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GENDER DIFFERENCES IN THE BIOMECHANICS OF THE VERTICAL JUMPS IN YOUNG ADULT HANDBALL PLAYERS: EFFECT OF THE COUNTERMOVEMENT AND THE ARM SWING

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Abstract: *The purpose of the study was to examine the sex and jump test effect on the biomechanics of vertical jump performance in young adult handball players. Nineteen men and 19 women handball players were tested in the squat jump (SQJ) and the countermovement jump with (CMJF) and without (CMJ) an arm swing. Results indicated a significant (p < .05) sex and jump test main effect on jump height and power output. Also, a significand (p < .05) sex, jump test and sex-jump test interaction was revealed for impulse time, time to achieve maximum force and work output. No sex differences (p > .05) were observed for the jump height increment when using a countermovement and an arm swing. The differences found suggest that sex-specific training should be applied to optimize jumping ability in young adult handball players.*

Key words: *biomechanics, sports performance, power, pre-stretch augmentation, inter-segmental energy flow.*

1. Introduction

Vertical jump tests comprise a well-established evaluation of the strength and conditioning status for athletes [24]. This is because power output is suggested to be a crucial factor regarding the vertical jump performance [7], [28]. In the game of handball, power is a main goal in the conditioning program since it is related with sprint running performance and throwing velocity [36]. Thus, the systematic evaluation of vertical jump performance in handball players is a common practice [11], [21], [30].

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Performance (jump height) in the vertical countermovement jump (CMJ) is higher than the squat jump (SQJ) [10]. CMJ height is further higher when an arm swing (CMJF) is used [29]. It has been proposed that the SQJ consists an appropriate test to evaluate the concentric muscular strength application capability [3]. In addition, the percentage difference in the jump height between SQJ and CMJ (PSA) is suggested to represent the gain resulted from the pre-stretch occurring during the SSC [33]. Furthermore, the respective difference between CMJ and CMJF (ASA) depicts the intra-segmental neuromuscular coordination across the upper and lower limbs [8], [12], [19].

Previous research evidence suggests that handball players execute the vertical jump tests with an ineffective force-dominant pattern [16] and with the lack of explosiveness [17], [28]. However, there are contradicting findings concerning the sex differences in vertical jump performance of handball players. For example, no differences were found in junior elite male and female handball players [15]. On the opposite, young male players seem to jump higher than female players [9], [25], [27].

Based on the above, to the best of our knowledge, there seems to be a gap in the literature about the sex differences and the possible differentiations in the biomechanical parameters of vertical jump tests in young adult handball players. Such information could be beneficial for coaches and athletic trainers when designing training programs to improve power in handball players.

2. Objectives

The purpose of the present study was to examine the possible differences due to sex and vertical jump test in vertical jump performance of young adult handball players. The biomechanical parameters of the vertical jump were used as indicators of sex differences when a countermovement and an arm swing were utilised in comparison with the SQJ. In detail, the sex differences were examined when a pre-stretch and a work flow from the upper through the lower limbs were enabled to augment vertical jump performance. It was hypothesized that the biomechanical parameters related with vertical jump performance will be different across the vertical jump tests and that men will present higher values than women.

3. Material and Methods

3.1. Participants

Nineteen young adult men (20.3 ± 1.0 yrs, 1.86 ± 0.08 m, 86.8 ± 10.0 kg, 8.5 ± 3.7 yrs of playing experience) and 19 young adult women (19.7 ± 1.9 yrs, 1.69 ± 0.06 m, 67.4 ± 7.5 kg, 7.1 ± 4.3 yrs of playing experience) handball players, members of the respective Men's and Women's U21 National Handball Teams, participated in the study. Inclusion criteria were the participation in systematic training and the absence of an injury for a period up to six months prior testing. The sample size corresponds to 0.65 power and 0.4 effect size at a significance level of a = 0.05 according to the G-power v.3.1.9.4 software (University of Kiel, Germany).

All participants provided a signed informed consent. The study was conducted according to the guidelines of the Declaration of Helsinki and of the Institution's Research Committee's Ethics Code (protocol code: 9193/1199).

3.2. Procedure

At first, participants completed a warm-up procedure comprised of 10-min cycling on an 817E Monark Exercise Cycle (Exercise AB, Vansbro, Sweden), followed by 10 min of dynamic stretching exercises and series of submaximal and maximal vertical jumps. Afterwards, three attempts in each vertical jump test were conducted in a randomized order. However, only the best jump (criterion: jump height) was selected for further analysis. A minimum of 60 s was allowed as rest in order to avoid fatigue. For the same reason, 3 min rest was allowed between different vertical jump tests. In all cases, the jumps were performed barefooted. The participants were instructed to jump as high and as fast as possible. The SQJ was initiated with the arms kept on the hips, full feet contact with the floor, while the knee joint was flexed at an approximate 90° angle. To record a valid SQJ, no countermovement was allowed. This was checked following a previously described method [28].

As for the CMJ, the arms were on the hips during the entire jump. In the case of the CMJF, the arms were at first parallel to the body, followed by an explosive backward and forward swing during the impulse for the execution of the jump. The extent of the knee flexion during the downward phase was self-selected at the CMJ and CMJF tests.

3.3. Instrumentation

All tests were performed on an AMTI mod. OR6-5-1 force plate (AMTI, Newton, MA). The vertical ground reaction forces (vGRF) were acquired with a nominal sampling frequency of 1 kHz. All data acquisition and analyses were accomplished using custom made software.

3.4. Data analysis

The jump height (h_{JUMP}) was calculated as the outcome of the body center of mass (BCM) vertical take-off velocity which was extracted after the integration of the vGRF. The vertical BCM displacement during the downward phase (S_{DOWN}) and from the lowest BCM position up to the take-off (S_{UP}) was extracted by integrating the vertical BCM velocity. The peak rate of force development (RFD_{MAX}) was calculated as the maximum value of the first time derivative of the vGRF. Peak work at the downward (W_{DOWN}) and upward phase (W_{UP}) was defined by multiplying the vGRF and the vertical BCM displacement. Peak body power output (P_{MAX}) was the peak value of the multiplication product of the vGRF by the vertical BCM velocity.

Temporal parameters such as the total duration of the impulse (t_C), the duration of the upward phase (t_{UP}) and the time (tF_Z) to achieve the maximum vGRF (Fz_{MAX}) were also examined. Finally, the PSA was calculated as [(CMJ-SQJ) × 100]/SQJ and the ASA as [(CMJF-CMJ) × 100]/CMJ.

3.5. Statistical analysis

Descriptive statistics for the examined parameters are depicted as Mean (*M*) ± standard deviation (*SD*). Normality of distribution and the equality of variance were assessed using the Kolmogorov-Smirnov test ($p > .05$) and the Levene's test ($p > 0.05$), respectively.

In order to fulfil the purpose of the

study, a 2 (sex) × 3 (vertical jump test) repeated measures ANOVA with Bonferroni adjustment was used to examine the main effects and the interaction of the examined factors on the biomechanical parameters of the vertical jump tests. Significant differences were followed up with pairwise comparisons. Effect sizes were checked with the partial eta-squared statistic (η_p^2), with values of above 0.01, 0.06, and 0.14 being interpreted as small, medium, and large effect size, respectively [31]. In addition, an independent sample *T*-test was used to check possible sex differences in the PSA and the ASA. Effect sizes were determined after calculating Cohen's *d*, with values considered as small ($d < 0.5$), medium ($0.5 < d < 0.8$) or large ($d > 0.8$) effect size, respectively.

The statistical tests were conducted with the IBM SPSS Statistics v.27 software (International Business Machines Corp., Armonk, NY, USA). The level of significance was set at $a = .05$.

4. Results and Discussions

There was a significant sex ($F = 200.997$, $p < .001$, $\eta_p^2 = .650$; large effect size) and jump test ($F = 20.243$, $p < .001$, $\eta_p^2 = .273$; large effect size) main effect in h_{JUMP}. No significant sex and jump test interaction was observed ($F = 7.251$, $p = .595$, $\eta_p^2 = .010$; trivial effect size).

The results of the temporal parameters are presented in Table 1. A significant sex ($F = 16.319$, $p < .001$, $\eta_p^2 = .131$; medium effect size), jump test ($F = 8.212$, $p < .001$, $\eta_p^2 = .132$; medium effect size), and sex and jump test interaction ($F = 7.174$, $p = .001$, $\eta_p^2 = .117$; medium effect size) were revealed for t_C. Concerning tF_Z, a significant jump test main effect ($F = 24.939$, p < .001, $\eta_p^2 = .316$; large effect size) and a sex and jump test interaction ($F = 4.240$, p = .017, $\eta_p^2 = .073$; medium effect size) was evident, but not a sex main effect ($F = 1.873$, p = .174, $\eta_p^2 = .017$; small effect size). t_{UP} showed only a significant jump test main effect ($F = 1070.796$, $p < .001$, $\eta_p^2 = .952$; large effect size) and no significant sex main effect ($F = 1.001$, $p = .319$, $\eta_p^2 = .009$; trivial effect size) and sex and test interaction ($F = 0.328$, $p = .721$, $\eta_p^2 = .006$; trivial effect size).

The examined spatial parameters are also presented in Table 1. Results indicated a significant jump test ($F = 339.741$, $p < .001$, $\eta_p^2 = .863$; large effect size), sex ($F = 42.038$, $p < .001$, $\eta_p^2 = .280$; large effect size), and sex and jump test interaction ($F = 4.496$, $p = .013$, $\eta_p^2 = .077$; medium effect size) for S_{DOWN}. As for S_{UP}, only a significant sex main effect was observed ($F = 80.207$, $p < .001$, $\eta_p^2 = .426$; large effect size). No jump test main effect ($F = 0.792$, $p = .456$, $\eta_p^2 = .014$; small effect size) or jump test and sex interaction ($F = 0.990$, $p = .375$, $\eta_p^2 = .018$; small effect size) were evident.

Table 2 depicts the results for the kinetic parameters. A jump test ($F = 15.264$, $p < .001$, $\eta_p^2 = .220$; large effect size), but not a sex main effect ($F = 2.348$, $p = .128$, $\eta_p^2 = .021$; small effect size) or a sex and test interaction ($F = 2.754$, $p = .068$, $\eta_p^2 = .049$; small effect size) was revealed for Fz_{MAX}.

The same outcome was revealed for RFD_{MAX} (test: $F = 3.439$, $p < .001$, $\eta_p^2 = .060$; small effect size; sex: $F = 0.006$, $p = .938$, $\eta_p^2 = .000$; trivial effect size; interaction: $F = 0.796$, $p = .454$, $\eta_p^2 = .015$; small effect size). Results for P_{MAX} showed a significant sex ($F = 32.420$, p < .001,

η_p^2 = .231; large effect size) and jump test (F = 38.381, p < .001, η_p^2 = .415; large effect size) main effect, but not an interaction (F = 1.076, p = .344, η_p^2 = .020; small effect size).

A significant sex (F = 38.113, p < .001, η_p^2 = .261; large effect size), jump test (F = 406.735, p < .001, η_p^2 = .883; large effect size), and sex and test interaction (F = 11.738, p < .001, η_p^2 = .179; large effect size) were revealed for W_{DOWN}. The same occurred for W_{UP} (test: F = 80.806, p < .001, η_p^2 = .599; large effect size; sex: F = 53.006, p < .001, η_p^2 = .329; large effect size; interaction: F = 2.186, p = .024, η_p^2 = .067; small effect size).

Figure 1 presents the results of PSA and ASA. No sex differences were observed (t = 1.082, p = .287, d = .35, small effect size and t = 0.229, p = .820, d = .07, small effect size, respectively).

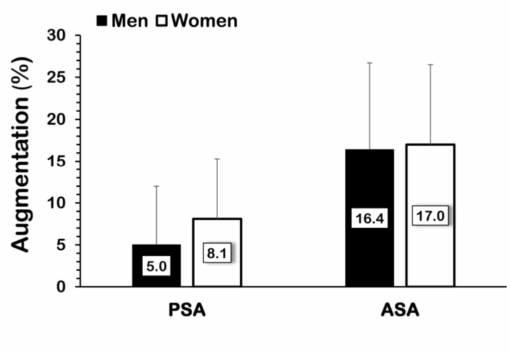

Fig. 1. h_{JUMP} *augmentation due to the pre-stretch (PSA) and the arm swing (ASA).*

A significant sex and test main effect on h_{JUMP} was observed. This can be explained, since the execution of the vertical jump with a preparatory countermovement generates a beneficial for the leg extensor muscles active state in order to develop increased force and work during their shortening compared to SQJ [1] than the re-use of the elastic energy alone [2]. The present findings of the sex and jump test main effects in the power and work output confirm the above notion. Based on the above mechanism, part of the sex differences can be attributed to the respective differences found in S_{DOWN}.

By disallowing the use of an arm swing, a vertical jump test is believed to evaluate the power production capacity of the lower limbs [3]. However, a larger jumping height is observed when the CMJ is executed with an arm swing [4-6], [8], [12], [19], [35]. The increased CMJF performance is believed to be the outcome of the increment the load imposed on the leg muscles because of the arm swing [12], which, in turn, leads to increased force, power and work outputs [13].

The significantly increased power output in men compared to women players and in the CMJF compared to SQJ is in agreement with the above mechanisms. This is in line with past research indicating power as the kinetic parameter that defines vertical jump performance [7], [22], [35]. In addition, ASA was in reasonable agreement with past findings [10]. However, the absence of a sex difference in the ASA does not confirm past findings that males rather than females exhibit highest maximum jump heights when using an arm swing [4], [35]. This could be a result of the sporting background, as the upper limbs are actively used in the game of handball and thus the effective strength for the arm swing could be adequately applied.

Despite the fact that considerations have been expressed about the relevancy of the CMJ with the jump-related strength utilised in handball skills [23], the standardized vertical jumping tests remain a mean to assess conditioning in handball

[4]. Under this perspective, the CMJF is considered to be an appropriate jump test to evaluate performance in handball because of its relevance with the sport-specific skills used in the game [20], [34].

Results for the examined spatio-temporal parameters Table 1

Parameter	**Test**	**Men (n = 19)** ***M ± SD***	**Women (n = 19)** ***M ± SD***
h$_{JUMP}$ (cm)	SQJ	27.3 ± 3.9	17.9 ± 3.0*
	CMJ	28.6 ± 4.0	19.2 ± 2.8*
	CMJF	33.3 ± 5.0^{a,b}	22.4 ± 3.1*^{,a,b}
t$_C$ (ms)	SQJ	530.4 ± 58.6	558.8 ± 158.9
	CMJ	704.2 ± 66.1^{a}	563.7 ± 124.7*
	CMJF	717.7 ± 115.6^{a}	565.9 ± 137.8*
S$_{DOWN}$ (% body height)	SQJ	0.0 ± 0.0	0.0 ± 0.0
	CMJ	-20.1 ± 3.9^{a}	-15.4 ± 3.8*^{,a}
	CMJF	-18.4 ± 3.2^{a}	-13.5 ± 2.8*^{,a}
S$_{UP}$ (% body height)	SQJ	30.7 ± 3.5	26.2 ± 3.4*
	CMJ	31.9 ± 2.7	26.4 ± 3.9*
	CMJF	32.7 ± 2.8	26.0 ± 3.4*
t$_{UP}$ (%t$_C$)	SQJ	100.0 ± 0.0	100.0 ± 0.0
	CMJ	50.0 ± 2.5^{a}	51.9 ± 7.6^{a}
	CMJF	52.1 ± 3.4^{a}	53.1 ± 9.5^{a}
tF$_Z$ (%t$_C$)	SQJ	67.0 ± 12.9	72.4 ± 9.6
	CMJ	55.4 ± 11.3^{a}	51.4 ± 10.4^{a}
	CMJF	76.3 ± 12.2^{b}	65.6 ± 15.2*^{,b}

*: sex difference (p < .05); ^{a}: difference vs. SQJ (p < .05); ^{b}: difference vs. CMJ (p < .05).

Results for the examined kinetic parameters Table 2

Parameter	**test**	**Men (n = 19)** **M ± SD**	**Women (n = 19)** **M ± SD**
Fz$_{MAX}$ (N/kg)	SQJA	2.2 ± 0.2	2.1 ± 0.2
	CMJA	2.3 ± 0.2	2.5 ± 0.3*^{,a}
	CMJF	2.4 ± 0.2^{a}	2.5 ± 0.3^{a}
RFD$_{MAX}$ (kN/sec)	SQJA	9.0 ± 3.3	7.6 ± 2.8
	CMJA	10.0 ± 4.3	11.0 ± 5.1^{a}
	CMJF	10.4 ± 3.9	10.5 ± 5.4
P$_{MAX}$ (W/kg)	SQJA	25.0 ± 3.3	20.6 ± 3.5*
	CMJA	24.4 ± 3.6	21.2 ± 4.0*
	CMJF	33.3 ± 5.9^{a,b}	27.2 ± 4.8*^{,a,b}
W$_{DOWN}$ (J/kg)	SQJA	0.0 ± 0.0	0.0 ± 0.0
	CMJA	-4.8 ± 0.9^{a}	-3.3 ± 0.9*^{,a}
	CMJF	-3.4 ± 0.7^{a,b}	-2.6 ± 0.5*^{,a,b}
W$_{UP}$ (J/kg)	SQJA	2.7 ± 0.5	2.1 ± 0.6*
	CMJA	5.3 ± 1.0^{a}	3.8 ± 0.9*^{,a}
	CMJF	3.9 ± 0.7^{a,b}	2.9 ± 0.5*^{,a,b}

*: sex difference (p < .05); ^{a}: difference vs. SQJ (p < .05); ^{b}: difference vs. CMJ (p < .05).

Finally, there are conflicting findings in the literature about the effect of playing level on vertical jump performance. Others have found that vertical jump performance is different due to team level [18], [26], but others suggest that no differences exist between top and players of lower level [32]. This factor should be further examined in the future.

This study is not without limitations. The absence of joint angular parameters could add context about the movement patterns adapted by the participants and might had provided additional information about the neuromuscular mechanisms that caused the observed main effects of sex and jump tests. Future research should address this topic as well.

5. Conclusions

The study aimed to examine the possible differences due to sex and vertical jump test in vertical jump performance of young adult handball players. Results revealed a significant sex and jump test main effect on jump height. This was mainly due to the higher power production, work output and countermovement depth observed in men compared to women. Based on the findings of the study, training programs for handball players using jumping drills should aim to the development of power production ability of the lower limbs.

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