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Quasi-simplex Structure among Physical Ability Factors with Relation to Sprint Speed in Pubescent Male Soccer Players

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The purpose of this study was to determine the quasi-simplex structure among physical ability factors with relation to sprint speed in pubescent male soccer players. Pubescent male soccer players aged 13.7 ± 1.2 years (U-15 category) volunteered to participate in this study, and their relative peak height velocity age (the maturity status factor), 70% and 30% leg muscle cross sectional areas (the leg muscle size factor), knee extension torque and knee flexion torque (the leg muscle strength factor), five-step jump and counter movement jump tests (the jump power factor), 20-m and 5-m sprint tests (the sprint speed factor) were measured. The quasi-simplex structure of measurement items or physical ability factors among pubescent soccer players was analyzed statistically using a correlation matrix and structural equation modeling (SEM). The correlation matrix of the measurement items indicated a quasi-simplex structure. The quasi-simplex structure model of the physical ability factors indicated a goodness-of-fit. The degree of the model fitting indicators were 14.439 (0.914) for Chi-square (p-value), 0.928 for GFI, 0.859 for AGFI, 1.000 for CFI, 0.969 for NFI, 0.951 for RFI and 0.000 for RMSEA. Pass coefficients between physical ability factors were statistically significant ($p < 0.05$). In conclusion, it was statistically demonstrated that a quasi-simplex structure in which maturity status influences leg muscle size, leg muscle size influences leg muscle strength, leg muscle strength influences jump power, jump power influences sprint speed exists.

Keywords: Growth and development, Peak height velocity, Speed, Power, Strength

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1. Introduction

With regards to the selection of pubescent soccer players, there is a trend of fast players being chosen (Hirose, 2008). Yagüe & Fuente (1998) reported that sprint speed develops remarkably before and after peak height velocity age (PHVA). As a difference of four to five years in PHVA may be observed even in players of the same chronological age (Chuman et al., 2009), it is believed that the closer early-maturing players get to PHVA during puberty, the higher their sprint speed. We have previously reported in an earlier study that there is a significant correlation between 20-m sprint times (sprint speed) and PHVA (maturity status) (Chuman et al., 2013).

Yamada & Nishijima (2001) arrayed the physical ability factors that soccer players should aim to achieve through power development programs with strength, power and speed, and showed that these physical ability factors follow a simplex structure. A simplex structure refers to differences in the extent of compositeness among tests shown using a simple hierarchical system (Guttman, 1966). In the correlation matrix among the physical ability tests arrayed with strength, power and speed, there exists a structure in which values that are closer to the main diagonal are larger while values that are further away are smaller (Yamada & Nishijima, 2001). While the correlation coefficient changes by a predetermined percentage according to the composite loading under a perfect simplex structure, as the actual test includes errors in the variables, the correlation coefficient does not change by a predetermined percentage. This type of structure is known as a quasi-simplex structure.

In the case of pubescent soccer players, the factors behind the development of strength, power and speed include not only training but also the influence of growth. As a result of a heightened maturity status, one's physique, as well as physical ability, develops. As remarkable differences in maturity statuses among pubescent soccer players have been confirmed (Chuman et al., 2009), it is believed that differences in physique and physical ability (strength, power and speed) arise as a result of maturity status. In other words, among pubescent soccer players, maturity status does not directly affect sprint speed; instead, it is believed that there exists a quasi-simplex structure where maturity status influences physique (leg muscle size), physique influences strength (leg muscle streugth), strength influences power (jump power) and power (jump power) influences speed (sprint speed, see **Figure 1**).

However, there have not been reports examining the quasi-simplex structure among the physical ability factors that contribute to the sprint speed of pubescent soccer players. Clarifying the hierarchy of such factors allows pubescent soccer players to grasp their strengths and weaknesses in physical ability through comparative evaluation on an individual basis, and verify which are the areas that they should focus on for training in the future in order to become professional soccer players. To validate and analyze such a quasi-simplex structure, Structural Equation Modeling (SEM) may be used (Yamada & Nishijima, 2001). On that note, this study sets out to validate the quasi-simplex structure among physical ability factors related to sprint speed among pubescent soccer players using SEM.

2. Methods

42 field soccer players (13.7 ± 1.2 years old) belonging to U-15 category (junior high school students aged 13-15 years) team of club participating in the Japan Professional Football League Division 1 (J1-League) were chosen as subjects for this study. The subjects were all male players who had been selected through the soccer selection process. The subjects had permission from their parents and guardians to participate in the training with their soccer club, and this study was conducted as a part of their training under the management of the supervisor of the soccer club. This study is endorsed by the Ethics Committee of the University of Tsukuba.

In this study, we validated the conceptual model shown in **Table 1** based on the hypothesis that a quasi-simplex structure exists among physical ability factors related to sprint speed among pubescent soccer players. Nine items that fulfilled the condition of content validity with respect to the five factors were chosen as measurement items. The item chosen for maturity status factor was relative peak height velocity age (RPHVA). PHVA was calculated from the height and chronological age (CA) during the nine years between seven and fifteen years of age using the BTT model of AUXAL3 (SSI), which is a software for analyzing vertical height. In addition, RPHVA at the time of the 20-m sprint trial was calculated by subtracting PHVA from the chronological ages of the subjects. School annual health reports were used to determine height between seven and twelve years of age while height between thirteen and fifteen years of age was measured at the time of the trial.

The item chosen for leg muscle size factor was thigh muscle cross sectional area (MCSA). The MR machine of 0.2T (Signa Profile, GE Yokogawa Medical Systems Ltd.) was used to take cross sectional images of the thighs of the subjects. The distance between the upper extreme of the greater trochanter and the lower extreme of the femur was designated as femur length, and the area of the muscle (30% MCSA and 70% MCSA) was calculated from the images at 30% and 70% of the femur length (from the distal end).

The items chosen for leg muscle strength factor were knee extension torque (KET) and knee flexion torque (KFT), as measured by an isokinetic dynamometer (Biodex-System3, Biodex Medical

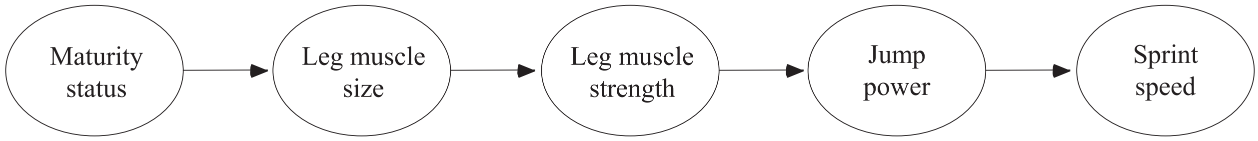

Figure 1 Conceptual model of physical ability factors in pubescent male soccer players.

Table 1 Descriptive statistics (N=42).

Item	Mean ± S.D.	Min	Max
CA (years old)	13.7 ± 1.2	12.2	15.5
PHVA (years old)	12.7 ± 1.0	11.1	15.3
RPHVA (years old)	0.93 ± 1.4	-1.82	3.77
Height (cm)	162.9 ± 8.2	142.2	180.1
Body mass (kg)	51.1 ± 9.7	33.3	82.3
70%MCSA (cm^2)	126.8 ± 26.0	88.8	194.1
30%MCSA (cm^2)	78.1 ± 17.5	48.5	124.5
KET (Nm)	130.9 ± 38.5	52.9	243.0
KFT (Nm)	68.1 ± 22.1	28.2	140.6
5J (m)	10.64 ± 1.03	8.80	12.91
CMJ (cm)	47.0 ± 5.7	35.9	59.9
20MST (km/h)	22.3 ± 1.0	20.1	24.2
5MST (km/h)	16.9 ± 0.8	15.2	18.5

Systems Inc.). The measurements were conducted based on an angular velocity of 60 degrees.

The items chosen for jump power factor were the counter movement jump test (CMJ) and the five-step jump test (5J). For CMJ, the side view of the jumping motion of the subjects was taken using a video camera (at 30 frames/sec) and the vertices of the subjects were identified using the differences in brightness; jump height was then calculated from the difference in height up to the subjects' vertices at standing and upon jumping. Note that jump height was obtained by recording images of a calibration instrument with multiple attached markers beforehand and converted based on the actual length between markers and the number of pixels. For 5J, subjects were made to adopt a starting position with both feet together, jump five times while alternating between their left and right feet, and end with both feet on the ground. The shortest distance between the subject's toe at the start of the test and the subject's heel upon landing was measured, and this was used as the result for 5J.

The items chosen for sprint speed factor were the 5-m and 20-m sprint tests (5MST and 20MST). Using a photoelectric measurement device (Hamamatsu Photonics K.K.), the measurement was started at the instant the subject's foot left the ground, and the time until his body passed the light sensor set up at the 5-m and 20-m positions was converted into speed (km/h). This was then recorded as the result for the 5-m and 20-m sprints.

This study sought to validate the quasi-simplex structure according to the following procedure based on the methodology of Yamada & Nishijima (2001): (1) constructing a measurement model that fulfills the condition of content validity; (2) conducting the test; (3) calculating the descriptive statistics (mean ± standard deviation); (4) examining the construct validity through the confirmatory factor analysis using structure equation modeling (SEM); (5) examining the hierarchy among the physical ability factors using the multiple indicator model obtained using SEM. For the SEM parameter estimation, maximum-likelihood estimation, the most commonly used method in applied research using SEM, was used (Toyoda, 1992). In the interests of discrimination, parameter control was implemented. The control conditions were: (1) fixing the path coefficient from the error variable to the endogenous variables at 1; (2) fixing the path coefficient from the latent variables, which is an endogenous variable, to the observed variable at 1; (3) fixing the variance of the latent variables, which is an exogenous variable, at 1; (4) fixing the variance of the error variable e1 at 0. For the degree of the model fitting indicators,χ^2(P value), GFI, AGFI, CFI, NFI, RFI and RMSEA were used. The significance level was designated as $p < 0.05$. SPSS 12.0J for Windows and Amos 5.0J were used in the statistical analysis.

3. Results

Table 2 shows the correlation matrix among the observed variables. Significant correlation coefficients (r = 0.53–0.94) were obtained among all the observed variables. **Table 3** shows the correlation matrix among the factors. Significant correlation coefficients (r = 0.70–0.90) were obtained among all the factors.

Figure 2 shows the standardized solution of the confirmatory factor structure. The degree of the model fitting indicators was obtained as χ^2= 16.472 (P value = 0.626), GFI = 0.918, AGFI = 0.805, CFI = 1.000, NFI = 0.964, RFI = 0.932, RMSEA = 0.000. The path coefficients among the factors reflected values from 0.70 to 0.90. The path coefficients from the factors to the observed variables reflected values from 0.85 to

Table 2 Correlation matrix among measurement items (N=42).

Factors	Item	RPHVA	70%MCSA	30%MCSA	KET	KFT	5J	CMJ	20MST	5MST
Maturity status	RPHVA	—								
Leg muscle size	70%MCSA	0.85	—							
	30%MCSA	0.84	0.94	—						
Leg muscle strength	KET	0.77	0.86	0.79	—					
	KFT	0.71	0.78	0.70	0.83	—				
Jump power	5J	0.74	0.75	0.71	0.68	0.58	—			
	CMJ	0.64	0.74	0.66	0.66	0.53	0.78	—		
Sprint speed	20MST	0.73	0.80	0.72	0.68	0.59	0.81	0.75	—	
	5MST	0.66	0.67	0.59	0.59	0.58	0.71	0.60	0.88	—

Table 3 Correlation matrix among physical ability factors (N=42).

Factors	F1	F2	F3	F4	F5
F1: Maturity status	—				
F2: Leg muscle size	0.85	—			
F3: Leg muscle strength	0.81	0.90	—		
F4: Jump power	0.79	0.84	0.78	—	
F5: Sprint speed	0.73	0.80	0.70	0.88	—

1.00. The values of the path coefficients in the model were all significant.

Figure 3 shows the standardized solution of the quasi-simplex structure among the physical ability factors related to sprint speed among pubescent soccer players. The degree of the model fitting indicators was obtained as χ^2= 14.439 (P value = 0.914), GFI = 0.928, AGFI = 0.859, CFI = 1.000, NFI = 0.969, RFI = 0.951, RMSEA = 0.000. The path coefficients among the factors were 0.91 from the maturity status factor to the leg muscle size factor, 0.99 from the leg muscle size factor to the leg muscle strength factor, 0.87 from the leg muscle strength factor to the jump power factor and 0.91 from the jump power factor to the sprint speed factor. The path coefficients from the factors to the observed variables reflected values from 0.78 to 1.00. The values of the path coefficients in the model were all significant.

4. Discussion

First, we examined the construct validity of the nine observed variables that explain the five latent variables in the conceptual model (**Figure 1**) for this study (**Figure 2**). The construct validity coefficient, represented by the path coefficient from the latent variables to the observed variables, reflected significant, large values from 0.85 to 1.00. In addition, the degree of the model fitting indicators was favorable, and it was shown that the nine observed variables used fulfill the condition of construct validity.

The simplex structure among test items may be confirmed from the correlation matrix among the test items. In the case where it may be verified that the correlation matrix bears a simplex structure, the closer the elements to the main diagonal in the correlation matrix the higher the correlation, and the further they are located towards the top right or bottom left the lower the correlation. In the case of cross sectional data, where there exists a hierarchical inclusion relation among the test items that fulfills the condition of content validity, a simplex structure may be observed from the correlation matrix. In the correlation matrix among the nine observed variables for which construct validity was verified, the correlations (r = 0.53–0.94) were all found to be significant (**Table 2**). It was confirmed that the

N=42, χ^2=16.472 (P value=.626), GFI=.918, AGFI=.805, CFI=1.000, NFI=.964, RFI=.932, RMSEA=.000

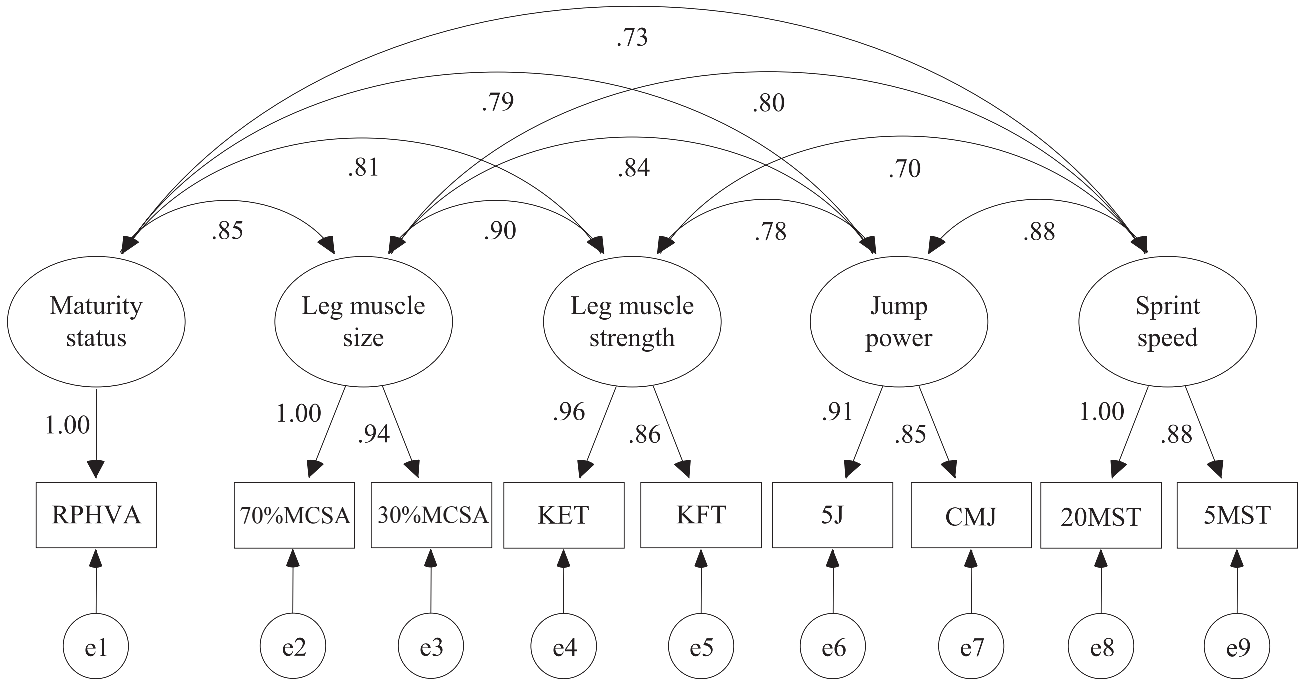

Figure 2 Confirmatory factor structure of physical ability factors in pubescent male soccer players.

N=42, χ^2=14.439 (P value=.914), GFI=.928, AGFI=.859, CFI=1.000, NFI=.969, RFI=.951, RMSEA=.000

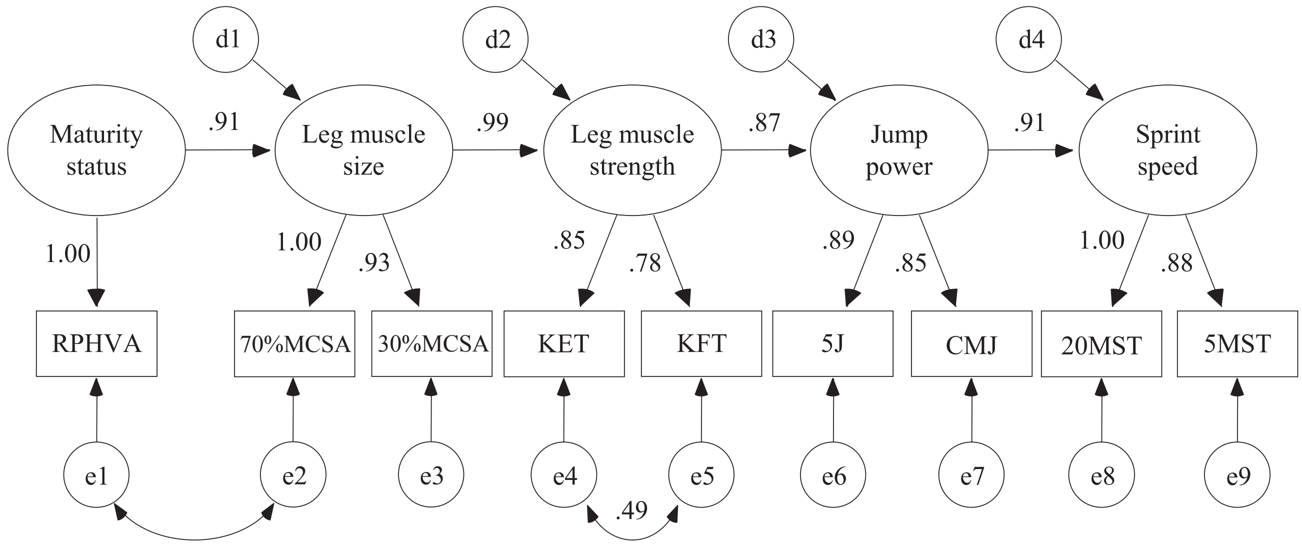

Figure 3 Quasi-simplex structure of physical ability factors in pubescent male soccer players.

correlation at the main diagonal of the correlation matrix was high, while a trend of low correlation as we move away from the main diagonal was verified. This result shows that the correlation matrix of the nine observed variables bears a simplex structure. In addition, significant correlations (r = 0.70–0.90) were also found among the five factors that are explained by the nine observed variables (**Table 3**). Arraying these observed variables or factors according to the permutations of the factors in the conceptual model (**Figure 1**), a trend in which the nearer to the main diagonal the higher the correlation and the further away the smaller the correlation was verified in both cases. These results show that the correlation matrix among the five factors bears a simplex structure (**Table 2** and **Table 3**). The hierarchy explained by a quasi-simplex structure refers to a relationship in which lower factors are included in upper factors. As it was verified that the correlation matrices among the permutated observed variables and among the factors bear a simplex structure, it may be inferred that the observed variables and factors in this study fulfill the condition of following a simplex structure.

Analyzing the conceptual model in **Figure 1** using SEM, the degree of the model fitting factors reflects favorable values, and significantly high path coefficients (0.87–0.99) were verified among the factors (**Figure 2**). These path coefficients were higher than the correlation coefficient between the maturity status factor and the sprint speed factor (r = 0.73). In other words, the relationships among factors permutated using the conceptual model were all stronger than the relationship between the maturity status factor and the sprint speed factor.

The path coefficient from the maturity status factor to the leg muscle size factor was 0.91, and a strong causal relationship was found between the two factors. As the production of the protein anabolism hormone increases during puberty, growth in height is remarkable. In addition, the increase in muscle size reaches its maximum within one year of reaching PHVA (Beunen and Malina, 1988). However, it has been reported that a difference of four to five years in maturity status exists among pubescent soccer players (Chuman et al., 2009). This large difference in maturity status causes early-maturing players to approach maximum growth in muscle volume earlier than late-maturing players, and the thigh muscle cross sectional area (MCSA) increases (Chuman et al., 2009). Looking at these results, it may be surmised that among pubescent soccer players, the maturity status factor strongly influences the leg muscle size factor.

Next, the path coefficient from the leg muscle size factor to the leg muscle strength factor was 0.99, and a strong causal relationship was found between the two factors. As the representative muscular tension (specific tension) per unit of MCSA is almost constant, it is believed that the leg muscle size factor measured using thigh MCSA reflects the specific tension of the thigh muscle. On the other hand, the leg muscle strength factor reflects the specific tension and maximum voluntary contraction, which is determined by motor unit recruitment and their frequencies, of the thigh muscle. The similarity between the two is that both reflect the specific tension of the thigh muscle, while the difference is that the leg muscle strength factor reflects neural factors as well. Hoshikawa et al. (2008) reported that among male sports players (including soccer player) aged 15.2 years (junior high school students), the larger the thigh MCSA, the higher the knee strength. Based on these findings, it may be surmised that although the leg muscle size factor and the leg muscle strength factor are independent factors, among pubescent soccer players, the leg muscle size factor strongly influences the leg muscle strength factor.

The path coefficient from the leg muscle strength coefficient to the jump power coefficient was 0.87, and a strong causal relationship was found. The leg muscle strength factor reflects the maximum voluntary contraction of the legs that is not accompanied by counter movement. On the other hand, in addition to the maximum voluntary contraction of the legs, the jump power factor reflects the elastic energy resulting from stretch-shortening cycle (SSC) motions. The similarity is that both factors reflect the maximum voluntary contraction of the legs, while the difference is that the jump power factor also reflects elastic energy. For the single jumping motion of the standing broad jump and vertical jump, strength is exerted through the concentric contraction of the quadriceps femoris muscle, while strength is exerted through the eccentric and concentric contraction of the quadriceps femoris muscle for the continuous jumping motions of the five-step jump test and the rebound jump. Takamatsu et al. (1990) reported that knee extension strength influenced by the jumping motions of exercises such as the standing broad jump and five-step jump test. From these findings, it may be surmised that although the leg muscle strength factor and the jump power factor are independent factors, among pubescent soccer players, the leg muscle strength factor strongly influences the jump power factor.

Lastly, the path coefficient from the jump power factor to the sprint speed factor was 0.91, and a strong causal relationship was verified. The jump power factor reflects the ability of the legs to exert a large amount of strength in a short span of time. The muscular activity pattern for a jumping motion is an SSC motion, and the landing time is around 0.2–0.9 seconds (Takamatsu et al., 1989; Zushi et al., 1993). On the other hand, the sprint speed factor reflects the ability of the legs to exert a large amount of strength in a short span of time to a greater extent than the jump power factor. The muscular activity pattern in a sprinting motion is also SSC motion. The landing time is around 0.1–0.2 seconds (Mero et al, 1992), and requires the ability to swiftly move all for limbs.

The similarity is that both factors reflect the ability of the legs to exert a large amount of strength in a short span of time using SSC motion, while the difference is that as compared to the jump power factor, the sprint speed factor sees the exertion of a large amount of strength by the legs in a short span of time being repeated many times. Iwatake et al. (2008a, 2008b) reported that the 50-m sprint time has a correlation with the jumping ability used in exercises such as the five-step jump test and the vertical jump, and that 50-m sprint times improved as a result of an increase in leg function, which exerts a large amount of strength in a short span of time, through jump training. Tsuda (2009) reported that in a study of children aged from 10 to 12 years of age, the greater the jumping ability for exercises such as the standing broad jump, vertical jump and rebound jump, the better the 50-m sprint times. As such, jump power may be considered as a factor that is directly related to the improvement of sprint speed. Based on these findings, it may be surmised that among pubescent soccer players, the jump power factor strongly influences the sprint speed factor.

From the discussion above, it may be inferred that among pubescent male soccer players, there exists a quasi-simplex structure where the maturity status factor influences the leg muscle size factor, the leg muscle size factor influences the leg muscle strength factor, the leg muscle strength factor influences the jump power factor and the jump power factor influences the sprint speed factor. It is implied that using these results, we can conduct a comparative evaluation involving the various physical ability factors on an individual basis to clarify the training that each player should focus on. However, as the PHV (peak height velocity) timing and tempo differ depending on conditions such as race, ethnicity and sex, the broad application of the findings of this study is limited by the fact that the subjects for this study were chosen from pubescent Japanese male soccer players.

Conclusion

Among pubescent male soccer players, a quasi-simplex structure exists in the sequence of maturity status factor, leg muscle size factor, leg muscle strength factor, jump power factor and sprint speed factor.

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