
MANIFESTATIONS OF PROPRIOCEPTION DURING VERTICAL JUMPS TO SPECIFIC HEIGHTS

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ABSTRACT

Artur, S, Bogdan, P, Kawczyński, A, Winiarski, S, Grzegorz, J, and Andrzej, R. Manifestations of proprioception during vertical jumps to specific heights. *J Strength Cond Res* 31(6): 1694–1701, 2017—Jumping and proprioception are important abilities in many sports. The efficiency of the proprioceptive system is indirectly related to jumps performed at specified heights. Therefore, this study recorded the ability of young athletes who play team sports to jump to a specific height compared with their maximum ability. A total of 154 male (age: 14.8 ± 0.9 years, body height: 181.8 ± 8.9 cm, body weight: 69.8 ± 11.8 kg, training experience: 3.8 ± 1.7 years) and 151 female (age: 14.1 ± 0.8 years, body height: 170.5 ± 6.5 cm, body weight: 60.3 ± 9.4 kg, training experience: 3.7 ± 1.4 years) team games players were recruited for this study. Each participant performed 2 countermovement jumps with arm swing to 25, 50, 75, and 100% of the maximum height. Measurements were performed using a force plate. Jump height and its accuracy with respect to a specified height were calculated. The results revealed no significant differences in jump height and its accuracy to the specified heights between the groups (stratified by age, sex, and sport). Individuals with a higher jumping accuracy also exhibited greater maximum jump heights. Jumps to 25% of the maximum height were approximately 2 times higher than the target height. The decreased jump accuracy to a specific height when attempting to jump to lower heights should be reduced with training, particularly among athletes who play team sports. These findings provide useful information regarding the proprioceptive system for team sport coaches and may shape guidelines for training routines by working with submaximal loads.

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INTRODUCTION

Jumping is an important ability in many sports. In team sports, the level of jumping ability indirectly determines the team's final success during competition (6,18,33). For example, in volleyball, the skill of blocking, in which a player or players jump to a specific or maximal height and extend their upper limbs above and over the net (without touching the net) to block an attack (spike) by the opponent, is crucial to team success (9,25). In basketball, the 2-legged jump shot has become more frequent, accounting for more than 70% of all shots during a game (31). Therefore, within 20 years the number of jumps during a basketball game increased twofold (29,36). Each sport that involves jumping is characterized by sport-specific jump types. For instance, basketball players and volleyball players perform different types of jumping movements (3).

Jumping abilities are required for both offensive and defensive activities. During attack, basketball players use jumping during jump shots, layups, and dunking. Jumps help to avoid the defensive players and improve scoring chances. Defensive players jump to steal or block the ball, prevent opponents from shooting and passing, and limit the visibility range of offensive players. Similar jumps are observed during handball games. In addition, in basketball, players on both teams fight for the ball in the air near the backboard after a missed shot. In volleyball, jumping is used during blocking, spiking, and serving. Setters also often perform jumps while setting (3,6,18,24). Other actions that involve jumps but cannot be categorized into the above groups should also be considered. In all of these activities athletes often aim to jump to a specific height rather than to the maximum height, although the target height is often near the maximum. Connected, repeated jumps must also be performed at specific heights (to steal the ball or maintain possession), which often leads to performing a maximum height jump (29). Thus, the height of a jump depends strongly on the temporary situation on the court.

In general, jumping ability is related to the properties of the neuromuscular system, which is responsible for proper muscle coordination during jumping (39). An external manifestation of the efficiency of the central nervous system is the quality of the movements performed. Proprioception is based on an accurate perception of forces (muscle tension), timing (movement velocity), and space (position of body segments with respect to each other) during the performance of a particular motor activity. Proprioception is essential to properly use the control impulses (based on the incoming information and evaluation and adequate processing of this information) and facilitates the optimal performance of the motor task. Proprioceptors located in the muscles and tendons provide information to the brain about muscle tone. Furthermore, the proprioceptors present in joint capsules are responsible for information about the changes in intraarticular pressure caused by movements. These systems help humans know their current body position (without seeing). Receiving and processing information from proprioceptors are required for proper reflexes, planning and performing movements, regulation of muscular tension cocontraction of antagonistic muscles, and for increased mental activity (especially regarding body position) (14,17). To properly perform a submaximal jump, maximal capabilities must be corrected in terms of movement patterns and muscular tensions. Thus, the proprioceptive system manifests during the performance of jumps to varied heights.

Kai et al. (19) reported a relationship between the vertical jump height and knee joint flexion angle. Furthermore, Vanrenterghem et al. (41) concluded that movement effectiveness (energy cost reduction) is a driving criterion of the submaximal jump performance technique. Lees et al. (22) stated that submaximal jumps seem to stress the ankle and knee muscle as adequately as maximal jumps. However, maximal jumps are achieved through greater engagement of the hip extensor muscles (22). Despite the substantial interest among researchers regarding vertical jumps (because of applications in sports practices), some questions remain unanswered, particularly concerning submaximal jumps (23,26,29). A limited number of studies have analyzed jumps to a specific percentage height (19,40,41), especially at low heights (25 or 50% of the maximum height). Because of the specific nature of team sports, the proprioceptive system manifests indirectly during the performance of jumps to varied heights. In many team sport games, success requires accurate and well-controlled jumping. Therefore, the efficiency of the proprioceptive system among individuals who play team sports that require jumping to a specific height, such as basketball, volleyball, and handball, is an interesting topic.

A limited number of studies have analyzed jumping accuracy ability. If jumping ability is influenced by different training protocols, we assume that athletes from different disciplines and of different ages and sexes will also be

characterized by different jumping abilities (10,27,28,33). Therefore, we evaluated differences in accuracy in the performance of a vertical jump to a specific height among players from different team sports and of different ages and sexes. We also examined whether the level of maximal jumping ability correlated with the accuracy of performing a vertical jump to a specific height. Because jumps are complex movements and are related to the properties of the neuromuscular system, they should include all 3 components of the proprioception system: force, timing, and space. However, to perform a jump to a specific height, adequate force value (muscle tension) must be generated. Therefore, the question is whether the accuracy of a jump to a specific height is related to maximal value of force during the take-off phase. The aim of the present study was to determine the level of ability to control jump height with respect to maximum jumping ability among a group of young athletes in team sport games in which jumping plays an important role.

MATERIALS AND METHODS

Experimental Approach to the Problem

Proprioceptive system efficiency was evaluated indirectly in young athletes who played team sports and was estimated based on the ability to control vertical jump height. To properly perform a submaximal jump, maximal capabilities must be corrected in the neuromuscular system. Thus, the proprioceptive system manifests during the performance of jumps to specified heights. The dependent variable was the accuracy of performing a jump to a specific height. The independent variables were age, sex, sport discipline, maximal countermovement jump (CMJ) height, and maximum take-off force. In total, 12 teams were studied at the end of a preparation macrocycle.

Subjects

The examinations of selected teams members were performed in a group of 305 participants (age range = 12–16) selected among young individuals who trained at team sport games (basketball, volleyball, and handball). The selected members were the most talented players chosen by coaches for regional teams. A detailed characterization of the study groups is presented in Table 1. Before the tests, each participant was familiarized with the task. Parents were informed about the purpose of the study and provided written permission for the tests. The experiments were performed in the Biomechanical Analysis Laboratory (with PN-EN ISO 9001:2009 certification). The research project was approved by the Senate's Research Bioethics Commission, and the procedures complied with the Declaration of Helsinki regarding human experimentation.

Procedures

Participants performed a 15-minute warm-up before performing the jumping tasks: 5 minutes of jogging, 5 minutes of dynamic stretching exercises, and 5 minutes of general and

TABLE 1. Characteristics of the research groups (mean ± SD).*

Group	N	Age (y)	Body height (cm)	Body mass (kg)	Training experience (mo)
BMY	28	13.5 ± 0.5	177.5 ± 12.5	64.3 ± 12.6	40.9 ± 14.2
BMJ	14	15.1 ± 0.3	183.3 ± 12.7	72.5 ± 10.2	67.4 ± 27.4
BFY	26	13.6 ± 0.7	166.6 ± 9.1	53.5 ± 8.2	42.6 ± 15.8
BFJ	23	14.9 ± 0.5	171.3 ± 6.2	61.0 ± 7.7	51.9 ± 19.4
VMY	24	14.1 ± 0.3	175.9 ± 6.5	60.9 ± 9.0	30.6 ± 17.0
VMJ	27	15.2 ± 0.4	186.3 ± 5.9	72.0 ± 7.3	32.7 ± 16.0
VFY	32	13.3 ± 0.7	173.2 ± 4.9	59.5 ± 7.0	37.2 ± 14.9
VFJ	19	14.7 ± 0.5	172.8 ± 6.4	63.6 ± 8.3	49.3 ± 19.6
HMY	34	15.1 ± 0.3	183.0 ± 4.8	71.5 ± 7.6	53.9 ± 15.2
HMJ	27	16.0 ± 0.3	184.7 ± 6.5	77.4 ± 15.2	53.8 ± 17.0
HFY	29	14.1 ± 0.4	169.0 ± 4.1	62.5 ± 11.7	40.8 ± 15.0
HFJ	22	14.9 ± 0.5	170.2 ± 5.7	63.2 ± 10.0	52.0 ± 13.8
Total	305	14.5 ± 0.9	176.2 ± 9.7	65.1 ± 11.7	45.1 ± 18.9

*B = basketball; M = male; Y = youth; J = junior; F = female; V = volleyball; H = handball.

test-specific drills, lower leg drills and technique drills, and easy run outs over 30–60 m. Each participant performed 8 CMJs with arm swing. The jumps were repeated 2 times to the following heights: maximum height (h_{max}), 25% h_{max} , 50% h_{max} and 75% h_{max} . The 2 maximal height jumps were performed first. Then, the participants were given the following instructions: “Knowing the maximum height you are able to jump to, perform a jump at 25%, 50%, and 75% of your maximum abilities.” During performance of the jump, the subjects were asked not to flex their lower limbs during the flight phase. Whenever a mistake was made during the jump, the jump was repeated. The participant did not receive feedback on the jump heights. A maximum CMJ height (greater value of the 2 attempts) was recorded. The mean accuracy of the 2 attempts for the specific percentage value (D_x for $x = 25, 50, \text{ or } 75$) of each jump to a specific height was also calculated. The jump accuracy to a specific height was calculated as a mean of the percentage and the sum of errors methods according to the equations in Struzik et al. (37). We propose equations 1 and 2. The jump accuracy was based on the mean value of 2 trials for each percentage value (D_x), with the error score calculated both as a percentage (equation 1) and as the total error (equation 2):

$$D_{x, \text{percentage}} = \frac{\sum_{i=1}^2 |0.01 \cdot x \cdot h_{max} - h_{x, i}|}{2 \cdot 0.01 \cdot x \cdot h_{max}} \times 100\%, x \in \{25, 50, 75\}, \quad (1)$$

$$D_{x, \text{total errors}} = \frac{\sum_{i=1}^2 |0.01 \cdot x \cdot h_{max} - h_{x, i}|}{2}, x \in \{25, 50, 75\}. \quad (2)$$

The symbol $h_{x,i}$ denotes successive jumps (i) to a particular percentage height x . The best accuracy result when

performing a jump to a specific height was 0, and greater values corresponded to lower accuracy levels. The methodology of the sum of errors yields a quantitative absolute value when exceeding the demanded height, whereas the percentage method additionally normalizes this value with respect to the maximum jump height.

The ground reaction forces during jumping were recorded with an ACCUPOWER force plate manufactured by AMTI (Watertown, MA, USA) with ACCUPOWER software. This equipment enabled an accurate measurement of the take-off and landing time (using the force plate) and aided the assessment of the duration of the flight phase and, consequently, the jump height. Furthermore, the value of the maximum take-off force (F_{max}) during all types of jumps was also recorded. The sampling frequency for the signal from the plate was set at 240 Hz. The jump height (h) was calculated using the following formula:

$$h = \frac{1}{8} g \cdot t_f^2 \quad (3)$$

where t_f was the flight time and g was the acceleration due to gravity (5,7,12).

In the reliability part, the subjects performed 4 jumps at each percentage of jump (25, 50, 75, and 100%) on 2 consecutive days. During each session, jumps were separated by a 3-minute rest period to avoid fatigue (34).

Statistical Analyses

The normality of the distributions of each variable was tested using the Shapiro-Wilk and Lilliefors tests. The data did not follow normal distributions. Thus, Spearman’s rank correlation coefficients were used to analyze the relationships between the maximum jump height and accuracy of performing jumps to specific heights. Differences between variables (stratified according to age categories, sex, and

TABLE 2. Mean values (\pm SD) of the maximum countermovement jump (CMJ) height (h_{max}) and jump accuracy to a specific height (D_x) for each subgroup.*

Group	h_{max} (cm)	Percentage method (%)			Total errors method (cm)		
		D_{25}	D_{50}	D_{75}	D_{25}	D_{50}	D_{75}
BMJ	45.6 \pm 4.4	106.8 \pm 57.7 [†]	39.7 \pm 20.7 ^{††}	14.6 \pm 9.5 [‡]	11.9 \pm 6.2 \S	8.9 \pm 4.5 \S	5.0 \pm 3.2 \S
BFY	33.3 \pm 3.8	106.1 \pm 53.0 [†]	41.7 \pm 22.4 ^{††}	11.0 \pm 8.4 [‡]	8.7 \pm 4.4 \S	6.7 \pm 3.3 \S	2.7 \pm 2.1 \S
BFJ	34.3 \pm 5.9	92.7 \pm 48.6 [†]	39.9 \pm 19.5 ^{††}	14.0 \pm 8.1 [‡]	7.6 \pm 3.4	6.6 \pm 3.1 \S	3.6 \pm 2.2 \S
VMY	42.3 \pm 6.2	107.4 \pm 59.3 [†]	38.4 \pm 25.3 ^{††}	13.6 \pm 9.3 [‡]	10.8 \pm 5.3 \S	7.8 \pm 4.7 \S	4.2 \pm 2.7 \S
VMJ	47.0 \pm 4.7	109.5 \pm 56.2 [†]	45.6 \pm 20.4 ^{††}	13.1 \pm 11.0 [‡]	12.9 \pm 6.8	10.6 \pm 4.5 \S	4.5 \pm 3.4 \S
VFY	33.0 \pm 4.6	126.1 \pm 60.3 [†]	41.6 \pm 21.3 ^{††}	10.8 \pm 7.0 [‡]	10.2 \pm 4.8 \S	6.6 \pm 3.0 \S	2.6 \pm 1.7 \S
VFJ	34.2 \pm 4.1	93.3 \pm 44.4 [†]	30.0 \pm 23.4 ^{††}	9.0 \pm 6.8 [‡]	7.8 \pm 3.4 \S	5.0 \pm 3.6 \S	2.3 \pm 1.5 \S
HMY	42.0 \pm 5.5	109.7 \pm 56.3 [†]	47.6 \pm 18.0 ^{††}	13.0 \pm 7.3 [‡]	11.3 \pm 5.6 \S	9.8 \pm 3.7 \S	3.9 \pm 2.0 \S
HMJ	45.7 \pm 6.7	80.1 \pm 41.6 [†]	32.2 \pm 17.2 ^{††}	11.1 \pm 6.8 [‡]	8.8 \pm 4.2 \S	7.1 \pm 3.6 \S	3.9 \pm 2.6 \S
HFY	33.8 \pm 6.7	117.3 \pm 42.4 [†]	41.7 \pm 15.6 ^{††}	8.9 \pm 5.0 [‡]	9.8 \pm 3.7 \S	7.0 \pm 2.8 \S	2.2 \pm 1.3 \S
HFJ	39.0 \pm 7.2	94.5 \pm 57.5 [†]	35.2 \pm 16.5 ^{††}	8.6 \pm 5.4 [‡]	9.0 \pm 5.1 \S	7.1 \pm 3.9 \S	2.5 \pm 1.8 \S

*B = basketball; M = male; Y = youth; J = junior; F = female; V = volleyball; H = handball.
[†]Significant differences between variables at $p < 0.001$.
[‡]Significant differences between variables at $p < 0.01$.
 \S Significant differences between variables at $p \leq 0.05$.

sport) were analyzed using a multivariate analysis of variance. Significant differences between the jump accuracies to specific heights were verified with the Wilcoxon signed-rank test for dependent variables. The level of significance was set at $\alpha = 0.05$ in all tests.

The relative and absolute reliability across the reliability session were computed using Intraclass Correlation

Coefficient (ICC). The relative reliability was evaluated by calculating a 2-way fixed ICC_{2,1} (for absolute agreement). Reliability coefficients (i.e., ICC values) were interpreted according to Landis and Koch (21): an ICC between 0.00–0.20 was considered poor, 0.21–0.40 fair, 0.41–0.60 moderate, 0.61–0.80 substantial, and 0.81–1.00 almost perfect.

RESULTS

The reliability of the performed measurements for jumping to 100% of the maximum height was almost perfect (ICC 0.929, 95%). The reliability of the performed measurements for jumping to 75% of the maximum height was almost perfect (ICC 0.833, 95%). The reliability of the performed measurements for jumping to 50 and 25% of the maximum height were almost perfect (ICC 0.887, 95%) and substantial (ICC 0.730, 95%), respectively. The statistical power was sufficient to detect the described differences. For significant changes ($p \leq 0.05$), the partial η^2 effect size was found between 0.52 and 0.83.

TABLE 3. Correlation coefficients between maximum countermovement jump (CMJ) height (h_{max}) and jump accuracy to a specific height (D_x).*

Group:	h_{max}					
	Percentage method			Total errors method		
	D_{25}	D_{50}	D_{75}	D_{25}	D_{50}	D_{75}
BMJ	-0.39 [†]	-0.46 [†]	-0.08	-0.05	-0.16	-0.03
BFY	-0.30	-0.61 [†]	-0.12	-0.07	-0.44 [†]	0.09
BFJ	-0.48 [†]	-0.37	-0.10	-0.20	-0.03	0.10
VMY	-0.63 [†]	-0.45 [†]	-0.37	-0.40 [†]	-0.22	-0.23
VMJ	0.04	-0.25	-0.34	0.26	-0.03	-0.12
VFY	-0.29	-0.47 [†]	-0.27	0.03	-0.20	0.04
VFJ	-0.35	-0.33	-0.27	-0.11	-0.19	0.05
HMY	-0.30 [†]	-0.42 [†]	-0.47 [†]	-0.03	-0.06	-0.23 [†]
HMJ	-0.54 [†]	-0.43 [†]	0.23	-0.30	-0.18	0.37
HFY	-0.21	-0.14	-0.09	0.37 [†]	0.41 [†]	0.20
HFJ	-0.22	0.41	-0.01	0.07	0.63 [†]	0.07

*B = basketball; M = male; Y = youth; J = junior; F = female; V = volleyball; H = handball.
[†]Significant at $p \leq 0.05$.

TABLE 4. Mean values ($\pm SD$) of the maximum take-off force (F_{max}) during countermovement jumps (CMJs).*

Group	F_{max} (N)			
	CMJ for h_{max}	CMJ for 25% of h_{max}	CMJ for 50% of h_{max}	CMJ for 75% of h_{max}
BMJ	1,572.4 \pm 523.5	1,611.0 \pm 388.4	1,623.3 \pm 373.1	1,572.7 \pm 375.5
BMJ	1,896.0 \pm 257.9	1,967.8 \pm 321.1	2,031.4 \pm 267.8	1,956.1 \pm 278.4
BFY	1,389.9 \pm 272.4	1,519.1 \pm 243.7	1,493.4 \pm 245.6	1,468.9 \pm 291.3
BFJ	1,569.7 \pm 259.1	1,702.7 \pm 221.2	1,650.6 \pm 242.9	1,639.4 \pm 289.4
VMY	1,576.8 \pm 401.7	1,541.6 \pm 214.7	1,555.6 \pm 282.9	1,434.3 \pm 212.4
VMJ	1,782.1 \pm 233.7	1,922.9 \pm 304.5	1,771.5 \pm 288.9	1,847.9 \pm 301.9
VFY	1,500.9 \pm 310.9	1,637.4 \pm 335.1	1,570.6 \pm 236.8	1,599.3 \pm 297.1
VFJ	1,561.4 \pm 206.5	1,728.2 \pm 334.5	1,667.2 \pm 262.8	1,578.1 \pm 260.9
HMY	1,705.1 \pm 440.4	1,925.6 \pm 499.3	2,012.9 \pm 329.7	1,953.6 \pm 306.8
HMJ	1,982.8 \pm 327.8	2,232.5 \pm 354.0	2,214.5 \pm 330.0	2,103.7 \pm 345.1
HFY	1,673.7 \pm 395.3	1,701.0 \pm 333.9	1,673.3 \pm 264.8	1,671.8 \pm 261.5
HFJ	1,768.9 \pm 491.6	1,948.0 \pm 479.5	1,835.9 \pm 392.3	1,995.8 \pm 548.0

*B = basketball; M = male; Y = youth; J = junior; F = female; V = volleyball; H = handball.

Table 2 contains the mean values ($\pm SD$) of the maximum CMJ heights and jump accuracies to specific heights. The jump accuracy to a specific height increased as the percentage value expected to be reached increased (Table 2). The exceptions were groups of junior female basketball players, junior male volleyball players, and youth male basketball (BMJ) players. In these groups, the difference between D_{25} and D_{50} (calculated using the sum of errors) was not significant. Jumps to 25% of the maximum height were (significantly) approximately 2 times higher than the target values.

Table 3 presents the relationships between the maximum CMJ heights and jump accuracy to specific heights. We observed negative relationships between the maximum CMJ height and jump accuracy to specific heights (particularly when using the percentage method). These relationships were significant or insignificant depending on the subgroup (most of the significant relationships were among handball players). However, groups of handball players (handball female youth and handball female junior) demonstrated positive significant relationships between the maximum CMJ height and jump accuracy to a specific height (calculated by means according to the sum of errors method).

No significant differences were observed for maximum CMJ height between groups divided according to age, sex, and sport. Only BMJ players and youth male handball (HMY) players demonstrated significant differences in the jump accuracy to a specific height. Basketball players demonstrated greater levels of accuracy for jumps to 25 and 50% of the maximum height (for percentage and sum of errors methods).

Table 4 presents the mean values ($\pm SD$) of the maximum take-off force during CMJs. No statistically significant

correlations were found between the jump accuracy to specific heights (percentage and total errors methods) and maximum take-off force.

DISCUSSION

Many motor tasks can be performed at maximal (attempts to achieve the highest possible performance) or submaximal (attempts to achieve a certain level of performance) levels of performance. The central nervous system generates an appropriate set of control signals to all muscles involved during the performance of a motor activity. Performing a motor task at the maximum level can be relatively easy because of the existence of a unique set of control signals yielding maximum performance. These optimal control signals may result from learning a motor task over a longer period of time. Performing a motor task at submaximal capabilities is more difficult because of the presence of many movement patterns (and different sets of control signals) that can be used for these tasks (8,22,40,41).

The neural control of jumping is highly complex, and both feedforward (preprogrammed) and feedback (reflex) mechanisms have to be highly adaptive to ensure balance between achieving maximum performance (power) and the risk of overload injuries (39). A vertical jump is a complex movement characterized by eccentric-concentric muscle work during the countermovement and take-off phases, with different characteristics and purposes of the 2 phases. The total duration of the countermovement and take-off phases (which contribute to jump effectiveness) is approximately 0.5 seconds (38). Thus, the movements performed during both phases are regarded as nearly ballistic. Therefore, during the countermovement or take-off phase, movement modifications (corrections) during that respective phase are impossible unless planned before the movement begins.

Control signals must (to a large extent) be preprogrammed. Consequently, jump control relies heavily on the storage capacity of the central nervous system (17,38,40).

A jump performed to a submaximal height has a slightly different movement pattern compared with the maximum jump. A jump to the maximum height is characterized by a greater range of movement in the joints of the lower limbs to achieve greater kinetic energy in the counter-movement phase (4,19). Changes are also observed in the proportions of individual muscle and joint contributions (8,22,41). Less energy is needed when performing a submaximal jump; thus, to reduce energy waste, counter-movement and arm swing are reduced (16,23,41). Therefore, during a submaximal performance, active stretch during the stretch-shortening cycle only created minor benefits for the utilization of elastic energy in muscles (11). Consequently, a decline in the accuracy of performing the movement with a reduction in the jump height seems to be undesirable and may cause fatigue. Young athletes, who jump approximately 2 times higher than necessary during the performance of jumps to 25% of their maximum height, consume (unnecessarily) too much energy (42). Performing a series of tasks with excessive intensity (excessive load) might lead to the premature depletion of energy sources. This situation might lower the subject's performance during the final phases of the game. It should be noted that during the game, the athlete has to cope with quickly changing situations on the court, time pressure, the defensive actions of opponents, and emotions. These issues might additionally deteriorate sport movement efficiency.

To properly perform a task, submaximal capabilities have to be corrected in terms of movement patterns and muscular tensions. Young athletes tended to increase their accuracy when performing a jump to a specific height when the desired percentage value was increased. Thus, young athletes may lack the ability to work within submaximal loads. Young athletes aged 13–15 do not perform a high number of strength exercises during practice. Therefore, a decline in the accuracy of performing a jump to lower target heights may be because of puberty and the changes that occur during physical development (6,20). According to Lloyd et al. (26), children become more reliant on feedforward mechanisms as they mature. Certain age-related developments in short-latency stretch-reflex responses may influence the neural regulation of the stretch-shortening cycle during submaximal hopping. However, in the study performed by Struzik et al. (37) in postpubertal basketball players, the accuracy of releasing a particular value of static torque by elbow joint extensors decreases as the target values decrease. This finding might suggest that the efficiency of the proprioceptive system is nonuniform and depends on the type of motor activity. The level of proprioceptive (or kinesthetic) sensitivity is highest in the body parts involved in a given sport and

higher in athletes compared with untrained people. For example, table tennis players can more accurately reproduce range of movement and pressure force (1,2). Furthermore, Han et al. (15) argue that ankle proprioception scores (an active movement extent discrimination test) have a positive relationship with competition level in soccer. Proprioception also has a crucial role in balance control, and ankle proprioception is the most important aspect of balance (13). Because of the efficiency of the proprioception system, basketball players may organize compensatory behaviors with the joints of their upper limbs, which are used for shooting (35). Because of the lack of relationships between jump accuracy to specific heights (percentage and total errors methods) and maximum take-off force, this variable cannot be used to evaluate the efficiency of the proprioception system. The lack of relationships may be because of the presence of too many variables related to jump height (30).

In this study, the maximum CMJ height was negatively associated with jump accuracy to specific heights (particularly using the percentage method). Therefore, an increase in maximum jump height is also accompanied by increased jump accuracy to a specific height. This relationship, however, was not observed in all subgroups. Thus, its regular presence cannot be unequivocally demonstrated.

The maximum CMJ height and jump accuracy to a specific height did not differ between groups divided according to age, sex, and sport (with one exception). The BMY group demonstrated significantly higher jump accuracies to 25 and 50% of their maximum ability compared with the HMY group. This exception may reflect the greater number of jumps performed in basketball compared with handball games. The level of ability (jumping accuracy) analyzed in this study was relatively constant among the groups divided according to team sport.

One limitation of this study may be the different sizes of the groups. In most cases, the groups contained fewer than 30 people. We realize also that the determination of jump height based on the flight phase duration has some limitations and is not a perfect method. However, the measurement error is relatively small compared with other currently used methods.

PRACTICAL APPLICATIONS

Proprioception plays a crucial role in the control of human movement, which is fundamental for exercise and sports. Our study analyzed a component of proprioception related to the ability to reach a specific jump height. Because a vertical jump is a complex movement, its proper performance involves all 3 components of the proprioception system: force, timing, and space. This task involves perceptual and motor abilities and also the sensing and differentiation of the position of individual body parts (pelvis, knee, and ankle positions) while using only a percentage of the maximal muscle contraction. The decreased jump accuracy to a specific height when

attempting to jump to lower heights should be reduced with training, particularly among athletes who play team sport games in which success requires accurate and well-controlled jumping. A player who jumps lower might miss the ball, whereas a player who jumps higher might lose time. Impaired proprioception might be associated with functional instability, decreased muscle strength (43), or a history of injury (32). These findings provide useful information regarding the proprioceptive system for team sport coaches and may shape guidelines for training routines involving work with submaximal loads.

CONCLUSIONS

Increasing the target jump height increases the accuracy of reaching the desired height. Jumps to 25% of the maximum height were approximately 2 times higher than the target height, which might reflect a lack of ability to work with submaximal loads. A negative correlation between the maximum CMJ height and accuracy of performing the jump to a specific height was observed (particularly using the percentage method). Individuals who had greater maximum jump heights also exhibited greater accuracy when jumping to a specific height. However, these relationships were not significant in all studied groups (stratified by age, sex, and sport). Significant differences in the jump accuracy to a specific height were found only between groups of youth basketball players and youth handball players. Higher levels of jump accuracy to 25 and 50% of the maximum height were obtained by basketball players. Therefore, there was little difference between the subgroups regarding the jump ability analyzed in this study.

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