  was significantly higher in arm assisted jump relative to the jump without arm swing; whereas other studies<sup>4,6</sup> have shown that the  $F_{\text{ave}}$  achieved during the propulsive phase, remains unchanged between the two types of jumps. The cause of this discrepancy could be related to differences in the skill level of participants of the above studies. A high skill level improves the ability to coordinate joint movements, change joint torque patterns, and alter the generation of vertical ground reaction forces.<sup>4</sup> Further studies are needed to improve the understanding of the relationship between the increase in work and parameters related to the application of force and

displacement in the vertical jump.

This study has demonstrated that children take advantage of the action of the arms in vertical jump in a different way compared to adults. Both children and adults improve the vertical jump performance with the arm action increasing both the  $h_{\text{flight}}$  and  $h_{\text{TO}}$ . However, in children this is mainly because of an increased  $h_{\text{TO}}$ , while in adults the improved performance was due to the increase in the  $h_{\text{flight}}$ . Moreover, the action of arms not only allows children to take-off from a more advantageous position for the vertical jump but enlarges the distance over which the force is applied.

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