The Contribution of Stretch-Shortening Cycle and Arm-Swing to Vertical Jumping Performance in Children, Adolescents, and Adult Basketball Players

Vassilis Gerodimos, Andreas Zafeiridis, Stefanos Perkos, Konstantina Dipla, Vassiliki Manou, and Spiros Kellis

This study examined from childhood to adulthood: (1) the effects of countermovement (use of stretch-shortening cycle-SSC) and arm-swing (AS) on vertical jumping (VJ) performance and (2) the ability to use the SSC and AS during VJ. Male basketball players (n = 106) were divided according to their age into: children (12.0 ± 0.23), young adolescents (14.5 ± 0.41), old adolescents (16.9 ± 0.27), and adults (21.9 ± 0.32). Each participant executed three maximal squat jumps (SJ), countermovement jumps without arms (CMJ) and with arms (CMJA). The contribution of SSC and AS was calculated by the augmentation (difference and percent change) in performance between CMJ and SJ, and CMJA and CMJ, respectively. CMJA performance was significantly (p < .05) higher than CMJ and SJ, and CMJ was higher than SJ within all age-groups. There were no significant differences (p > .05) among children, young and old adolescents, and adults in the percent contribution of SSC and AS to VJ performance. The variability in the contribution of SSC and AS to VJ performance was about twofold higher in children vs. adults. It appears that the ability to use the SSC and AS is not affected by the maturation process in males, trained in basketball.

Vertical jumping (VJ) ability is an important element for a successful performance in several sports and leisure activities. The use of a downward movement before the push-off phase (countermovement jump-CMJ) increases VJ performance (4,6,12,20,25) by utilizing the stretch-shortening cycle (SSC) mechanism. The time available for force development, the potentiation of the contractile machinery, the contribution of stretch-reflexes, as well as, the storage and reutilization of elastic energy have been proposed to contribute to the enhancement of VJ using countermovement (utilization of SSC; 1,3,4,16,19,20,21). The use of arm-swing (AS) may also improve VJ performance (9,11,12,28,31) due to mechanical, neural, or physiological factors. More specifically, the potentiating effect of AS to VJ performance is a result of changes in the level of muscular

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activation, the work-torque production and the recruitment patterns of the lower extremities muscles (9,11).

During developmental years the skeletal muscle undergoes structural, neural, and metabolic changes (2). These changes may alter the following: the excitability, the neuromuscular activation and the contractile properties of the muscles (2,33), the musculotendinous stiffness (10,23,27,30,41), the capacity to store and use elastic energy and the stretch reflex potentiation (32), as well as, movement coordination (36) and control (17). Furthermore, changes in the VJ technique from childhood to adulthood may result in increased active state of SSC and influence VJ performance (41). Thus, based on the association of the above parameters with the ability to effectively use countermovement (SSC) and AS it is possible that the relative contributions of SSC and AS to VJ performance may change from childhood to adulthood.

Indeed, Paasuke et al. (33) reported an inability of prepubertal and postpubertal boys to use the positive effect of SSC to VJ, while numerous studies in adults have reported potentiating effects of SSC to VJ performance. Two studies that directly compared the contribution of SSC to VJ performance between children and adults reported either age-related differences (6) or no effect of age (14). However, the first study (6) based its conclusions on descriptive statistics and the children’s group was composed of 13–17 year-olds, and the second study (14) compared the contribution of SSC to VJ performance between 6.0 year-olds and adults. Thus, in addition to the equivocal results on the effect of age on the contribution of SSC to VJ performance, the information on the evolution and the ability to use SSC during VJ from childhood to adulthood are lacking. Furthermore, to our knowledge, studies that examined the contribution of AS on VJ performance have used adult subjects despite that the mechanical and muscular coordination of lower and upper extremities may influence VJ performance and coordinated movements are linked to growth and maturation of the musculoskeletal system (36). Since the SSC is an important component of muscle function and the investigation of the contribution of the SSC and/or AS to jumping performance is an important issue, it is essential to study how the ability to use SSC and AS develops from childhood to adulthood. This study will also extend the existing knowledge on the effect of age on the performance of various types of jumps.

Therefore, the primary aims of this study were to examine in children, young adolescents, old adolescents and adults trained in basketball: (1) the effects of countermovement (use of SSC) and AS on VJ performance, and (2) the contribution of SSC (ability to use a SSC) and AS (effectiveness of arm-swing) to VJ performance. Furthermore, we evaluated the variability in the contribution of SSC and AS to VJ performance during developmental years and in adults.

**Methods**

**Participants**

One hundred and six male basketball players (11- to 25-year-old), who trained three to four times per week, volunteered to participate in this study. Following a completion of a medical history form, the participants were divided according to
their chronological age into four groups: children, young adolescents, old adolescents, and adults. All participants were healthy and had no injury of lower limbs. Before the study, the institutional Ethics Committee approved the experimental protocol, and the parents of young athletes signed the written informed consent form. The physical characteristics of the subjects are presented in Table 1.

**Study Design**

Each subject completed the testing over two days. On the first day the subject performed a familiarization session of the three types of VJ: squat jump (SJ), countermovement jump without arms (CMJ) and countermovement jump with arms (CMJA). On the second day, the subjects performed three maximal trials of each type of jump in a random order. The best performance in each type of jump was used for the evaluation of jumping performance for each type of jump, and for the contributions of SSC and AS to VJ performance.

**Procedure–Instrumentation**

On the first day, each participant was instructed in how to perform the different types of jumps. More specifically, for the execution of SJ the participant was asked to assume a semisquatting position with a knee joint flexed at 90° to best stabilize the joint during the phase of contact with the ground (7). For the CMJ the participant was allowed a downward movement by rapidly bending and extending his knees to jump as high as possible. During the SJ and CMJ the participant maintained his trunk in an upright posture and his hands on hips to eliminate the influence of AS. For the CMJA the participant was allowed to swing their arms backward (during the downward movement), and then forward and upwards (during the push-off phase). Bosco ergojump system was used for the assessment of SJ, CMJ and CMJA performances (Ergojump, Psion© CM, MAGICA, Rome, Italy). The system estimates the elevation of the body mass center based on the flight time and calculates the height (cm) of the jump.

On the second day, height, body mass, and pubertal stage were determined before the testing session. The pubertal stage was determined according to pubic hair development (38). Next, the participant performed a standardized warm-up that included two to three preliminary trials for each type of jump to ensure that the jumps were performed with the proper technique and to get acquainted with the recording procedure and instruments. Finally, the participants executed three

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*p < .05 vs. all other groups; # p < .05 vs. old adolescents and adults; † p < .05 vs. adults
maximum trials of SJ, CMJ and CMJA in a random order. The heights of all jumps were recorded and the best performance for each jump was used for analysis of CMJ, CMJA, and SJ performance, and contributions of SSC and AS.

The contribution of the SSC to jumping performance was calculated by both the differences (delta scores) in performance between CMJ and SJ, and the percent change in CMJ relative to SJ using the equation \((\text{CMJ}-\text{SJ}) \div \text{SJ} \times 100\). The use of the ratio and difference in performance between CMJ and SJ as an index of contribution of the SSC to VJ performance was based on the following facts collectively: (1) a single maximal CMJ is a typical natural exercise (performed in many sports) that incorporates a maximal SSC action of lower limbs; (2) the purpose of SSC (eccentric action followed by concentric action) is to enhance the performance of the concentric phase of the SSC exercise (CMJ) when compared with isolated concentric action (SJ). Thus, the CMJ/SJ ratio (or difference) that represents the enhancement of performance from SJ (purely concentric) to CMJ (eccentric followed by concentric action) may well reflect the contribution of SSC; and (3) numerous previous studies have investigated the potentiating effect (contribution, performance, effectiveness) of a SSC by the augmentation in jump height from SJ to CMJ (or torque produced during eccentric + concentric action relative to only concentric action) using either the difference in cm (5, 6, 33, 34, 37) or the ratios/percent change (14, 15, 22, 24–26, 40, 42) between the two jumps. Similarly, the contribution of AS to CMJ was evaluated by the difference of CMJA and CMJ, and the percent change in jumping performance between CMJA and CMJ by the equation \((\text{CMJA}-\text{CMJ}) \div \text{CMJ} \times 100\).

**Data Analysis**

All data are presented as means ± SD and were analyzed using SPSS 13.0 (Illinois, USA). A two-way ANOVA (age × jump) with repeated measures on “jump” was used to analyze the performances of SJ, CMJ, and CMJA. An one-way ANOVA for independent groups was used to examine the effect of age on anthropometrical characteristics and the contributions of SSC and AS. ANOVAs were followed by Schéffe comparisons. The level of significance was set at \(p < .05\). The variability in the contributions of SSC and AS to VJ performance within age-groups was assessed by the coefficient of variation: \(CV(\%) = (SD \div \text{mean}) \times 100\).

**Results**

**Age and Jumping Performance**

The ANOVA indicated a significant age × jump interaction \((p < .001; \text{Figure 1})\). Posthoc comparisons within each age-group revealed that CMJA performance was significantly higher vs. both CMJ and SJ \((p < .05)\), and CMJ higher vs. SJ \((p < .05)\) in all age-groups. Pairwise comparisons within each type of jump showed that SJ, CMJ, and CMJA performances increased with age \((p < .05)\), with the exceptions of old adolescents vs. adults that did not differ in all types jumps \((p > .05)\).
Use of Stretch-Shortening Cycle and Arm-Swing During Jumping in Children

Contributions of SSC and AS

When the percent change between jumps performances was used to evaluate the contribution of SSC or AS to VJ performance (Figure 2a), there was no significant age effect ($p > .05$). More specifically, the contributions of SSC were $9.6 \pm 8.6\%$, $10.3 \pm 6.8\%$, $10.1 \pm 5.7\%$, and $9.1 \pm 4.3\%$ for children, young adolescents, old adolescents, and adults, respectively. The respective values for AS were $16.1 \pm 12.4\%$, $20.9 \pm 8.8\%$, $19.1 \pm 6.0\%$, and $18.2 \pm 6.7\%$.

However, when delta scores between jumps were used to evaluate the contributions of SSC or AS (Figure 2b), the Schéffe comparisons revealed no significant differences ($p > .05$) among children, young and old adolescents, and adults ($2.2 \pm 1.8$, $3.0 \pm 1.7$, $3.5 \pm 2.1$, and $3.3 \pm 1.4$cm, respectively), and significantly ($p < .05$) lower contribution of AS to CMJA performance in children ($4.1 \pm 3.0$cm) vs. young ($6.8 \pm 2.7$cm) and old ($7.4 \pm 2.3$cm) adolescents, and adults ($7.2 \pm 2.6$cm).

Variability in Jumping Performance and Contribution of SSC and AS

The coefficients of variation for the contribution of SSC and AS to VJ performance (Figure 3a) were 91–146% higher in children compared with adults. The variability in the contribution of SSC to CMJ performance gradually decreased from childhood to adulthood (90%, 66%, 57%, and 47%). Relatively similar reduction from childhood to adulthood was observed for the variability in the contribution of AS to CMJA performance (77%, 42%, 32% and 37% for children, young adolescents, old adolescents and adults, respectively). Figure 3b depicts the individual values for the contribution of SSC and AS to VJ performance (%) for all age-groups.
The main findings of this study are that the relative contributions (% augmentation) of SSC and AS to VJ performance did not change from childhood to adolescence and to adulthood in males, trained in basketball. The results of this study are in agreement with those of Harrison and Gaffney (14) who reported no difference in the ability to use SSC between 6 year-olds and young adults. However, when the contribution of AS was calculated in absolute values (delta scores between jumps), children used the AS less effectively compared with young and old adolescents, and adults. This raises the question whether the contribution of SSC or AS to VJ performance should be evaluated using percent change or delta scores when comparing groups with different jumping abilities.

### Discussion

The main findings of this study are that the relative contributions (% augmentation) of SSC and AS to VJ performance did not change from childhood to adolescence and to adulthood in males, trained in basketball. The results of this study are in agreement with those of Harrison and Gaffney (14) who reported no difference in the ability to use SSC between 6 year-olds and young adults. However, when the contribution of AS was calculated in absolute values (delta scores between jumps), children used the AS less effectively compared with young and old adolescents, and adults. This raises the question whether the contribution of SSC or AS to VJ performance should be evaluated using percent change or delta scores when comparing groups with different jumping abilities.

### Stretch-Shortening Cycle During VJ and Age

In this study, the height of CMJ was greater compared with that of SJ across all age-groups. This is in accordance with previous studies in children (6,14), and in
young and old adults. However, Paasuke et al. (33,34) reported a significant increase in VJ performance using a countermovement only in young individuals and failed to demonstrate significant differences between CMJ and SJ performances in prepubertal, postpubertal, middle-aged and elderly individuals.

The improvement in VJ performance using a countermovement has been attributed to the utilization of SSC. The potentiating effects of SSC have been also reported for isokinetic movement in young and old males and females when the concentric action was preceded by an eccentric action (37). Only two studies compared directly the extent of a potentiating effect of SSC to VJ performance in children vs. adults (6,14). Bosco and Komi (6) concluded that the ability to use the SSC (CMJ-SJ) is affected by the maturation and aging process; while Harrison and Gaffney (14) using the percent change (SJ to CMJ) reported that children (6-year-old) and adults (23 years-old) use the SSC equally well. In our study, both the absolute (delta scores) and the relative (% change) contributions of SSC to VJ performance were analyzed using a countermovement.
performance were almost similar among children, young and old adolescents and adults. It appears that the different conclusion between the present and Harrison and Gaffney (14; % change) studies vs. Bosco and Komi (6; delta score) is due to the method of calculating the effect of SSC and to the statistical approach (descriptive) used by Bosco and Komi (6). This is evident by the relatively similar prior-stretch augmentation in VJ performance reported for children, adolescents and adults males in the three studies. In fact, if in Bosco and Komi (6) study the contribution of SSC is calculated by % change, then children appear as capable as adults to use the SSC (20% and 15%, respectively; 14).

The storage of elastic energy during the downward movement and its subsequent reutilization during the push-off phase has been the leading explanation for the potentiating effects of SSC to VJ performance (6). However, there is a view that the enhancement in maximal CMJ performance over that in SJ (when the SSC does not occur repeatedly) is not the result of storage and reutilization of elastic energy (4,16). Alternative explanations for the enhancement of maximal VJ by a countermovement include the time available for force development, the potentiation of the contractile machinery, and the contribution of stretch-reflexes (3,4,16,20,21). The first factor is considered to play the major role in potentiating effect of SSC to VJ performance (3,4), while the other mechanisms play a secondary role (16). Neuromuscular activation, musclotendonous/leg stiffness, and stretch-reflex potentiation continues to develop from childhood to adulthood (2,10,23,27,30,32,41) and may affect the utilization of SSC. Studies that examined the relationship between musclotendonious/leg stiffness and the potentiating effect of SSC report either inverse correlation (22,24,25,40,42) or no correlation (5,26). Despite the above, this study failed to document a significant effect of age on the contribution of SSC to VJ performance. In fact, the percent augmentation in performance after SSC was identical between children (9.6%) and adults (9.1%). It is difficult to speculate the reasons that explain these findings.

Arm-Swing During VJ and Age

In this study, the use of AS improved the CMJ performance in all age groups by 4–7cm (16–20%). This is in agreement with previous studies in adults, which reported that arm motion increased CMJ height or take-off velocity by 4–10cm or 5–20% (9,12,18,28,31,35,39). Possible explanations (not independent among each other) to explain the enhancement of VJ performance after AS include: increased ground reaction force (12,31,35), increased height and velocity of the center of mass at takeoff (8,9,12,29,31,35), and augmented transfer of energy from the arms that is used to increase the work-torque by hip, ankle, and-or knee joints (8,9,11) and to pull on the rest of the body (28,29).

The superiority of older athletes in VJ performance may be due to the combination of leg power and AS coordination. This is supported by observations that strength of lower limbs and intersegment coordination (to lesser extent) may influence VJ performance (39) and coordinated movements are linked to growth of the musculoskeletal system (36). To our knowledge this is the first study to investigate the effects of age and maturity on the contribution of AS to VJ performance. In this study, the absolute magnitude of an increase in CMJ after using AS was significantly lower in children vs. young and old adolescents, and adults. However, when the contribution of AS was adjusted to jumping performance the relative benefits of AS
on CMJ were not different among all age-groups. The above may be in line with evidence that the benefit of an AS increases as jump height increases and is related to maximum kinetic energy of the arms during downswing (29), since adults had higher jumping performances versus children and were likely to generate more energy and work during the downswing. There is also evidence that the angular velocity of arms has a positive correlation with the velocity at take-off and that AS can increase the ground reaction force and improve the SSC of leg muscles (18).

**Age and Variability in Utilization of SSC and AS**

The results of this study demonstrated a twofold higher variability in the contribution of SSC and AS to VJ performance in children versus adults. These results are in line with Harrison and Gaffney (14) who have reported that the variability in the augmentation of take-off velocities after utilizing a SSC (CMJ ÷ SJ) is higher in 6-year-old boys (172%) vs. men (50%). Examining the results Harrison and Gaffney (14) and this study, it is interesting to document the trend and the magnitude of reduction in the variability in the contribution of SSC to VJ performance across age: 172% in 6-year-olds (14) and 90% in 12-year-olds, 66% in 14.5-year-olds, 57% in 16.9-year-olds, and 47% in 22-year-olds (this study). The gradual reduction of variability in the contribution of SSC and AS to VJ performance from childhood to adulthood in previous (14) and this study is in accordance with findings that a process of motor development is characterized by reductions in the variability of VJ kinematics with respect to developmental age (13) and provide further support to the notion that the acquaintance of specialized movement skill is dependent on age, experience, and practice.

**Conclusions**

In summary, the utilization of SSC (countermovement) or AS significantly increase VJ performance in children, young and old adolescents, and adults, trained in basketball. Moreover, it appears that the percent contribution of both SSC and AS to augment VJ performance remains relatively unchanged throughout the developmental years (12–17 year-olds) and is similar to that in young adults. Thus, the ability to use the SSC or AS is not affected by the maturation process in males, trained in basketball. However, it should be noted that the results of the current study are limited to male basketball players, since movement skill may be affected by practice and experience and the subjects of this study were basketball players accustomed to both CMJ and SJ.

**References**


