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Original article

Sport specificity background affects the principal component structure of vertical squat jump performance of young adult female athletes

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Abstract

Purpose: Long-term training specificity is thought to alter performance in tests evaluating strength and power production capability. The aim of the present study was to provide additional information to the limited existing knowledge concerning the possible differences of the force/time profile of squat jumping among different groups of young female athletes.

Methods: One hundred and seventy-three adult women (20.1 ± 2.8 years, 1.71 ± 0.09 m, 65.6 ± 10.3 kg, mean ± SD for age, height, and mass, respectively) engaged in track and field (TF), volleyball (VO), handball (HA), basketball (BA), and physical education students (PE) executed maximal squat jumps (SQJ) on a force plate. Pearson's correlation was used to identify the relationship between SQJ performance, the anthropometric characteristics and the biomechanical parameters. Differences concerning the biomechanical parameters among groups were investigated with analysis of variance, while the force- (FPD) or time- (TPD) dependency of SQJ execution was examined using principal components analysis (PCA).

Results: SQJ was unrelated to body height but significantly correlated with body mass ($r = -0.26$, $p = 0.001$). TF jumped higher and produced larger peak body power output compared to all the other groups ($p < 0.05$). All athletes were superior to PE since they performed the SQJ with a longer ($p < 0.05$) vertical body center of mass trajectory during the propulsion phase. PCA results revealed that TF significantly differentiated than the other groups by relying on FPD.

Conclusion: Various different profiles of FPD and TPD were detected due to different sporting background in young female athletes. Since TF superiority in SQJ was relied on the larger power production and a greater FPD, female indoor team sport athletes are suggested to execute jumping exercises adopting the jumping strategies utilized by TF.

Keywords: Gender differences; Performance assessment; Power output; Principal components analysis; Rate of force development

1. Introduction

The ability to jump high is widely considered a fundamental physical ability demand in the majority of sporting activities. Vertical jumping performance and the ability to generate the acquired impulse for the take-off is depended on a variety of factors such as the ratio of fast and slow twitch muscle fibers,[1,2] the activation of the lower extremity muscles[3,4] and the coordinated energy transfer of the produced joint power in a proximal to distal sequence.[5–9] In the case of the vertical squat jump, performance (i.e., the jumping height), is greatly depended upon the muscular strength of the leg extensor muscles.[10] However, the whole body peak mechanical power output has been found to be the most important factor regarding vertical jumping performance.[2,11–14]

The long-term training specificity is considered to have an effect on the strength and power production capabilities of

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individuals involved in sporting activities of different discipline.[15–17] Specifically, the training background is a factor that modifies the parameters defining vertical jumping performance among athletes of different sporting activities.[12,15,18–21] A more sophisticated investigation with the use of principal component analysis (PCA), a method that extracts a fewer number of factors from interrelated parameters that assess vertical jump performance,[22] revealed that athletes of different sporting background tend to achieve higher vertical jumps by utilizing the force and temporal parameters in a sport-background based combination.[22–26] The results of those studies agree that power-trained athletes (i.e., volleyball players (VO) and track and field athletes (TF)) perform better in vertical jumping tests. Additionally, the findings of the above mentioned PCA studies converge to the fact that TF rely mainly on a force-dominant pattern when aiming for maximum jumping height, whereas handball (HA) and basketball (BA) players show an ineffective utilization of force parameters.

Despite the research conducted concerning the principal component structure of vertical jumping in male athletes, no studies addressing this issue in female athletes have been found. It is well documented that vertical jumping performance is significantly different between males and females due to the existing gender differences concerning the strength and power production abilities.[27–29] Furthermore, it has been reported that although the temporal parameters are not different, significant gender differences exist concerning the magnitude of the force dominancy of maximal vertical squat jump (SQJ) performance in untrained young adult males and females.[30] Since previous studies have reported differences concerning the principal component structure of vertical jumping only for male athletes of various sport-specific backgrounds,[22–26] it is of interest to examine the effect of sport specificity on the maximal SQJ performance indices in female athletes. The purpose of the present study was to investigate the possibility that young adult female athletes from different sports utilize a force- and time-dependency pattern representative of their sporting background when executing a vertical SQJ. It was of interest to examine if female TF and VO rely more on a tendency of force dominance opposed to HA and BA players, as previously shown for male athletes of the same sports.

2. Materials and methods

2.1. Participants

A hundred and seventy-three women (20.1 ± 2.8 years, 1.71 ± 0.09 m, 65.6 ± 10.3 kg, mean ± SD for age, height, and mass, respectively) volunteered for the study. In detail, 136 of the participants were athletes (Table 1) and were evaluated at the beginning of their competitive season, 51 were national level TF (sprinters, jumpers, and throwers), 48 were VO, 19 were HA, and 18 were BA, all competing in top leagues of their respective sport. Inclusion to the study required athletes to constantly participate in systematic training programs for a period of at least 8 years. The sample also included 37 females who were physical education students (PE) and did not participate, besides their academic courses, in a systematic training program for at least 2 years prior to the study. No previous severe lower extremity injury was reported from the participants who gave their informed consent for participation in the study, which was accomplished according to the Institutional Research Ethics Code for the use of human subjects.

2.2. Procedure

Prior to the actual testing, the participants' anthropometric data (body height, body mass, and body fat composition) were collected.[31] Before testing, participants performed a 10-min cycling session at a constant pedaling velocity of 5.5 m/s with no additional load for warm-up, followed by a 10-min flexibility program. Afterward, the participants executed three bare footed maximal SQJ on a force-plate without the swing of the arms. At the starting position for the execution of the SQJ, the arms were placed on the hips, the feet were in full contact with the force-plate and the knee joint was in an approximate 90° angle. The 90° angle of the knee joint was controlled by video-recording the SQJ attempt with a JVC GR-D720E video camera (Victor Company of Japan Ltd., Yokohama, Japan) which was connected to a PC through an IEEE 1394 interface (Texas Instruments Inc., Dallas, TX, USA). The camera was fixed on a stationary tripod placed at a height of 1.2 m and at a distance of 7 m from the participants. The optical axis of the camera was perpendicular to the sagittal plane of the participants. The recorded video was

Table 1
Participant characteristics (mean ± SD).

Group	*n*	Age (year)	Body height (m)	Body mass (kg)	Lean body mass (kg)	BMI (kg/m^2)
TF	51	20.3 ± 2.8	1.71 ± 0.07	65.5 ± 14.0	54.9 ± 11.7	22.5 ± 4.7
VO	48	19.6 ± 3.7	1.79 ± 0.06†	68.1 ± 5.5	53.3 ± 4.3	21.2 ± 1.4
HA	19	19.7 ± 2.9	1.68 ± 0.09$^{\#}$	67.4 ± 7.5	50.0 ± 5.6$^{\#}$	24.3 ± 5.0$^{\#}$
BA	18	21.6 ± 2.6	1.76 ± 0.08¶	71.4 ± 5.6	54.1 ± 4.2	23.1 ± 1.6
PE	37	20.0 ± 0.8	1.64 ± 0.06$^{†\#§}$	59.2 ± 9.6$^{\#§}$	46.0 ± 5.7$^{†\#§}$	21.9 ± 2.6

Abbreviations: TF = track and field athletes; VO = volleyball players; HA = handball players; BA = basketball players; PE = physical education students; BMI = body mass index.
$^{†}p < 0.05$, compared to TF, $^{\#}p < 0.05$, compared to VO, $^{¶}p < 0.05$, compared to HA, $^{§}p < 0.05$, compared to BA.

displayed simultaneously on the capture screen of the Kinovea 0.8.15 software (Joan Charmant & Contributors, Bordeaux, France). This enabled to project a right angle mark on the displayed video, which helped the researchers to guide the participants in order to acquire the initial squatting position. When the desired 90° knee angle was obtained, the participants were instructed to "jump as high and as fast as possible without a countermovement or the use of an arm-swing". This instruction was provided because the arm swing and the countermovement have independent effects on lower extremity work and their combined effect produce greater jump height by enabling mechanisms other than the concentric strength of the leg extensor muscles which is assessed by the SQJ test.[10,32,33] A couple of trials were allowed for familiarization. For an SQJ to be considered valid, the participants had to land on the force-plate and had to avoid any downward movement of the body. The latter was evaluated immediately using the time history curve of the recorded vertical ground reaction force (vGRF). If the vGRF curve progressed lower than the line representing the body mass at the initial stages of the propulsion phase, the attempt was not considered valid and it was repeated. The progression of the vGRF curve below the line representing the body mass indicates a downward movement of the body which is caused by a countermovement. As mentioned above, the validity of the SQJ test requires the absence of a countermovement, because it allows muscles to be activated in a higher level and thus a greater amount of force is produced compared to the concentric contraction of the leg extensor muscles.[33] In all cases, a minimum of 1-min interval was permitted between the executions of the SQJ in order to avoid fatigue. Only the best attempt, as indicated by the height of the jump achieved, was selected for further analysis.

2.3. Instrumentation and data acquisition

The values of the anthropometric characteristics of the participants were collected using a Laffayette skinfold caliper (Laffayette Instrument Co, Laffayette, IN, USA) and an SECA 220 scale with telescopic measuring rod (Seca Deutschland, Hamburg, Germany). Warm-up was conducted on a Monark 817E cycle ergometer (Exercise AB, Vansbro, Sweden). An AMTI OR6-5-1 force-plate (AMTI, Newton, MA, USA) was used to record the vGRF, which was sampled at a nominal frequency of 500 Hz. The signal from the force-plate was simultaneously stored in a Pentium II personal computer after being digitally converted using a PC-LabCard PCL-812PG (Advantech Co., Taiwan, China) 12 bit analogue-to-digital converter.

2.4. Data analysis

Custom designed software was used to extract the biomechanical parameters that define SQJ performance (achieved jump height, h_{jump}) from the recorded vGRF-time curve. h_{jump} was extracted using the body center of mass (BCM) vertical take-off velocity which was derived through the integration of the net vGRF. The analysis included only the best attempt, as indicated with the adoption of the criterion described above.

According to relative studies,[22–24,26,30] selected force and spatio-temporal parameters are included in PCA based on the fact that these parameters were found to represent the tendency of force- or time-dependency of SQJ performance. PCA is a mathematical procedure that investigates the variances of a set of variables and it is used as a descriptive tool.[34] PCA converts a large number of highly intercorrelated variables into a smaller number of linearly combined uncorrelated (i.e., "orthogonal") computed factors named principal components. If a substantial correlation exists among the initial variables, the first principal components will account for most (approximately 70%–90%) of the variation of the original variables.[34] Thus, the derived principal components preserve most of the information given by the initial variables. This procedure extracts a factor pattern matrix, in which the number of principal components is defined by the number of eigenvalues larger than 1. This is adopted because a principal component with a variance less than the above mentioned value contains less information than of the original variance (Kaiser's rule).[34] In order to rationalize the identification of the extracted factors, the factor pattern matrix is rotated using specific criterions (i.e., the loadings of the variables on the extracted factor) and a number of iterations of the procedure in a way that the original variables are eventually strongly related to one of the extracted principal components. The use of PCA assists the acquisition of information about the force- or time-dependency of an individual's jumping profile by reducing the large number of biomechanical parameters needed to express vertical jumping performance into the coordinates of the factor scores (the plot of the individual scores on the rotated principal components).[22] Under this perspective, the following force and spatio-temporal parameters were calculated (Fig. 1): peak vGRF relative to body mass (F_{Zbm}), peak power relative to body mass (P_{bm}), maximum rate of force development (RFD_{max}), impulse time (t_{C}), time to achieve peak force (t_{FZmax}), and vertical BCM trajectory during the propulsion phase (S_{BCM}). RFD_{max} was directly extracted as the first time derivative of the recorded vGRF. P_{bm} was obtained by multiplying the vGRF by the vertical BCM velocity during the propulsive phase and divided by the participant's body mass. S_{BCM}, from the initial starting position described in Section 2.2 to the instant of take-off, was extracted through integration of the vertical BCM velocity.

2.5. Statistical analysis

Data were presented as mean ± SD and differences concerning the anthropometric data and the biomechanical parameters were identified with a one-way analysis of variance (ANOVA). A Scheffe *post-hoc* analysis with Bonferroni adjustment was conducted to detect differences among groups. Two-tailed Pearson correlation was used to detect the relationships among the anthropometric data and h_{jump}. A PCA utilizing a Varimax rotation with Kaiser normalization on the data from the 173 participants was executed to

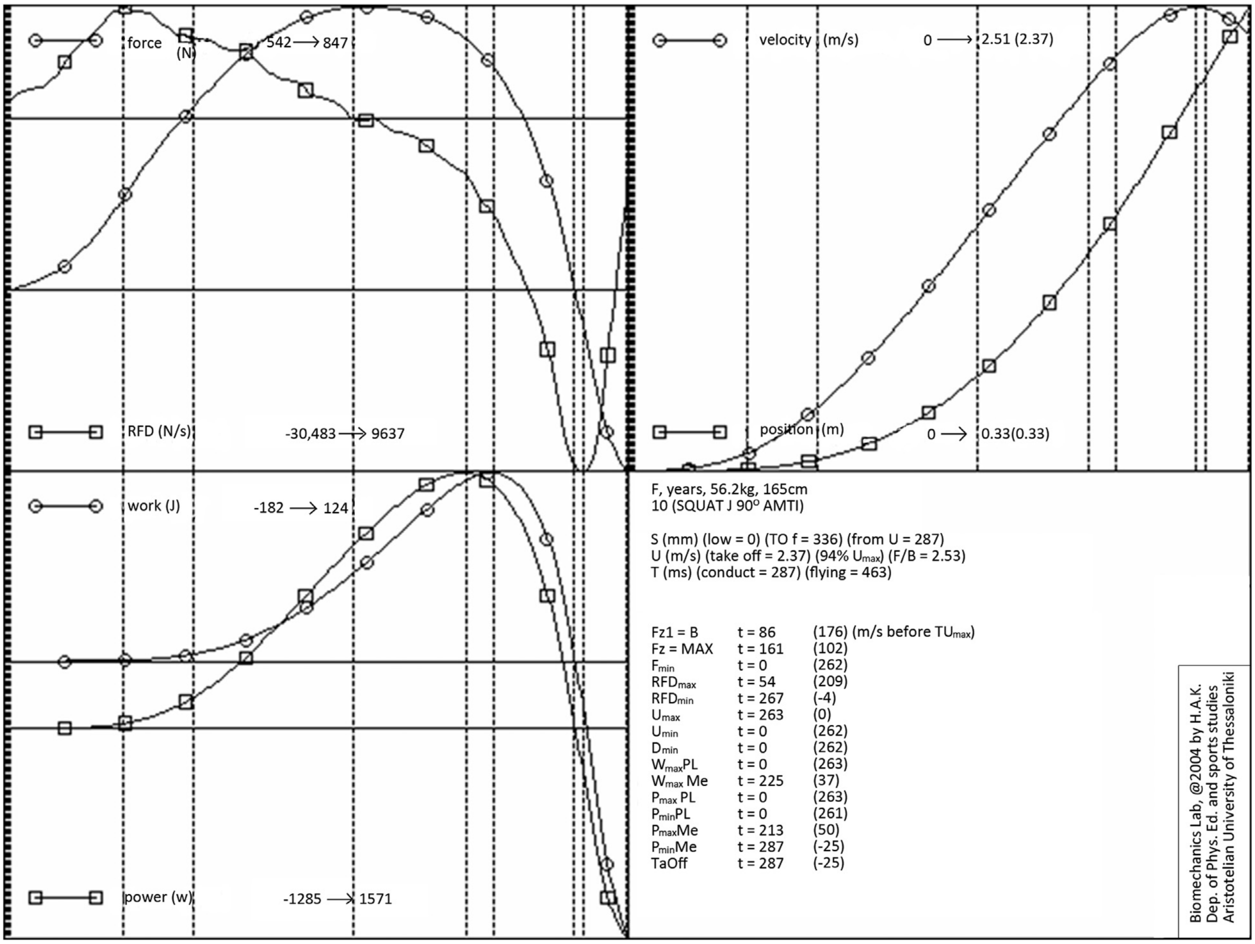

Fig. 1. A typical vertical ground reaction force curve (upper left plot, force) and the parameters calculated from it (rate of force development (RFD), work, power, velocity, position of the body center of mass). Values next to the curve legends represent the minimum and maximum values of each parameter during the push-off. The lower right section provides the details concerning the selected time instances of achieving maximum and minimum values during the jump.

examine the individual tendency toward force- or time-dependency for the achievement of maximum SQJ performance. The number of principal components in the extracted factor matrix was determined by the number of eigenvalues larger than one. Crombach's α was used to test the reliability of the extracted rotated principal components. Differentiations among athletes of different sports concerning the tendency for force- or time-dependency were searched by plotting the individual factor regression scores on the rotated principal components and by performing an one-way ANOVA and Scheffe *post-hoc* analysis with Bonferroni adjustment on the extracted individual factor regression scores. The level of significance was set at $p = 0.05$ for all statistical procedures. SPSS 10.0.1 software (SPSS Inc., Chicago, IL, USA) was used for the execution of the statistical tests.

3. Results

3.1. Anthropometric data

The comparison of anthropometric data revealed that VO were taller ($p < 0.05$) compared to HA, TF, and PE (Table 1). HA were also significantly shorter ($p < 0.05$) than BA. Additionally, PE were significantly lighter than VO and BA and also had lower lean body mass compared to TF, VO, and BA ($p < 0.05$). HA had the largest body mass index (BMI), which was significantly larger compared to VO ($p < 0.05$).

3.2. Group results for the examined SQJ biomechanical parameters

Results indicated that participants executed the SQJ in a consistent manner (intraclass correlation coefficient: 0.95, coefficient of variation: 2.9% ± 2.2%), but the values of the biomechanical parameters were significantly different ($p < 0.05$) among the examined groups (Table 2). In detail, the *post-hoc* analysis revealed that TF achieved the highest h_{jump} ($p < 0.05$) after producing the largest P_{bm} ($p < 0.05$) compared to the rest of the participants. Furthermore, TF was observed to have applied significantly higher F_{Zbm} ($p < 0.05$) than VO, HA, and PE. Significantly faster t_C and t_{FZmax} ($p < 0.05$) was noted for TF compared to VO and HA, who both in turn were significantly slower ($p < 0.05$) in the above mentioned parameters than BA and PE. Lower value for

Table 2
Group results for the biomechanical parameters of the squat jump (mean ± SD).

Parameter	TF	VO	HA	BA	PE
h_{jump} (m)	0.24 ± 0.05	0.21 ± 0.03†	0.18 ± 0.03†	0.18 ± 0.05†	0.16 ± 0.03$^{†\#¶§}$
t_C (ms)	566 ± 146	684 ± 139†	702 ± 162†	560 ± 122$^{\#¶}$	552 ± 98$^{\#¶}$
t_{FZmax} (ms)	431 ± 148	525 ± 126†	560 ± 177†	387 ± 128$^{\#¶}$	401 ± 115$^{\#¶}$
S_{BCM} (m)	0.42 ± 0.07	0.47 ± 0.09	0.42 ± 0.07	0.43 ± 0.06	0.32 ± 0.07$^{†\#¶§}$
F_{Zbm} (N/kg)	2.34 ± 0.19	2.02 ± 0.17†	2.13 ± 0.18†	2.24 ± 0.18$^{\#}$	2.14 ± 0.37†
P_{bm} (W/kg)	26.42 ± 4.17	20.53 ± 2.62†	20.58 ± 3.49†	21.82 ± 1.88†	18.10 ± 4.10†§
RFD_{max} (kN/s)	8.9 ± 3.6	6.2 ± 1.9†	7.6 ± 2.8	8.7 ± 2.6	8.3 ± 7.2

Abbreviations: h_{jump} = height of jump; t_C = impulse time; t_{FZmax} = time to achieve peak force; S_{BCM} = vertical body center of mass trajectory during the propulsion phase; F_{Zbm} = peak force relative to body mass; P_{bm} = peak power relative to body mass; RFD_{max} = maximum rate of force development; TF = track and field athletes; VO = volleyball players; HA = handball players; BA = basketball players; PE = physical education students.
$^{†}p < 0.05$, compared to TF, $^{\#}p < 0.05$, compared to VO, $^{¶}p < 0.05$, compared to HA, $^{§}p < 0.05$, compared to BA.

RFD_{max} was recorded for VO compared to TF ($p < 0.05$). Finally, PE had the shortest S_{BCM} compared to the examined groups of athletes ($p < 0.05$).

3.3. Results of correlation and principal components analysis

h_{jump} was found to be negatively correlated with body mass ($r = -0.26$, $p = 0.001$) but not with lean body mass ($r = -0.11, p > 0.05$) or body height ($r = 0.04, p > 0.05$). The force parameters examined (F_{Zbm}, P_{bm}, and RFD_{max}) were significantly ($p < 0.001$) correlated to each other, with correlation coefficients (r) ranging from 0.32 to 0.73 (Table 3). Lower, yet significant, correlation coefficients were observed among the spatio-temporal parameters (t_C, t_{FZmax}, and S_{BCM}) as well ($p < 0.01$). With the exception of P_{bm}, negative correlations were detected between the spatio-temporal and the force parameters. h_{jump} was highly correlated with P_{bm} ($r = 0.70$, $p < 0.001$).

The correlation analysis revealed that it was valid to conduct the PCA because significant intercorrelations were detected among the tested variables. PCA revealed the existence of two principal components that explained 69.1% of the variance of the examined biomechanical parameters. The variable scores of the two extracted principal components are presented in Fig. 2. The first rotated principal component, which accounted for 40.2% of the variance, was interpreted to be associated with the time characteristics of SQJ (eigenvalue: 2.41) since it was linked with the spatio-temporal parameters (S_{BCM}, t_C, t_{FZmax}). In detail, S_{BCM}, t_C, t_{FZmax} were highly and positively loaded on this factor (loadings: 0.60−0.93; communalities: 0.36−0.88; $\alpha = 0.65$). These loadings suggest that long t_C is combined with larger S_{BCM} and slower t_{FZmax}. Negative relationships on this principal component (individuals spotted in sections A and C, Fig. 3) indicate, with respect to force application, fast athletes, while positive relationships represent slow athletes (sections B and D). The second rotated principal component accounted for 28.9% of the variance and was related with the force characteristics (F_{Zbm}, P_{bm}, and RFD_{max}) of SQJ (eigenvalue: 1.73). In specific, F_{Zbm}, P_{bm}, and RFD_{max} had high positive loadings of 0.92, 0.89, and 0.59 respectively on this factor (commonalities: 0.36−0.87; $\alpha = 0.72$). These loadings suggest that high F_{Zbm} was achieved through high RFD_{max} and thus resulted in large P_{bm}. Positive relationships on this principal component (individuals spotted in sections A and B, Fig. 3) suggest strong athletes, while negative relationships are interpreted to represent weak athletes (sections C and D).

The individual regression scores on the two principal components of the examined athletes for SQJ are plotted in Fig. 3. The horizontal axis corresponded to the component identified as time-dependent, while the vertical axis was suggested to represent force-dependency. In general, the regression scores seem to be concentrated on the horizontal axis. As mentioned above, athletes with high positive loadings on the second principal component and high negative loadings on the first principal component are more likely to produce larger peak force and power outputs in a shorter duration of impulse. Thus, “fast and strong” (i.e., powerful, since power = force × velocity) athletes are marked in the upper left section of the plot, a section mostly marked by TF. On the other hand, the vast majority of PE was in the bottom left section. This could be interpreted that PE, despite having a fast t_C, failed to produce large F_{Zbm} and P_{bm} to accelerate and to raise their BCM during the propulsion phase resulting in their poor SQJ performance. These two distinct patterns of the utilization of the biomechanical parameters for maximizing SQJ performance exhibited by TF and PE were verified by the analysis of variance of the regression scores on the vertical and horizontal axes, respectively. Furthermore, BA were linked more to a “fast” profile compared to HA and VO ($p < 0.05$),

Table 3
Correlation matrix presenting the relationship among the examined biomechanical parameters and the squat jump height ($n = 173$).

Parameter	h_{jump}	t_C	t_{FZmax}	S_{BCM}	F_{Zbm}	P_{bm}	RFD_{max}
h_{jump}	–	0.03	0.13	0.21**	0.30***	0.70***	−0.07
t_C		–	0.92**	0.21**	−0.29***	−0.14^{a}	−0.23**
t_{FZmax}			–	0.24**	−0.25**	−0.04	−0.26**
S_{BCM}				–	−0.26**	0.17*	−0.33***
F_{Zbm}					–	0.73***	0.66***
P_{bm}						–	0.32***
RFD_{max}							–

Abbreviations: h_{jump} = height of jump; t_C = impulse time; t_{FZmax} = time to achieve peak force; S_{BCM} = vertical body center of mass trajectory during the propulsion phase; F_{Zbm} = peak force relative to body mass; P_{bm} = peak power relative to body mass; RFD_{max} = maximum rate of force development.
*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$; ^{a} $p = 0.057$.

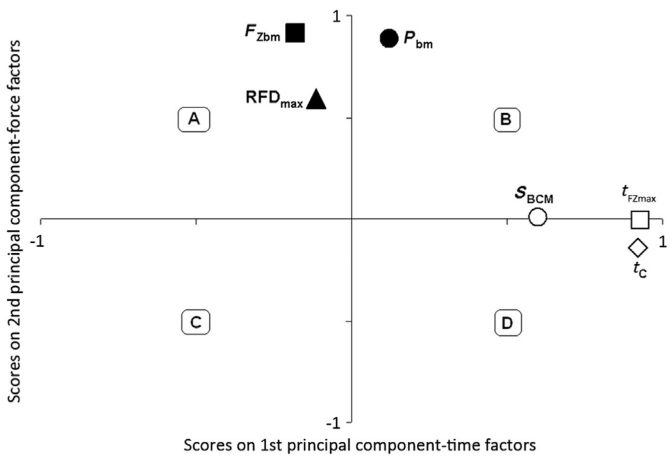

Fig. 2. The extracted principal components and factor loadings. Based on the plotting of the factor loadings of the initial variables, the extracted components were defined to represent the "time" (on the horizontal axis; S_{BCM}: the vertical body center of mass trajectory during the propulsion phase; t_{C}: impulse time; t_{FZmax}: the time to achieve peak vGRF) and the "force" (on the vertical axis; F_{Zbm}: peak vGRF relative to body mass; P_{bm}: peak power relative to body mass; $\mathrm{RFD}_{\mathrm{max}}$: the maximum rate of vGRF development) factors. In further detail, section (A) represents "strong and fast" athletes, section (B) represents "strong and slow" athletes, section (C) represents "weak and fast" athletes, and section (D) represents "weak and slow" athletes.

despite the fact that these groups showed the same force-dependent profile.

The different force/time-dependent profiles indicated by the individual regression scores on the two principal components could be used to better interpret the initial vGRF, P_{bm}, and vertical BCM velocity curves. Fig. 4 presents two cases on the opposite ends of the plots: a sprinter (TF) from the "fast and

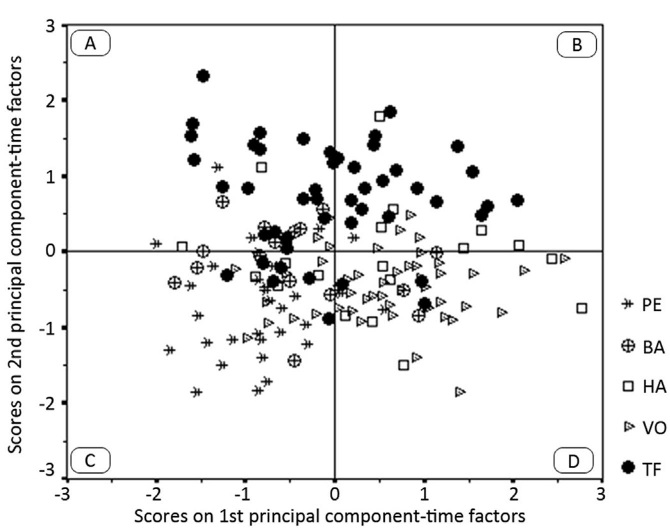

Fig. 3. Individual regression factor scores on the two rotated principal components. Section (A) represents "strong and fast" athletes; section (B) represents "strong and slow" athletes; section (C) represents "weak and fast" athletes; and section (D) represents "weak and slow" athletes (see text for further details). Abbreviations: PE = physical education students; BA = basketball players; HA = handball players; VO = volleyball players; TF = track and field athletes.

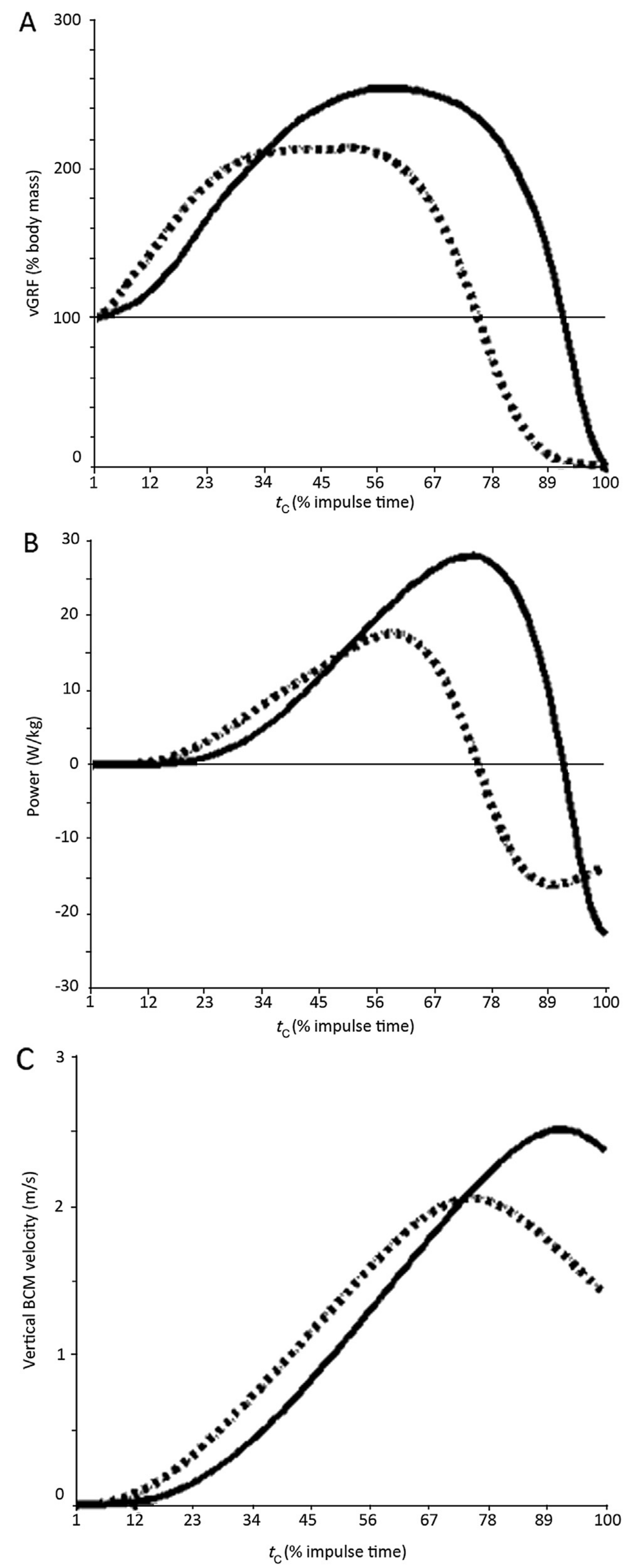

Fig. 4. Representative vertical ground reaction force (A), whole body power output (B) and vertical body center of mass velocity (C) curves of an sprinter (solid line) from the "strong and fast" section and a handball player (dotted line) from the "weak and slow" section of the plot of the individual regression scores on the extracted principal components. All curves are normalized with respect to impulse time (t_{C}). vGRF = vertical ground reaction force.

strong" section and a goalkeeper (HA) from the "weak and slow" section. TF has a steeper ascent and a higher peak in all three curves compared to HA, thus justifying their positioning on the plot.

4. Discussion

Results indicated that the sport specific background had an effect on the biomechanical parameters that define the vertical SQJ performance in young adult female athletes from different sports, since differences concerning the force- and time-dependency were observed among the examined groups. In detail, TF achieved the highest h_{jump} and the largest P_{bm} among the participants, and alterations were observed among the indoor team sport athletes concerning t_C and t_{FZmax}. Despite being the first (to the best of our knowledge) research dealing with the principal component structure of SQJ for female athletes, the present results verified previous findings concerning the importance of power on vertical jumping ability[2,11−14,27,35] and the differentiations of jumping ability parameters among different groups of athletes.[15,18,19,22−26]

Alterations in ability is believed to be characterized by particular, well distinguished anthropometric and biomotor profiles for each sport from the early stages of participation.[36−38] The present findings suggested that body height and lean body mass were found to be unrelated to the values of the biomechanical parameters and h_{jump}. Additionally, the intra-group comparisons of the anthropometric parameters were in agreement with previous findings.[31,35,39−44] In particular, the participants with the higher lean body mass (mainly TF and VO) had the better SQJ performance. This could be interpreted under the perspective that body mass has been found to be a predictor of vertical jumping height.[44,45] However, the total body mass was found to be negatively related to h_{jump}. This was a result of the fact that the heavier team sport athletes (BA and HA) had the lowest SQJ performance. It could be suggested from the present results that the produced whole body power output for the heavier athletes was not efficient enough for accelerating the BCM during the propulsion.

Vertical jumping performance was found to be different among athletes from different sporting backgrounds, confirming similar comparisons.[19,37] This study reproduces the finding that female TF exert larger power outputs in shorter impulse times compared to other athletes.[19] This seems reasonable since the force parameters and power in particular has been found to be correlated with jumping height and thus they are considered to define jumping performance in women.[37,41,44,46] In the present study, young adult female TF displayed a force-dependent SQJ execution compared to the other groups of athletes, since TF performed the SQJ using a "fast and strong" pattern. Sport specificity of SQJ execution could be supported by the individual plotting. Based upon the participants' distribution in each section, TF are mainly at the "strong", BA at the "fast", PE at the "weak", and HA at the "slow" section of the principal components plot. The present study reveals that female TF enabled a distinguished power pattern for executing the SQJ, confirming previous findings for male TF.[22,26] An additional factor to support TF superiority in h_{jump} is thought to be connected with the finding that TF have a larger force production capacity of leg extensor muscles compared to other athletes,[17] with the knee extensors to be suggested as the major contributors to double leg vertical jump performance from a standing position.[1,47] It was also confirmed that VO adopted a jumping pattern emphasizing on long t_C and low F_{Zbm} as found elsewhere.[26] Being in agreement with the previous studies,[22,26] team sport athletes were characterized by a less effective utilization of the SQJ force parameters than TF. Similar observations[37] have attributed this finding to the fact that TF use a larger portion of single over double legged stationary jumps in training contrarily to the other groups. This training modality was found to be effective for strength and concentric power production of the lower extremities[47,48] and it composes a factor that is suggested to distinguish the jumping ability among TF and team sport athletes.[26] In general, differences in vertical jumping ability among different group of athletes has being attributed to the fact that prolonged training in a specific sport causes the central nervous system to program the muscle coordination for the execution of the jump according to the demands of that sport.[15]

Despite the fact that previous PCA studies on vertical jumping accounted for a higher percentage of variance (ranging from 74.1% to 78.8%),[22−24,26,30] the reliability scores of the two extracted rotated principal components revealed the validity of the present findings. Additionally, as mentioned previously, the comparison of the biomechanical parameters among the examined groups was consistent with previous findings for female athletes.[19,37] However, h_{jump} achieved in the present study seems to be lower than reported elsewhere for respective groups of female athletes.[42,49−55] Besides skill level, the experimental procedure to disallow the use of the arm swing for the jump seems to attribute to these alterations.[53,54] Another constrain was the instruction given to the participants to "jump as high and as fast as possible". This is because temporal constrains are suggested to be a factor for the relevancy of RFD to achieve maximum jumping heights.[21] Additionally, the starting posture with the demand of full foot contact on the force-plate imposes a limitation regarding the ankle flexion that differentiates SQJ performance,[56,57] particularly for females with limited ankle dorsi-flexion.[58]

The results of the present study converge to the finding that the factor that differentiated SQJ performance among groups of young female athletes with different sporting backgrounds was the whole body peak mechanical power output and the force/time structure of the jump. This finding relays on the fact that many sport jumps are time-restricted with a combined demand for a maximization of the propulsive impulse.[59] The achievement of such a performance is determined by maximizing the capabilities of the lower limb neuromuscular system concerning its power output and by optimizing its force-velocity mechanical profile.[60] Under this perspective, neuromuscular and power training is found to be effective for enhancing vertical jump performance and is recommended for team sport athletes,[49,51–54] taking into consideration the player's playing position and skill level.[52,53]

5. Conclusion

Based on the findings of the present study, PCA is a suitable method to detect the reliance upon force- or time-dependency of vertical squat jump performance of young adult female athletes from different sports. Additionally, this method could be possibly used for talent identification and sport orientation of young female athletes on the basis of recognizing sport-specific force/time profiles of vertical squat jumping. For example, an individual's jumping pattern characterized by long impulse time and low force application could be interpreted as volleyball rather than a track and field sport specific skill. Furthermore, in the case of indoor team sport athletes, the need for larger jumping heights in limited time, as defined by the demands of their sporting activities, could be fulfilled by adopting the power-specific jumping exercises and training modalities used by TF.

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