Paper : Soccer

Regression Equations for Estimating $v\dot{V}O_2max$ and vOBLA from 3200-M Run Time in Japanese Male Junior Youth Soccer Players Using Longitudinal Data

Kentaro Chuman*, and Takahiko Nishijima*****

*JUBILO CO., LTD.
2500 Shingai, Iwata, Shizuoka 438-0025 Japan
chumank@jubilo.com
**College of Life and Health Sciences, Chubu University
***Institute of Health and Sport Sciences, University of Tsukuba

[Received March 24, 2023; Accepted July 4, 2023]

This study aimed to develop regression equations to estimate running velocity of maximal oxygen uptake ($v\dot{V}O_2max$) and onset of blood lactate accumulation (vOBLA) from a 3200-m run time using a soccer pitch. Forty-four Japanese male junior youth soccer players from a team in the Japan Professional Football League First Division (J1 League) participated in this experiment. In the laboratory, $v\dot{V}O_2max$ and vOBLA were measured using an incremental load test, while the 3200-m run time was measured on the soccer pitch. Structural equation modeling was applied to analyze the sequential causal structure and latent growth curve models of aerobic running capability development during soccer training. A regression equation (1) utilized the 3200-m run time (s) as the independent variable (x) and $v\dot{V}O_2max$ (km/h) as the dependent variable (y), resulting in the equation $y=-0.02461x+36.60$ ($r^2=0.564$). The regression equation (2) utilized the 3200-m run time (s) as the independent variable (x) and vOBLA (km/h) as the dependent variable (y), resulting in the equation $y=-0.01833x+29.30$ ($r^2=0.541$). The coefficient of determination (r^2) for the regression equations exceeded 0.5. We successfully developed to estimate $v\dot{V}O_2max$ and vOBLA from a 3200-m run time in Japanese male junior youth soccer players.

Keywords: structural equation modeling, aerobic running velocity, maximal oxygen uptake, onset of blood lactate accumulation

[Football Science Vol.20, 38-46, 2023]

1. Introduction

High-intensity running is repeatedly performed during soccer matches (Bangsbo, 1994). In professional soccer players, the higher the level of competition, the greater the distance covered in high-intensity running during a match (Mohr et al., 2003). The importance of the ability to repeatedly perform high-intensity running (intermittent endurance) has increased over the years (Bush et al., 2015). The Yo-Yo intermittent recovery test was developed to assess intermittent endurance in soccer players (Bangsbo et al., 2008). Aerobic capability influences Yo-Yo intermittent recovery test performance or intermittent endurance in professional soccer players (Ingebrigtsen et al., 2012). Therefore, it has been pointed out that a high level of aerobic running capability should be acquired during junior high school when aerobic running capability is primarily developed (Chuman and Hoshikawa, 2015).

The aerobic running capability index includes running velocity, which corresponds to maximal oxygen uptake ($v\dot{V}O_2max$), and running velocity, which corresponds to the onset of blood lactate accumulation (vOBLA). $v\dot{V}O_2max$ is the maximal index of aerobic running capability, and vOBLA is the submaximal index of aerobic running capability; both are effective values that can be used directly for training (Chuman, 2016, 2021). $v\dot{V}O_2max$ and vOBLA in Japanese male junior youth soccer players show significant development from U-13 to U-15 and can reach the same level as professional soccer players at U-15 or U-16 (Chuman, 2016, 2021). Therefore, regular measurements of $v\dot{V}O_2max$ and vOBLA and systematic training based on these data are necessary for male junior youth soccer players.

However, regularly incorporating $v\dot{V}O_2max$ and vOBLA measurements into training plans is difficult because of the time and cost required to perform these measurements in the laboratory (Chuman et al., 2015). Therefore, a low-cost field test that can simultaneously measure the $v\dot{V}O_2max$ and vOBLA of multiple players is required for male junior youth soccer players.

The 12-minute run test is used as a field test to determine aerobic running capability because of its strong relationship with $\dot{V}O_2max$ (Kenneth and Cooper, 1968). In the 12-minute run test, it is necessary to mark every 10 m on the track to determine the running distance, and it is necessary to have a measurer for each participant. In soccer training, labor-intensive preparation and measurement methods are difficult to sustain (Chuman et al., 2015). Therefore, Chuman et al. (2015) proposed a 3200-m run test using a soccer pitch to measure aerobic running capability. In this 3200-m run test, the preparation is completed only by placing eight cones on a line 11.1 m away from the four corners of a 105 m × 68 m soccer pitch, and a single measurer can measure many players at once. In male junior youth soccer players, the 3200-m run time showed a significant correlation with the results of the 12-minute run test, as well as with $v\dot{V}O_2max$ and vOBLA (Chuman et al., 2015). Therefore, the 3200-m run test using a soccer pitch can be used to measure aerobic running capability.

However, the relationship between intra-individual variability in 3200-m run time and that in $v\dot{V}O_2max$ or vOBLA has not been clarified using longitudinal data in male junior youth soccer players. To enable systematic aerobic training using the 3200-m run test in male junior youth soccer players, it is necessary to clarify these relationships and develop regression equations to estimate $v\dot{V}O_2max$ or vOBLA from the 3200-m run time.

Based on the above, two hypotheses were formulated regarding the development of aerobic running capability using longitudinal data from Japanese male junior youth soccer players and the relationship between intra-individual variability in the 3200-m run time and that in $v\dot{V}O_2max$ or vOBLA. The first hypothesis was that aerobic running capability, as determined by the 3200-m run time, $v\dot{V}O_2max$, and vOBLA, affects U-13 to U-14 and U-14 to U-15 in male junior soccer players (the sequential causal structure model). The second hypothesis was that a shorter 3200-m run time would affect the development of $v\dot{V}O_2max$ or vOBLA. That is, the 3200-m run time intercepts from U-13 to U-15 affect the $v\dot{V}O_2max$ or vOBLA intercepts from U-13 to U-15, and the 3200-m run time slopes from U-13 to U-15 affect the $v\dot{V}O_2max$ or vOBLA slopes from U-13 to U-15 (the latent growth curve model). To verify such complex relationships among latent and observed variables by presenting them in an easy-to-understand model using a path diagram, we can use structural equation modeling (SEM), a statistical analysis method (Toyoda, 1992).

The purpose of this study was to test the sequential causal structure and latent growth curve models of aerobic running capability development by applying SEM to aerobic running training in Japanese male junior youth soccer players and to develop regression equations to estimate $v\dot{V}O_2max$ or vOBLA, an indicator of aerobic running capability, from a 3200-m run time.

2. Methods

2.1 Study design

This study collected physical fitness data (anthropometric measurements, incremental load test (ILT), and 3200-m run test) collected in April of U-13, U-14, and U-15 from 44 Japanese junior youth soccer players. In cases where participants could not participate in the measurement due to school events, injuries, or poor health, the measurement was conducted within one month before or after the measurement (March to May). Additionally, data from participants for whom measurements could not be performed during these periods were excluded.

This study first conducted a one-way repeated measures analysis of variance (ANOVA) to examine the longitudinal effects of two years of soccer training from U-13 to U-15 on the development of aerobic running capability (3200-m run time, $v\dot{V}O_2max$, vOBLA). The within-participant factors were three levels of measurement time (U-13, U-14, and U-15).

Next, the sequential causal structure and latent growth curve models were tested using SEM to examine the relationship between intra-individual variation in the development of aerobic running capability (3200-m run time, $v\dot{V}O_2max$, and vOBLA) in male junior youth soccer players. When these hypothetical models were proved and a significant correlation between the 3200-m run time and $v\dot{V}O_2max$ or vOBLA was confirmed, regression equations were developed to estimate $v\dot{V}O_2max$ or vOBLA from the 3200-m run time.

2.2. Participants

The participants were 44 male Japanese junior high school students belonging to the junior youths of the Japan Professional Football League First Division (J1 League). All participants were field players. Participants U-13, U-14, and U-15 were first-, second-, and third-year junior high school students, respectively. The characteristics of the study participants are shown in **Table 1**.

The participants were trained for 90 minutes a day, five or six times a week. Physical and technical training was conducted on Tuesdays, technical and tactical training on Wednesdays to Fridays, and matches or technical and tactical training on Saturdays and Sundays. Physical training is aimed at improving aerobic capacity and agility. U-13 had rest days on Mondays and Thursdays, and U-14 and U-15 had rest days only on Mondays.

In this study, data obtained by the clubs as part of daily training were used secondarily by the researchers with the consent of club representatives. This study was approved by the Research Ethics Committee of the Institute of Health and Sport Sciences, University of Tsukuba (No.21-311).

2.3. Morphometric measurements

The morphometric parameters were body height and weight. Body height was measured in increments of 0.1 cm, and body weight was measured in increments of 0.1 kg.

2.4. Incremental load test (ILT)

Following the method described by Hoshikawa et al. (2000), an ILT on a treadmill was used as a laboratory test to measure aerobic running capability. The ILT protocol consisted of four to six repetitions of 3 min submaximal running and 1 min rest. The heart rate, oxygen uptake, and blood lactate concentration were measured at each running velocity. The submaximal running velocities were 10.8, 12.0, 13.2, 14.4, 15.6, and 16.8 km/h. Oxygen uptake was measured using MetaMax (Cortex Biophysic GmbH), and blood lactate concentration was measured using Lactate Pro (Arkray, Inc.). Blood samples were collected from the fingertips within 20 s of running at each velocity. Two or more blood samples were collected, and the mean blood lactate concentration at each running velocity was calculated. Outliers were excluded from the three blood draws, and the average blood lactate concentration was calculated.

After submaximal running, participants rested for 2 min and then ran for 3 min at 16.8 km/h (Hoshikawa et al., 2000). Thereafter, the incline was increased by 1% every minute until exhaustion was achieved. The $v\dot{V}O_2max$, which corresponds to oxygen uptake at exhaustion, was estimated (Morgan et al., 1989). The vOBLA, corresponding to a blood lactate concentration of 4 mmol/L, was also estimated.

2.5. 3200-m run test

Following the method of Chuman et al. (2015), the 3200-m run time was measured on a soccer pitch as a field test to measure aerobic running capability. We used a 105 m × 68 m artificial turf soccer pitch, which was usually used for soccer training, and cut four corners of the pitch by 11.1 m each to form an octagonal shape with a circumference of 320 m. Participants started at the signal of the measurer and

Table 1 Characteristics of the participants (n=44)

Variables	U-13	U-14	U-15
	Mean ± SD	Mean ± SD	Mean ± SD
Age (yr)	12.8 ± 0.2	13.8 ± 0.2	14.8 ± 0.2
Body height (cm)	157.8 ± 8.2	164.1 ± 7.2	168.6 ± 6.1
Body weight (kg)	46.1 ± 7.9	51.7 ± 8.3	56.6 ± 7.6

did ten laps around the 320-m running track. The 3200-m run time was measured with a stopwatch and conducted during the training session at 18:45 on Tuesday. Participants performed with soccer shoes.

2.6. Statistical analysis

A one-way repeated measures ANOVA was conducted to examine the effects of two years of soccer training from U-13 to U-15 on the 3200-m run time, $v\dot{V}O_2max$, and vOBLA. The measurement times were U-13, U-14, and U-15. When Mauchly's sphericity test was significant, the Greenhouse-Geisser test was used to test the effect of the time of measurement. A multiple comparison test using the Bonferroni method was conducted as a post hoc test.

The maximum likelihood estimation method, the most widely used method in applied SEM research (Toyoda, 1992), was used for parameter estimation in the SEM. The parameters were restrained to ensure discrimination. The restraint conditions were as follows: 1) the path coefficient from the error variable to the endogenous variable was fixed at 1; 2) the path coefficient from latent variables that were endogenous to observed variables was fixed at 1; 3) the path coefficient from latent variables that were exogenous to observed variables was fixed at 1; and 4) the variance of the error variable was fixed at zero. GFI, AGFI, NFI, CFI, RMSEA, AIC, and CMIN were used as goodness-of-fit indices.

Pearson's product-moment correlation coefficient was used to analyze the correlation between $v\dot{V}O_2max$, vOBLA, and the 3200-m run time. When significant correlations were found between the variables, regression equations were created to estimate $v\dot{V}O_2max$ or vOBLA from the 3200-m run time using regression analysis. According to Hopkins et al. (2009), the magnitude of correlation coefficient (r) was classified into $0.1 \le r < 0.3$, $0.3 \le r < 0.5$, $0.5 \le r < 0.7$, and $r \ge 0.7$ based on its absolute value and judged as "Small," "Moderate," "Large," and "Very large," respectively. In addition, since $r \ge 0.7$ was judged to be "Very large," the coefficient of determination (r^2) of 0.5 or greater was considered to be a good fit.

SPSS ver. 26.0 for Windows was used for statistical analysis. The significance level for statistical hypothesis testing was set at $\alpha=0.05$.

3. Results

Table 2 shows the results of the ANOVA for the 3200-m run time, $v\dot{V}O_2max$, and vOBLA. For the 3200-m run time, Mauchly's sphericity test result was not significant (W=0.885, p=0.076). The main effects analysis revealed that the within-participants factor was significant at the three measurement times (F(2, 86)=111.01, p=0.000). The multiple comparison test showed that there were significant differences between U-13 and U-14 (p=0.000) or U-15 (p=0.000) and between U-14 and U-15 (p=0.001). For $v\dot{V}O_2max$, Mauchly's sphericity test result was not significant (W=0.929, p=0.212). The main effect analysis revealed that the within-participant factor was significant at the three measurement times (F(2, 86)=44.69, p=0.000). The multiple comparison test showed significant differences between all measurement times (p=0.000). For vOBLA, the Mauchly's sphericity test result was significant (W=0.752, p=0.003). The main effect analysis

Table 2 Aerobic running capability of the participants (n=44)

Variables	U-13	U-14		U-15	
	Mean ± SD	Mean ± SD		Mean ± SD	
$v\dot{V}O_2max$ (km/h)	16.5 ± 1.4	17.7 ± 1.4	*	18.5 ± 1.3	**
vOBLA (km/h)	14.4 ± 1.1	15.2 ± 1.1	*	15.8 ± 1.1	**
3200-m run time (s)	812.6 ± 34.6	760.2 ± 41.9	*	745.4 ± 41.0	**

* Significantly different from U-13.
** Significantly different from U-13 and U-14
$v\dot{V}O_2max$: running velocity corresponding to maximal oxygen uptake
vOBLA: running velocity corresponding to onset of blood lactate accumulation

revealed that the within-participants factor was significant at the three measurement times (F(1.6, 68.9)=40.65, p=0.000). The multiple comparison test showed significant differences between all measurement times (p=0.000).

Figure 1 shows the standard solution of the sequential causal structure model of aerobic running capability development in Japanese male junior youth soccer players from U-13 to U-15, using SEM. The goodness of model fit index was GFI=0.900, AGFI=0.804, NFI=0.921, CFI=1.000, RMSEA=0.004, AIC=67.014, and CMIN=23.014 (df=23, p=0.460). The path coefficient between the latent variables from U-13 to U-14 was significant at 0.71, and from U-14 to U-15 was also significant at 0.93 (p<0.05).

Figure 2 shows the standard solution of the latent growth curve model of aerobic running capability development (3200-m run time and $v\dot{V}O_2max$) from U-13 to U-15 of Japanese male soccer player using the SEM. The goodness of fit indices were NFI=0.971, CFI=1.000, RMSEA=0.000, AIC=44.508, and CMIN=4.508 (df=7, p=0.720). The path coefficient between the intercepts from the 3200-m run time to $v\dot{V}O_2max$ was significant at -0.97, and between the slopes from the 3200-m run time to $v\dot{V}O_2max$ was also significant at -0.86 (p<0.05).

Figure 3 shows the standard solution of the latent growth curve model of aerobic running capability development (3200-m run time and vOBLA) from U-13 to U-15 of Japanese male soccer player using the SEM. The goodness of fit indices were NFI=0.964, CFI=1.000, RMSEA=0.000, AIC=46.156, and CMIN=6.156 (df=7, p=0.522). The path coefficient between the intercepts from the 3200-m run time to vOBLA was significant at -0.84, and between the slopes from the 3200-m run time to vOBLA was also significant at -0.90 (p<0.05).

Correlation analysis showed that the Pearson's product-moment correlation coefficient between the 3200-m run time and $v\dot{V}O_2max$ was significant (r=-0.751, p=0.000) and between the 3200-m run time and vOBLA (r=-0.735, p=0.000).

Figure 4 shows the results of the regression analysis. The 3200-m run time (s) was the independent variable (x), and $v\dot{V}O_2max$ (km/h) or vOBLA (km/h) were the dependent variables (y) for the regression equation.

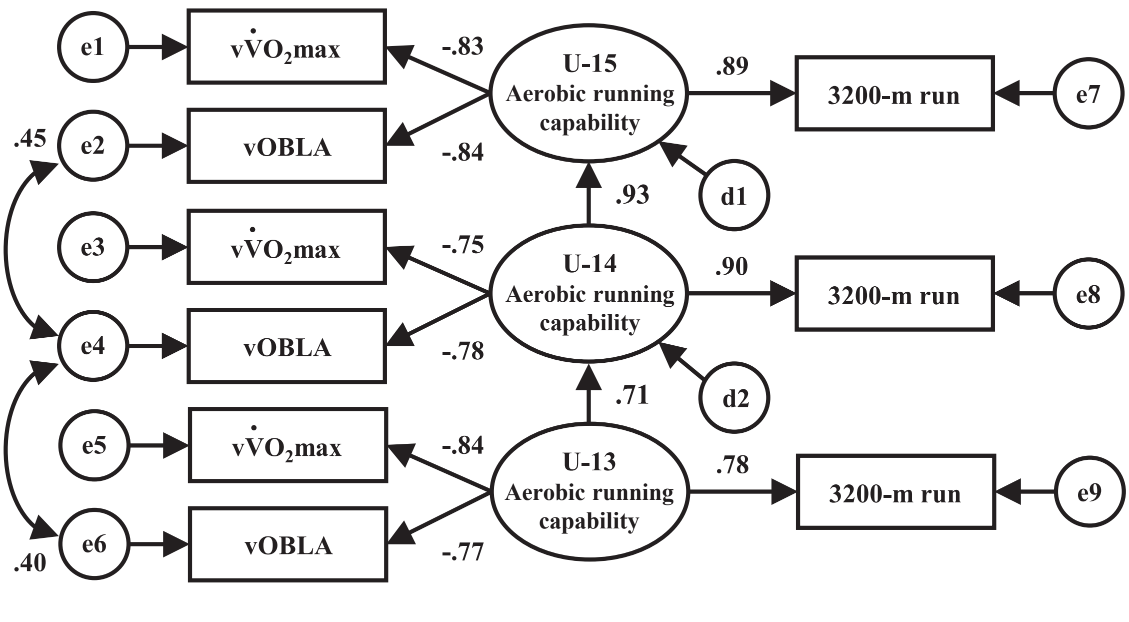
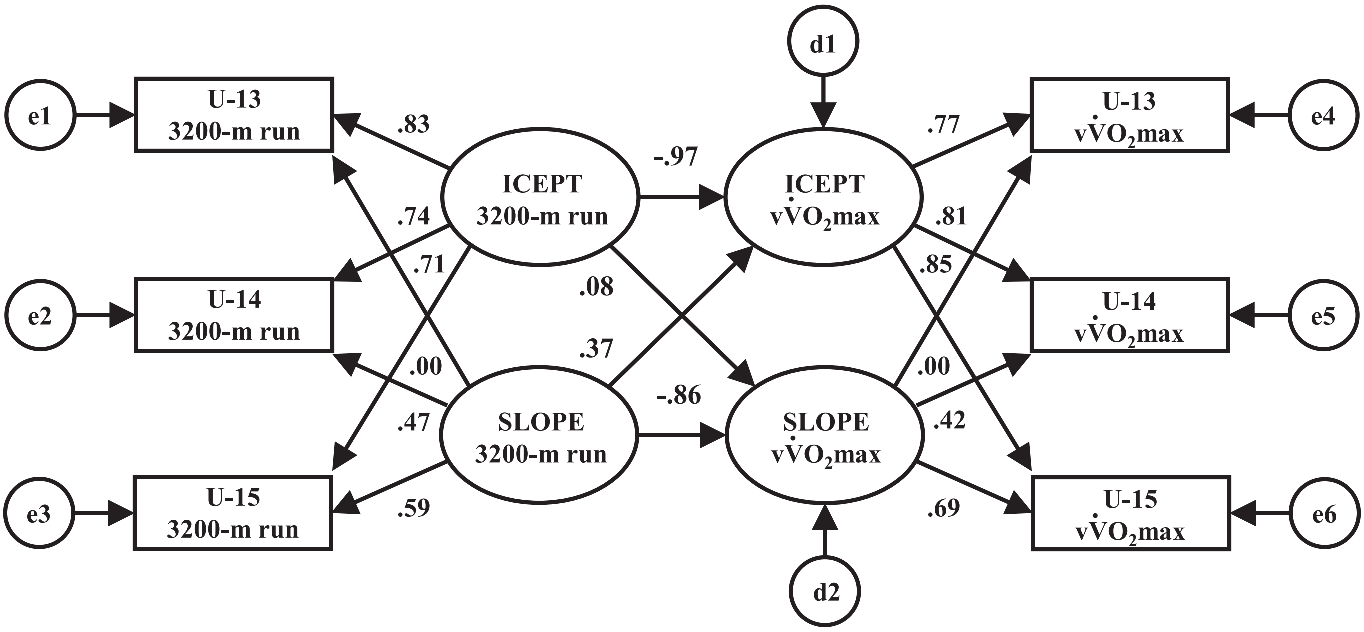


Figure 1 Sequential causal structure model of aerobic running capability development from U-13 to U-15 of Japanese male soccer player using structural equation modeling

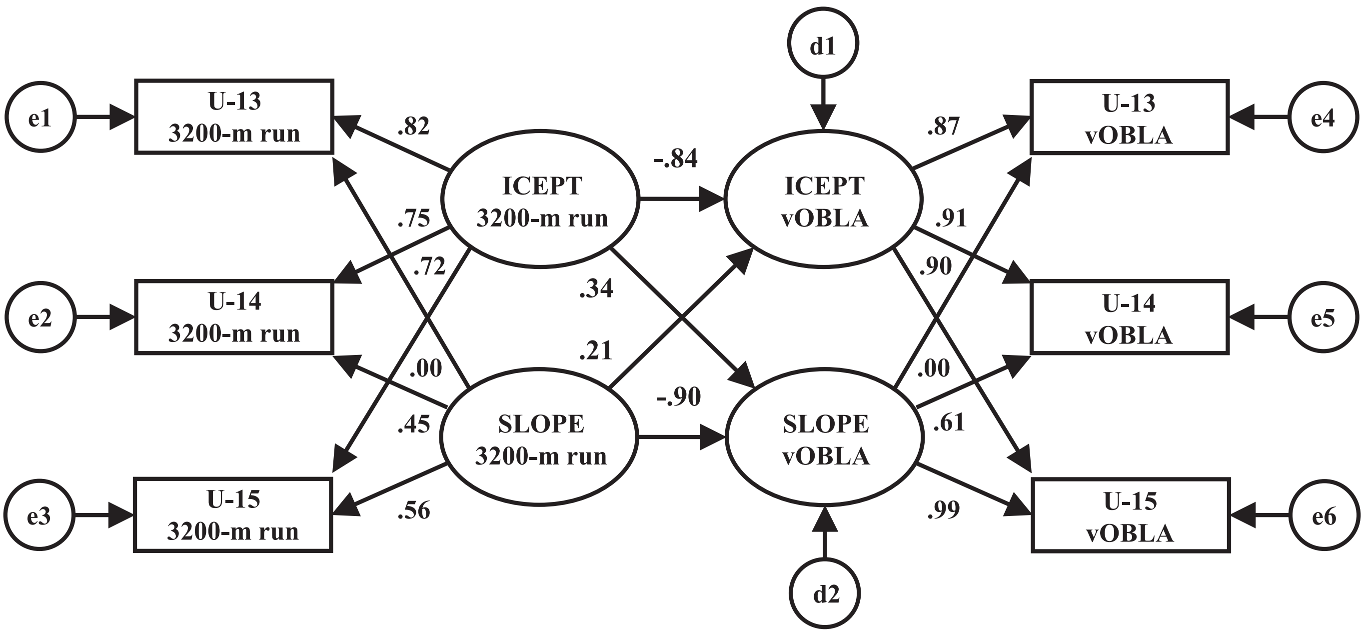
$v\dot{V}O_2max$: running velocity corresponding to maximal oxygen uptake

vOBLA: running velocity corresponding to onset of blood lactate accumulation



NFI=.971, CFI=1.000, RMSEA=.000, AIC=44.508, CMIN=4.508, df=7, P=.720

Figure 2 Latent growth curve model of aerobic running capability development (3200-m run time and v$\dot{V}O_2$max) from U-13 to U-15 of Japanese male soccer player using structural equation modeling
v$\dot{V}O_2$max: running velocity corresponding to maximal oxygen uptake



NFI=.964, CFI=1.000, RMSEA=.000, AIC=46.156, CMIN=6.156, df=7, P=.522

Figure 3 Latent growth curve model of aerobic running capability development (3200-m run time and vOBLA) from U-13 to U-15 of Japanese male soccer player using structural equation modeling
vOBLA: running velocity corresponding to onset of blood lactate accumulation

4. Discussions

This study aimed to test the sequential causal structure and latent growth curve models of aerobic running capability and to develop regression equations to estimate v$\dot{V}O_2$max or vOBLA from a 3200-m run time using longitudinal data from Japanese male junior youth soccer players. The main result of this study was that the following regression equations were developed to estimate v$\dot{V}O_2$max or vOBLA from the 3200-m run time in Japanese male junior youth soccer players **(Figure 4)**.

v$\dot{V}O_2$max (km/h) =

-0.02461×3200-m run time (s)+36.60 (r^2 = 0.564, n = 132)

vOBLA (km/h) =

-0.01833×3200-m run time (s)+29.30 (r^2 = 0.541, n = 132)

The present study examined the development of aerobic running capability using longitudinal data from participants and found that the 3200-m run time significantly shortened from U-13 to U-14 and from U-14 to U-15, and v$\dot{V}O_2$max and vOBLA significantly increased from U-13 to U-14 and from U-14 to U-15 **(Table 2)**. We did not find any previous reports examining age-related changes in 3200-m run time, v$\dot{V}O_2$max, and vOBLA using 2-year longitudinal data in male junior youth soccer players; therefore, the results of this study cannot be compared. Using cross-sectional data, Chuman et al. (2015) examined age-related changes in the 3200-m run time in male junior youth soccer players and reported that the 3200-m run time was shortened from U-13 to U-15. Chuman (2016, 2021) examined age-related changes in v$\dot{V}O_2$max and vOBLA in young male soccer players using cross-sectional data and reported that v$\dot{V}O_2$max and vOBLA significantly increased from U-13 to U-15. This suggests that 3200-m run time, v$\dot{V}O_2$max, and vOBLA in male junior youth soccer players show development from U-13 to U-15 and that their development is similar.

Analysis of the sequential causal structure model of aerobic running capability from U-13 to U-15 in the participants of this study showed that the goodness-of-fit indices of the model were very good, with significantly higher values for path coefficients between the latent variables **(Figure 1)**. These results indicate that the aerobic running capability affects from U-13 to U-14 and from U-14 to U-15. To date, no reports have examined the causal structure of aerobic running capability across age groups using longitudinal data from male junior youth soccer players; therefore, the results of this study cannot be compared. However, as mentioned above, in the present study, the 3200-m run time, v$\dot{V}O_2$max, and vOBLA showed significant development from U-13 to U-15, and their development was similar **(Table 2)**. Therefore, the sequential causal structure of aerobic running capability in Japanese male junior youth soccer players is likely affected by U-13 to U-14 and

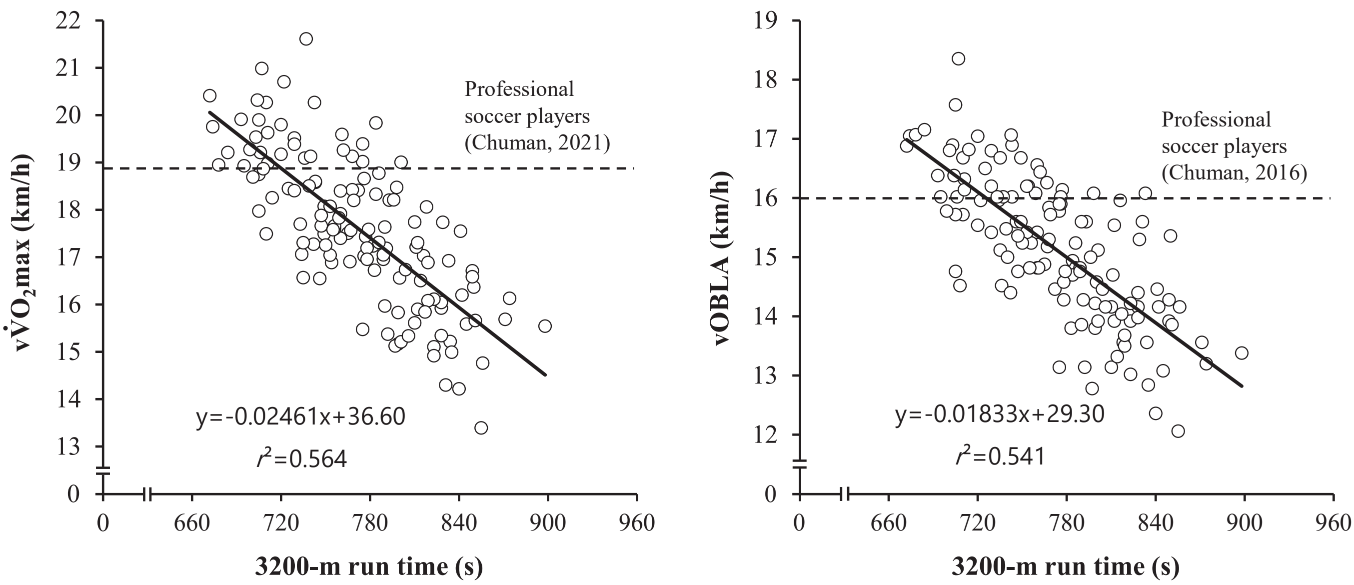


Figure 4 Relationship between 3200-m run time and v$\dot{V}O_2$max or vOBLA in Japanese male soccer players from U-13 to U-15
v$\dot{V}O_2$max: running velocity corresponding to maximal oxygen uptake
vOBLA: running velocity corresponding to onset of blood lactate accumulation

U-14 to U-15.

Analysis of the latent growth curve model of aerobic running capability in this study's participants showed that the model's goodness-of-fit index was very good, and the path coefficients between latent variables were significantly higher **(Figures 2 and 3)**. These results indicate that a shorter 3200-m run time affects the increases in $v\dot{V}O_2max$ and vOBLA. Participants with a greater shortening of the 3200-m run time had greater increases in $v\dot{V}O_2max$ and vOBLA. There have been no previous reports examining the relationship between shorter 3200-m run times and increased $v\dot{V}O_2max$ or vOBLA using longitudinal data in male junior youth soccer players; therefore, the results of this study are not comparable. Chuman et al. (2015) reported a significant correlation between 3200-m run time and $v\dot{V}O_2max$ or vOBLA using cross-sectional data from Japanese male junior youth soccer players. These findings suggest that a shorter 3200-m run time may increase $v\dot{V}O_2max$ or vOBLA in Japanese male junior youth soccer players.

As mentioned above, this study did not simply examine the relationship between 3200-m run time and $v\dot{V}O_2max$ or vOBLA in male junior youth soccer players and used two years of longitudinal data from U-13 to U-15 to determine the relationship between intra-individual variability in 3200-m run time and that in $v\dot{V}O_2max$ or vOBLA. These results suggest that aerobic running capability, as measured by $v\dot{V}O_2max$ and vOBLA, should be improved to achieve high aerobic running performance in Japanese male junior youth soccer players. However, it is not easy to conduct ILT in the laboratory to measure $v\dot{V}O_2max$ and vOBLA in male junior youth soccer players because it takes a lot of time and costs (Chuman et al., 2015). Therefore, a regression equation to estimate $v\dot{V}O_2max$ and vOBLA from a simple field test is required to implement efficient aerobic training in junior youth soccer players. The coefficient of determination (r^2) of the regression equation developed in this study to estimate $v\dot{V}O_2max$ or vOBLA from a 3200-m run time was 0.564 or 0.541, respectively **(Figure 4)**. No regression equations have been developed to estimate $v\dot{V}O_2max$ or vOBLA from a 3200-m run time in Japanese male junior youth soccer players. Lorenzen et al. (2009) reported a regression equation to estimate $v\dot{V}O_2max$ from a 3200-m run time in elite Australian soccer players; the coefficient of determination ($r^2 = 0.63$) of the regression equation was similar to that of the participants in this study. According to Hopkins et al. (2009), a correlation coefficient (r) of 0.7 or greater can be considered "Very large," so a coefficient of determination (r^2) of 0.5 or greater indicates that the regression equation is a high fit. From these facts, it can be inferred that the regression equation developed in this study to estimate $v\dot{V}O_2max$ or vOBLA from a 3200-m run time has a high degree of fit.

However, the participants in this study were Japanese male junior youth soccer players at a highly competitive level who belonged to a single club, and it is unclear whether this regression equation can be applied to players at a lower competitive level. Whether the regression equation can be applied to male junior youth soccer players at various competitive levels remains to be clarified.

5. Conclusion

The purpose of this study was to test the sequential causal structure and latent growth curve models of aerobic running capability development by applying SEM to aerobic running training in Japanese male junior youth soccer players and to develop regression equations to estimate $v\dot{V}O_2max$ or vOBLA, an indicator of aerobic running capability, from a 3200-m run time. In conclusion, two hypothetical models were proved using longitudinal data for two years in Japanese male junior youth soccer players, and regression equations were developed to estimate $v\dot{V}O_2max$ or vOBLA from a 3200-m run time.

Acknowledgements

We would like to thank Hiroki Matsuoka, Ph.D. of R&D Center for Sport Innovation, University of Tsukuba, and Kozue Ando, Ph.D. of Institute of Health and Sport Sciences, University of Tsukuba, with the statistical data analysis of this study.

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Name:
Kentaro Chuman

Affiliation:
JUBILO CO., LTD.

Address:
2500 Shingai, Iwata, Shizuoka 438-0025 Japan

Brief Biography:
2003-2005 Master's Program in Health and Physical Education, University of Tsukuba
2009-2012 Doctoral Program in Physical Education, Health and Sport Sciences, University of Tsukuba
2004-2010 Physical coach, Jubilo Iwata Academy
2011-2020 Assistant director & Physical adviser, Jubilo Iwata
2016-2020 Physical coach, U-15 to U-23 Japan National Team
2021-2023 Physical coach, Jubilo Iwata

Main Publications:
- Chuman, K., Hoshikawa, Y., Iida, T., and Nishijima, T. (2014) Maturity and intermittent endurance in male soccer players during the adolescent growth spurt: A longitudinal study. Football Science, 11: 39-47.
- Chuman, K., Horio, K., Kitatsuji, K., Suijo, K., and Aoki, T. (2022) Relationship between CHU-Test results and high-intensity running during soccer matches. Football Science, 19: 78-84.

Membership in Learned Societies:
- Japanese Society of Science and Football
- Japan Society of Sports Performance Research
- National Strength and Conditioning Association