The Characteristics of Jump Ability in Elite Adolescent Athletes and Healthy Males: The Development of Countermovement and Rebound Jump Ability

Kenji Tauchi*, Toshinori Endo**, Mitsugi Ogata***, Akifumi Matsuo**** and Shigeo Iso*

*Faculty of Sports Sciences, Waseda University
2-579-15 Mikajima, Tokorozawa, Saitama 359-1192 Japan
tauchi@aoni.waseda.jp
**Ibaraki Prefectural University of Health and Sciences
4669-2 Ami, Ami-machi, Inashiki-gun, Ibaraki 300-0394 Japan
***Graduate School of Comprehensive Human Sciences, University of Tsukuba
1-1-1 Tennoudai, Tsukuba, Ibaraki 305-8574 Japan
****Department of Sports Sciences, Japan Institute of Sports Sciences
3-15-1 Nishigaoka, Kita-ku, Tokyo 115-0056 Japan

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The purpose of this study was to clarify the characteristics of jump ability in elite adolescent male athletes for the purpose of comparing them to healthy coeval males by referring to the results reported by Endo, et al., (2007). One hundred and twenty elite male athletes (alpine skiers, fencers, soccer players, track and field sprinters and jumpers, and weight lifters) aged 18 to 24 yrs and 316 healthy males aged 19 and 20 yrs performed countermovement jumps (CMJ) and five-repeated rebound jumps (5RJ) on a mat switch system. CMJ and 5RJ abilities were evaluated by jump height and RJ-index (= jump height/ground contact time), respectively. Although the jump height in CMJ and the RJ-index in 5RJ developed from ages 6 to 18 yrs, these values reached a plateau between the ages of 18 and 20 yrs in healthy males, elite athletes further developed after age 18. When the values for the healthy males in the present study were added to the results obtained for 1137 boys by Endo, et al., (2007), the regression line and correlation coefficient between jump height in CMJ and the RJ-index in 5RJ changed only slightly. However, the values for elite adolescent athletes tended to appear in the upper right from the population ages of 6 to 20 yrs; moreover, the scattering exhibited wide variation. The results revealed that although jump ability in healthy adolescent males changed little after age 18, jump ability in elite coeval athletes were superior after age 18 and that individual differences increased according to the length of specific training in each sport.

Keywords: Development, Countermovement jump, Rebound jump, Variation

1. Introduction

Jump ability is a fundamental component of physical fitness in humans, from children to adults. Previous studies have often used the vertical jump from an erect standing position with a preliminary countermovement (CMJ) or standing broad jump (SBJ) to evaluate jump ability in terms of cross-sectional or longitudinal physical fitness levels (Hansen, et al., 1999; Castagna, et al., 2005; Gabbett, 2005; Malina, et al., 2007). In contrast, it is rare to use a more ballistic jump such as hopping, drop jump (DJ), or rebound jump (RJ) (Bosco and Komi, 1980), except in experimental movements to research the mechanism of human movement. One jump movement study reported that hip extensors functioned mainly in jump movements such as CMJ or SBJ, while ankle planter flexors worked primarily in ballistic jump movements such as hopping or RJ (Fukashiro and Komi, 1987). It has also been reported that between the former and latter there was a different neural control mechanism operating, because the former jump had a takeoff time of over 0.5 s, and the latter under 0.2 s (Zushi, et al., 1993). Therefore, it may not necessarily be the case that jump ability in CMJ (CMJ ability) and RJ (RJ ability)
are the same.

Recently, in a cross-sectional study, our research group reported that the development of CMJ and RJ abilities occurs in individuals in the growth stage, from ages 6 to 18 yrs (Endo, et al., 2007). The main results that we obtained were that although both CMJ and RJ abilities developed with growth, there were subjects that exhibited higher or lower RJ ability even though they demonstrated the same CMJ ability; thus, the development of the two kinds of jump abilities did not always correspond. Moreover, we found that these individual differences (higher or lower RJ ability relative to CMJ ability) increased at a later growth spurt.

It is well known that jump ability improves with training. According to an examination of the jump power of various collegiate athletes by Zushi, et al., (1993), those with a higher RJ ability relative to their CMJ ability are jumpers and sprinters in track and field, and gymnasts; on the other hand, athletes with a lower RJ ability relative to their CMJ ability are skaters and ski jumpers. Therefore, the results we reported, which evaluated jump ability by CMJ and RJ, will be relevant to scouting talent in various sports events. However, it is not sufficient to clarify jump ability in elite athletes (Top National Level) from the viewpoint of growth and development. To understand this problem, it is important that jump ability can be used to set the standard values to judge the aptitude and target values for children to develop their capacity for exercise during the growth stage.

The purpose of this study is to clarify the characteristics of jump ability in elite adolescent male athletes in comparison with healthy coeval males by referring to the results reported by Endo, et al., (2007).

### 2. Methods

#### 2.1. Subjects

The participants in this study were 120 elite male athletes (alpine skiers, fencers, soccer players, track and field sprinters and jumpers, and weight lifters) aged 18 to 24 yrs and 316 healthy males aged 19 and 20 yrs. The body characteristics of the categorized subjects are provided in Table 1. All the elite athletes were at the Japan National Level and the other healthy males were vocational school students without habitual hard training in sports. Informed consent was obtained from all of the subjects prior to testing. Moreover, before being evaluated, the subjects practiced the jumps in order to be well familiarized with the jump performance tests they would perform.

#### 2.2. Jump performance tests

Two vertical jump performance tests, a countermovement jump (CMJ), and five-repeated rebound jump (5RJ) were used in this study as well as that of Endo, et al., (2007). The CMJ was the vertical jump from an erect standing position with a preliminary countermovement and the 5RJ was a repeated vertical jump with a rebound movement similar to bouncing a ball. Both jumps were performed with the self-selected amplitude of the joint angles at the leg and no pause during countermovement or rebound movement. The subjects were instructed to jump for maximum height in the CMJ, and for maximum height and minimum ground contact time in the 5RJ. In both jump tests, the arms were set at the hips to counter the effect of arm swing for jumping performance. We requested that the subjects perform each jump three times; however, if the performance was not satisfactory, subjects repeated the trial until they were satisfactory.

The subjects performed both CMJ and 5RJ on a mat switch (660 x 1000 mm), which was connected to a PC via an A/D converter (Multi Jump Tester, PH-1260D, DKH, Japan). The mat switch system read the ON and OFF signals during foot contact on the ground and the flight of the body at 1/1000s.
2.3. Measurements

2.3.1. Jump height in CMJ

The jump height in CMJ was calculated to evaluate CMJ ability by the following equation (Bosco, et al., 1983):

\[ \text{Jump height in CMJ (m)} = \left( \frac{g \times 11_{\text{CMJ}}^2}{2} \right)^{\frac{1}{2}}, \]

where \( g \) is acceleration due to gravity (9.81 m/s\(^2\)) and \( 11_{\text{CMJ}} \) is the time of the flight of the jump in CMJ (s). The mat switch system measured \( 11_{\text{CMJ}} \) as the time between the takeoff and subsequent ground contact. This calculation method is based on the premise that the postures at takeoff and at ground contact are the same. Therefore, we instructed the subjects to not bend their knee joints at ground contact. Furthermore, the trial judged bending of the knee joint at ground contact as an unsuccessful trial.

The maximum jump height in a subject was accepted as the representative value of the subject’s CMJ ability.

2.3.2. RJ-index in 5RJ

The RJ-index in 5RJ was calculated to evaluate RJ ability by the following equation:

\[ \text{RJ-index (m/s)} = \left( \frac{g \times T_{TJ}^2}{T_c} \right)^{\frac{1}{2}}, \]

where \( T_{TJ} \) is time of the flight of the jump in 5RJ (s) and \( T_c \) is the time of foot contact on the ground in 5RJ (s). \( 11_{\text{RJ}} \) and \( T_c \) are the values for one rebound jump during five repeated movements. The RJ-index is often used, though the description is not always the same, to evaluate the performance in a rebound-type jump (Zushi, et al., 1993; Young, et al., 1995, 1999; Bencke, et al., 2002). Fukashiro (1992) clarified that simplified power (SP) is a mechanical power during takeoff phase in vertical jump by simplified method using the flight time and the takeoff time. As a result of an examination of the relationships between SP and RJ-index, and SP per body weight (SP/BW) and RJ-index in preparatory tests, a higher positive correlation coefficient between SP/BW and RJ-index \((n=176, r=0.920, \text{RJ-index (m/s)} = 0.057 \times \text{SP/BW (W/kg)} + 0.178)\) rather than that between SP and RJ-index \((r=0.895, \text{RJ-index (m/s)} = 0.061 \times \text{SP (W)} \times 10^2 + 0.730)\) was confirmed (refer to appendix). Therefore, the RJ-index indicates the mechanical power per body weight during the takeoff phase in RJ. In addition, the reason that there was a slight variation between SP/BW and the RJ-index lies in the different methods of calculation between SP and the RJ-index. In other words, although SP was calculated using the time of takeoff phase (Fukashiro, 1992), the RJ-index was calculated using the time of foot contact on the ground (the sum of the time of braking and takeoff phase). The maximum RJ-index in a subject was accepted as the representative value of RJ ability in that subject.

2.4. Statistics

The values for measurements were given as mean ± SD. To test the difference in the jump height in CMJ and the RJ-index, jump height, and contact time in 5RJ, we used a one-way ANOVA for three groups (19 yrs, 20 yrs, and elite athletes). When the group-related effect was significant, Tukey’s post hoc test was employed to determine the significant difference among groups. The Pearson’s product moment correlations coefficient was used to determine the relationship between jump height in CMJ and the RJ-index in 5RJ. The significant level was set at \( p < 0.01 \).

3. Results

The jump performances in CMJ and 5RJ are provided in Table 2. The jump height in CMJ and the RJ-index and jump height in 5RJ were significantly higher for elite athletes than for the 19- and 20-year-olds. In particular, the jump height in CMJ in track and field (jumpers and sprinters)
Figure 1  Age-related change of the jump height in CMJ and RJ-index in 5RJ from ages 6 to 20 yrs and elite athletes (EA). The values from 6 to 18 yrs have been reported in Endo, et al., (2007).

Figure 2  The relationship between jump height in CMJ and RJ-index in 5RJ from ages 6 to 20 yrs. The values from 6 to 18 yrs have been reported in Endo et al. (2007).

Figure 3  The relationship between jump height in CMJ and RJ-index in 5RJ from ages 6 to 20 yrs and elite athletes. The solid line is the regression line (RJ-index = 4.22 ×CMJ height + 0.11) for 6- to 20-year-old subjects, from Endo, et al., (2007), and the dotted lines indicate the values ±1 SD from the regression line.

and weight lifting, and the RJ-index in track and field were notably high values. The contact time in 5RJ for elite athletes was significantly lower than for the 19- and 20-year-olds.

Age-related changes in jump height in CMJ and the RJ-index in 5RJ from ages 6 to 20 yrs and elite athletes are shown in Figure 1. The values for 6- to 18-year-olds have been reported by Endo, et al., (2007). Although both the jump height in CMJ and the RJ-index in 5RJ developed in the 6- to 18-year-olds, these values reached a plateau for healthy 18- to 20-year-old males; however, elite athletes developed further after age 18.

The relationship between jump height in CMJ and the RJ-index in 5RJ from ages 6 to 20 yrs is shown in Figure 2. From 6 to 18 yrs, the regression line and correlation coefficient between jump height in CMJ and the RJ-index in 5RJ were RJ-index = 4.22 ×CMJ height + 0.11 and r = 0.764, respectively, reported by Endo, et al., (2007). When the values in healthy males in the present study were added to the results of Endo, et al., (2007), the regression line and correlation coefficient changed only slightly (RJ-index = 4.19 ×CMJ height + 0.12 and r = 0.768).

Figure 3 provides the values for the elite athletes added to the results in Figure 2. The elite adolescent athletes tended to appear in the upper right for the population from 6 to 20 yrs; moreover,
In the present study, the characteristics of jump ability in healthy adolescent males and elite athletes were identified as three types (CMJ, RJ, and Even types) by assessment based on the residual between the actual RJ-index in each subject and the estimated RJ-index from the regression line (RJ-index = 4.22 × CMJ height + 0.11) using the actual CMJ height for each subject. Subjects with a residual of greater than +1 SD were classified as RJ type, subjects with a residual of less than −1 SD were classified as CMJ type, and subjects with a residual of greater than −1 SD but less than +1 SD were classified as Even type. For details on identifying jump ability type, refer to Endo, et al., (2007). The number of subjects in each jump ability type is shown in Table 3.

The percentage of the subjects in each jump ability type for age groups and elite athletes is given in Figure 4. The percentage of the Even type tended toward a significant decrease after a growth spurt (after 9 to 12 yrs of age), reported by Endo (2007), and the percentage of the Even type in 19- and 20-year-olds tended toward plateau from the value for 13-year-olds. However, the percentage of Even type in elite adolescent elite further decreased in comparison with 19- and 20-year-olds. In particular, track and field accounted for a large portion of the RJ type; in contrast, weight lifting accounted for a large portion of the CMJ type.

4. Discussion

According to Endo, et al., (2007), jump height in CMJ (= CMJ height) and the RJ-index in 5RJ (= RJ-index) develop from ages 6 to 16 yrs, and then, both values plateau from ages 16 to 18 yrs. The results of the present study also show that CMJ height and the RJ-index in 19- and 20-year-olds reached a plateau from age 16; however, both values in elite adolescent athletes were significantly higher than those in healthy coeval adolescent males (Figure 1). This result suggests that CMJ and RJ abilities in healthy males without the hard training that is required in sports did not develop during adolescence. In other words, it is possible that CMJ
and RJ abilities in adolescents were affected by the length of specific training in each sport.

There were some differences between CMJ and RJ abilities in terms of the contribution of the lower limb joints in performance or the neural control mechanism. Therefore, it may not necessarily be the case that CMJ and RJ abilities are the same in jump ability. The present study examined the relationship between CMJ height and the RJ-index to evaluate the characteristics of individual jump ability. As a result of the CMJ height and RJ-index in 316 healthy males ages 19 and 20 yrs added to the results of 1,137 healthy males ages 6 to 18 yrs, which were reported by Endo, et al., (2007), the correlation coefficient, gradient and intercept of the regression line changed only slightly compared with the results of Endo, et al., (2007) (Figure 2). Furthermore, the results of identification of the characteristics of jump ability type, CMJ type (subjects who were lower in RJ ability relative to CMJ ability), RJ type (higher RJ ability relative to CMJ ability), and Even type (corresponding RJ and CMJ abilities), using the residual from the regression line, the percentages of CMJ and RJ types in 19- and 20-year-olds showed that they were similar to the values for those aged 13 to 18 yrs (Figure 4). Endo, et al., (2007) have reported that individual difference in jump ability types increases at a later growth spurt (about 9 to 12 yrs). These results suggest that the characteristics of jump ability in 19- and 20-year-olds did not change after age 18.

Our main objective was to clarify the characteristics of jump ability in elite adolescent athletes. As a result of plotting CMJ and RJ values on the graph in Figure 2, the scattering in elite athletes was clearly wide (Figure 3). Furthermore, the percentage of CMJ and RJ types among elite athletes was higher than among 17- and 18-year-olds, who represented the highest percentage of CMJ and RJ types among the age groups (Figure 4). These results suggest that jump ability in several elite athletes was dominated by the CMJ or RJ abilities of coeval healthy adolescent males. In particular, track and field tended to appear in the upper right and weight lifting in the lower right on the scatter graph in Figure 3, while over 60% in track and field were RJ type, and a similar percentage in weight lifting were of the CMJ type (Figure 4). Sprints and jumpers in track and field are required to exert explosive power at the shallow joint angles and small angular displacements of the lower limbs during the leg support phase, and the duration during the leg support phase is very short (about 0.1 s) (Mero, et al., 1992). In contrast, weight lifters are required to exert at deep joint angles and large angular displacements of the lower limbs during the pulling phase, and the duration during the pulling phase is relatively long (over 0.7 s) (Gourgoulis, et al., 2000). These results enable us to presume that the movements in sprint and jump are similar in RJ movement and the movement in weight lifting is similar in CMJ movement. Therefore, the difference of the movement type and time that the above-mentioned explosive power is exerted affected the characteristics of jump ability types in elite athletes in addition to the effect of the length of specific training. Furthermore, considering the identification of jump ability types among elite athletes, we should not neglect inherited factors, which allow athletes to obtain better CMJ or RJ abilities when undergoing the same training.

5. Conclusion

The characteristics of the jump ability of elite adolescent male athletes and healthy coeval males as compared to the jump ability of males ages 6 to 18 yrs were examined. The results revealed that although jump ability in healthy adolescent males without hard training in sports changed only slightly after age 18, jump ability in elite athletes who engaged in long-term specific training in each sport were superior, and that many of the elite athletes possess a jump ability in which a better CMJ or RJ ability reflects the characteristics of each athletic event. Bencke, et al., (2002) have reported that jump ability in children who participate in each athletic event had already been characterized at 11 yrs of age. Therefore, it is necessary to develop multiple jump abilities at an earlier age to expand the potential for a child’s future physical fitness. In this respect, it is important to evaluate RJ ability added to CMJ ability. In addition, the values in elite athletes presented in this study will be the target values for children who participate in these sports.

References


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**Appendix**

The relationships between simplified power (SP) and RJ-index (left) and SP per body weight and RJ-index (right) in preparatory test. The calculation method of SP has been reported by Fukashiro (1992). The subjects in this figure were healthy children and males (including collegiate athletes) ages 9 to 24yrs.