RESEARCH ARTICLE

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An Evaluation of Change in the Physical Output in Female Youth Football Players During a Game

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ABSTRACT

This study evaluated the time-to-time aerobic and anaerobic exercise intensities, calculated using the Global Positioning System (GPS), using laboratory measurements of individual physical fitness throughout the game in each female youth football player. In addition, we examine if the anaerobic exercise index calculated by only GPS data presents this evaluation to examine its validity. In the laboratory, the oxygen uptake ($\dot{V}O_2$) matched with moving speed was identified during an incremental exercise test on the treadmill, and the ventilatory (anaerobic) threshold was also analysed to identify individual aerobic and anaerobic exercise intensities. Using these laboratory data, time-to-time changes in individual relative running intensity (aerobic and anaerobic) were visualised from individual GPS data during a football game, and an individual's sprint output (ability) during the game was evaluated. An index of running intensity and the percentage of anaerobic exercise over the game provided by the GPS software (equivalent distance index [%EDI] and anaerobic index [AI]) did not present the actual individual exercise intensity ($ICC_{(2,1)}$, absolute agreement=−0.031; P=0.596) and percentage of anaerobic exercise ($ICC_{(2,1)}$, absolute agreement=−0.003; P=0.698) values during the game, respectively. These findings suggest that only GPS measurement cannot present the individual actual exercise intensity during a football game because of different individual fitness levels to the same running speed.

Keywords: GPS, running speed, running strength, ventilatory threshold.

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I. INTRODUCTION

Football performance is determined by multiple factors, including skill, physical fitness, agility, muscle power, sprint faculty, team tactics, individual tactics, and physique (Akyildiz *et al.*, 2022; Helgerud *et al.*, 2001; Stolen *et al.*, 2005). Thus, evaluating football performance adequately is not simple because of the complicated contribution of these factors to football performance. To improve game performance in football players, previous studies (Almeida *et al.*, 2018; Rodriguez-Fernandez *et al.*, 2019; Wragg *et al.*, 2000) have investigated physical fitness, aerobic or anaerobic exercise capacities in football players or the effects of aerobic and anaerobic exercise training on football performance because these factors can be measured and contribute to football performance. However, motor characteristics, such as sprints and interval times between sprints, during football competition games are complicated; moreover, there is a difference in the contribution of aerobic and anaerobic exercise capacities to football performance between players. For these reasons, anaerobic strength and its recovery during the game have not been measured yet

European Journal of Sport Sciences
www.ej-sport.org

(Dasa *et al*., 2022), and the actual contribution of aerobic and anaerobic exercise capacities to football performance during a football game remains unclear because no study has measured changes in aerobic and anaerobic exercise intensity throughout a football game. At least no study has provided accurate and valid data regarding the energy requirements (e.g. oxygen uptake [$\dot{V}O_2$]) for each play during a football match (Stolen *et al*., 2005). Nevertheless, determining the time-to-time changes in physical strength or exercise intensity throughout a game in each player who has different physical fitness may be essential to improve football performance during a game.

Recently, it has become possible to measure the movements of players during football competition games using the Global Positioning System (GPS) and to quantify the exercise intensity of individual players by analysing the moving speed and acceleration. This method is widely used as an objective indicator, regardless of the type of competition, professional or amateur (Jagim *et al*., 2022; Moss *et al*., 2021; Reed, *et al*., 2013). However, changes in the required physical fitness (time-to-time energy demand according to exercise intensity) throughout the games that determine football performance, such as interval time, in football competitions are complicated. More importantly, the ratio of aerobic and anaerobic energy metabolism varies greatly among individuals. Therefore, estimating physical strength or exercise intensity (aerobic and anaerobic exercise intensities) at each time throughout the game using only the moving speed and acceleration information on the GPS may be difficult because of different sprint abilities and aerobic and anaerobic exercise capacities among players. In contrast, heart rate (HR) may not be suitable for assessing exercise intensity during a football game (Stolen *et al*., 2005) because the relationship between HR and $\dot{V}O_2$ is inaccurate during acute and short-term high-intensity exercises (i.e. sprint running or intermittent exercise). Therefore, simply quantifying aerobic and anaerobic exercise intensities or energy requirements using only GPS measurement-determined moving speed accumulation and HR, particularly during the games, is impossible (Oxendale *et al*., 2017).

Under these backgrounds, this study was designed to calculate the actual aerobic and anaerobic exercise intensities of each football player during a game using individual physical fitness data and to examine the validity of the index of exercise intensity in the GPS. In this study, we analysed time-to-time changes in the required $\dot{V}O_2$ (O_2 demand), the relative individual exercise intensity (percent $\dot{V}O$ peak [%$\dot{V}O_{2peak}$]) and both the ratio of aerobic and anaerobic exercise intensities to total exercise during a football game from GPS measurements of the game over time using laboratory measurements of $\dot{V}O_2$ that matched with the moving (running) speed. Additionally, these values were compared with the index of the GPS: the equivalent distance index (%EDI), as an index of exercise strength, and the anaerobic index (AI), as an index of the ratio of anaerobic exercise to total exercise, over the entire game. The findings in this study can construct a useful objective index for determining the physical level of each player during a football game and consequently provide important insights that contribute to improving the performance of top-level football players.

II. Material and Methods

A. Participants

Seven youth women football players from the women's professional football team Chifure AS Elfen Saitama participated in this study (age, 16.7±0.5 years). The experimental protocol of this study was approved by the Institutional Review Board of Toyo University (approval number: TU2021-022), and each participant provided written informed consent before participation. This study was conducted according to the principles of the Declaration of Helsinki.

B. Experimental Procedure

The laboratory experiment: The participants performed the incremental exercise test on a treadmill with respiratory gas analysis. Upon arrival to the laboratory, the participants rested in the seated position for at least 20 min before the exercise test. Then, the participants rested on the treadmill for 2 min (baseline) and after that started walking at 3 km/h for 3 min. Next, the treadmill speed was gradually increased by 0.1 km/h per 6 s to exhaustion. Meanwhile, the participants started to run from walking when the treadmill speed reached the preferred speed for running. During the test, the participants' exhaled and inspired gas was measured using the breath-by-breath method using a respiratory metabolism device (ARCO-2000N, Arco System, Chiba, Japan) to measure ventilation, $\dot{V}O_2$ and carbon dioxide output ($\dot{V}CO_2$). The highest $\dot{V}O_2$ obtained during the test was reported as peak $\dot{V}O_2$ ($\dot{V}O_{2peak}$). HR was measured using the lead II in electrocardiogram (bedside monitor, BMS-3400; Nihon Kohden, Tokyo, Japan) throughout the exercise test. The room temperature was set at 24°C.

The field experiment: The participants played in a competitive football game for 80 min (half time 10 min). The overall moving speed was measured by each participant throughout the game using GPS equipment (GPEXE, exelio srl, Udine, Italy). GPS data consisted of the %EDI as an index of sprint strength and the AI as an index of the ratio of anaerobic exercise to the total exercise over the entire game. The

European Journal of Sport Sciences
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equivalent distance (ED) is the distance calculated by moving energy. High energy (sprint) increases the ED compared with the actual moving distance. The AI was calculated by diving the anaerobic energy by the total energy. In this system, all moving energy was calculated by a change in moving velocity (acceleration), and anaerobic energy was determined by the threshold running speed; however, this value is constant between players. The following equations were used:

%EDI – (ED–actual total moving distance)/actual total moving distance × 100.

ED – actual total moving energy calculated by dividing the actual moving velocity by the energy cost for 1-m moving.

AI – anaerobic energy calculated by dividing the actual moving velocity by the actual total energy.

C. Data Analysis

In the breath-by-breath exhaled and inspired gas data during an incremental exercise test, the relationship between the walking or running speed on the treadmill and the $\dot{V}O_2$ was identified to estimate the time-to-time $\dot{V}O_2$ at each moving (walking or running) speed from the GPS data; moreover, the starting running speed from walking was identified during an intensity incremental exercise test (Fig. 1). Furthermore, the ventilatory threshold (V_T), which is an index of the anaerobic threshold, of each player was calculated (Wasserman *et al*., 1973) to identify the running speed at the V_T.

Accumulated $\dot{V}O_2$ as an index of energy metabolism and the relative (percentage) $\dot{V}O_2$ to peak value (%$\dot{V}O_{2peak}$) as an index of the relative exercise intensity were calculated for both ranges of aerobic (lower than the speed at V_T) and anaerobic (higher than the speed at V_T) moving speeds during a soccer game. The game was divided into four periods for analysis: 0–20 min (1st period, 1st half), 20–40 min (2nd period, 1st half), 40–60 min (3rd period, 2nd half) and 60–80 min (4th period, 2nd half).

D. Statistical Analysis

All statistical analyses were performed using Statistical Package for the Social Sciences (version 25; IBM Corp., Tokyo, Japan), and group data are expressed as means ± standard deviations. One-way repeated measures analysis of variance, followed by the Tukey test, was used to evaluate the changes in the variables during a soccer game. To verify the agreement between %EDI and %$\dot{V}O_2$ (an index of exercise strength) or AI and the ratio of anaerobic $\dot{V}O_2$ to the total $\dot{V}O_2$ (an index of anaerobic strength), intraclass correlation coefficient (ICC) estimates and their 95% confidence intervals were calculated using a two-way random-effects model (absolute agreement definition). Moreover, the difference in exercise strength (%EDI and %$\dot{V}O_2$) and anaerobic strength (AI and the ratio of anaerobic $\dot{V}O_2$ to the total $\dot{V}O_2$) was visualised using Bland–Altman plots and 95% upper and lower limits of agreement (mean difference ± 1.96 standard deviation), and the mean differences (or bias) were computed (Bland & Altman, 1986). The statistical significance threshold was set at $P<0.05$.

III. Results

Each player completed the incremental exercise test on the treadmill to analyse individual physical fitness ($\dot{V}O_{2peak}$, $\dot{V}O_2$ at V_T, running speed at V_T, etc.) (Table I) and the individual relationship between moving (walking or running) speed and $\dot{V}O_2$ (Fig. 1A).

TABLE I: Physiological Parameters Determined by Incremental Exercise Test

$\dot{V}O_{2peak}$	(ml/min/kg)	53.1±5.6
$\dot{V}O_2$ at V_T	(ml/min/kg)	37.7±4.0
%$\dot{V}O_{2peak}$ at V_T	(%)	71.0±5.2
HR at V_T	(bpm)	157±6
%HR at V_T	(%)	77.3±2.8
Run Speed at V_T	(km/h)	11.1±0.9

Mean ± standard deviation (N=7). $\dot{V}O_2$, oxygen uptake; V_T, ventilatory threshold, HR, heart rate.

Interestingly, the relationship between moving speed and $\dot{V}O_2$ was reset upward from walking to running because of different body movements, muscle work and energy efficiency (Santuz *et al*., 2022). Moreover, the relationships between the speed from walking to running, time-to-time change in $\dot{V}O_2$ and %$\dot{V}O_{2peak}$ throughout the game were calculated using the moving speed in the GPS data and the individual relationship between moving speed and $\dot{V}O_2$ (Fig. 1B). From this analysis, the O_2 demand (accumulated $\dot{V}O_2$) and averaged %$\dot{V}O_{2peak}$ for walking, running, and sprinting (running speed over V_T) were calculated in the 1st, 2nd, 3rd and 4th periods, respectively (Table II).

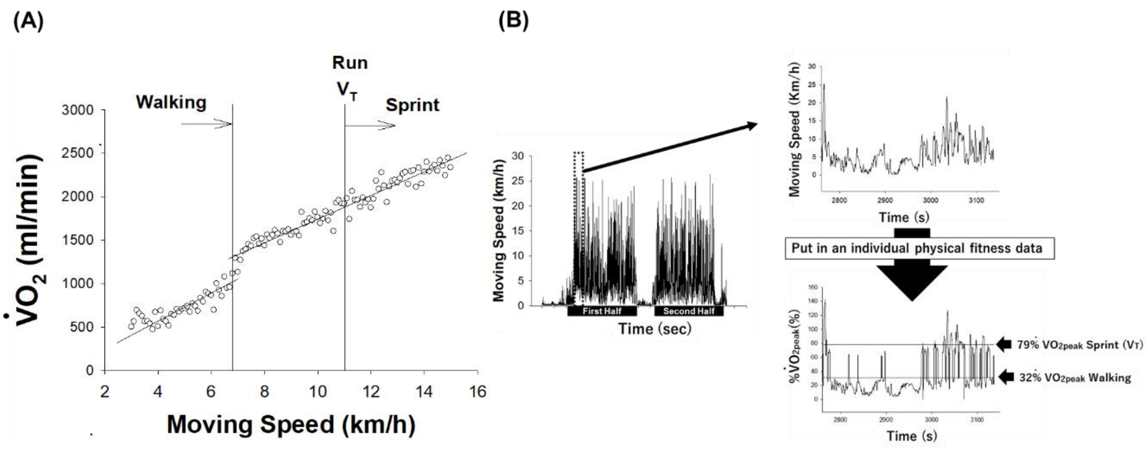

Fig. 1. (A). Representative data on $\dot{V}O_2$ during the incremental intensity exercise test on the treadmill. (B) The Global Positioning System (GPS) data during the football game. The moving speed during the game was changed to the percent maximal of oxygen uptake ($\%\dot{V}O_{2peak}$) as an index of exercise intensity obtained from the incremental intensity exercise test that identified the relationship between running speed and $\%\dot{V}O_{2peak}$. Furthermore, $\%\dot{V}O_{2peak}$ at the start of running from walking and at the ventilatory threshold (V_T) were marked.

TABLE II: GPS DATA AND THE INDEXES CALCULATED USING INDIVIDUAL PHYSICAL FITNESS DATA DURING WALKING, RUNNING AND SPRINT FROM 1ST TO 4TH PERIOD OF A FOOTBALL GAME

		1st	2nd	3rd	4th	Individual	P value
		GPS Data					
Total moving distance	(m)	2747±94	2723±155	2758±156	2572±265	P<0.001	P=0.006
Equivalent Distance Index (EDI)	(%)	10.2±1.4	10.9±1.3	10.0±1.2	10.2±1.2	P=0.001	P=0.025
Anaerobic Index (AI)	(%)	36.0±1.4	36.3±1.9	36.9±1.8	38.0±2.1	P<0.001	P=0.012
%Contribution of walking to the total time	(%)	59±4	60±6	60±3	64±4	P<0.001	P=0.017
%Contribution of running to the total time	(%)	26 ±3	24±3	24±2	20±2	P=0.004	P<0.001
%Contribution of sprint to the total time	(%)	20±4	20±2	20±4	18±1	P=0.003	P=0.241
Indexes calculated using individual physical fitness data							
Average $\%\dot{V}O_2$ (Walking)	(%)	23.9±3.7	23.8±4.2	23.0±4.6	22.9±4.5	P<0.001	P=0.264
Average $\%\dot{V}O_2$ (Running)	(%)	61.6±5.9	61.7±5.8	61.8±5.8	61.6±5.6	P<0.001	P=0.539
Average $\%\dot{V}O_2$ (Sprint)	(%)	86.2±9.9	86.3±10.7	86.8±9.7	86.8±10.8	P<0.001	P=0.615
Average $\%\dot{V}O_2$ (all moving)	(%)	43.3±6.0	43.1±6.5	42.7±4.5	40.6±5.5	P=0.002	P=0.319
O_2 demand/B.W. (Walking)	(L/kg)	0.192±0.027	0.192±0.026	0.182±0.028	0.207±0.034	P=0.006	P=0.292
O_2 demand/B.W. (Running)	(L/kg)	0.215±0.024	0.206±0.030	0.201±0.041	0.177±0.031	P=0.002	P= 0.050
O_2 demand/B.W. (Sprint)	(L/kg)	0.182±0.046	0.190±0.044	0.190±0.037	0.195±0.049	P<0.001	P=0.645
Total O_2 demand/B.W.	(kcal)	0.589±0.050	0.588±0.070	0.573±0.066	0.579±0.096	P<0.001	P=0.912
Sprint/Total	(%)	30.6±6.1	32.0±5.5	33.3±5.6	33.3±4.6	P<0.001	P=0.247
O_2 demand/B.W. (Walking)/Walking time	(mL/kg/min)	16.3±2.1	16.2±1.7	15.3±2.4	16.2±3.2	P<0.001	P=0.584
O_2 demand/B.W. (Running)/Runing time	(mL/kg/min)	42.1±4.1	42.9±8.7	41.8±6.6	44.1±6.4	P<0.001	P=0.776
O_2 demand/B.W. (Sprint)/Sprint time	(mL/kg/min)	47.6±13.8	47.8±12.1	49.5±15.4	55.3±15.4	P<0.001	P=0.021

Mean ± standard deviation (N=7). $\dot{V}O_2$, oxygen uptake; B.W., body weight.

The GPS data demonstrated that the moving distance decreased from the 1st to the 4th period of the game (P=0.006). However, the %EDI, as an index of running intensity, increased from the 1st to the 2nd period and returned to the 1st period level (P=0.025) (Table II). Additionally, the AI, an index of the ratio of anaerobic exercise to the total exercise, significantly increased from 36.0%±1.4% to 38.0%±2.1% (P=0.012). Furthermore, a significant individual variation in these values in the GPS data was observed among players (Total moving distance, %EDI, and AI; P<0.001, P=0.001, and P<0.001, respectively).

In the analysis using individual physical fitness data, the %contribution time of walking was longer (59%–64%) than that of running (20%–26%) and sprinting (18%–20%). The %contribution of walking increased from the 1st to the 4th period of the game (P=0.017) (Table II). In contrast, that of running decreased (P<0.001), whereas that of sprinting remained unchanged from the 1st to the 4th period of the game. A significant difference in the average $\%\dot{V}O_{2peak}$ for walking, running, sprinting, and total exercise among players was observed (P<0.001, P<0.001, P<0.001 and P=0.002, respectively) (Table II); however, the average $\%\dot{V}O_{2peak}$ for walking, running, sprinting and total exercise for all players were unchanged from the 1st to the 4th period of the game (P=0.264, P=0.539, P=0.615 and P=0.319, respectively) (Table II). The average $\%\dot{V}O_{2peak}$ for all moving should be matched with the %EDI in the GPS data; however, a significant relationship between the %EDI and average $\%\dot{V}O_{2peak}$ for all moving was not observed in analysing the ICC ($ICC_{(2,1)}$, absolute agreement=−0.003, P=0.698, 95%CI: -0.014-0.020) and Bland–Altman plots (Fig. 2A).

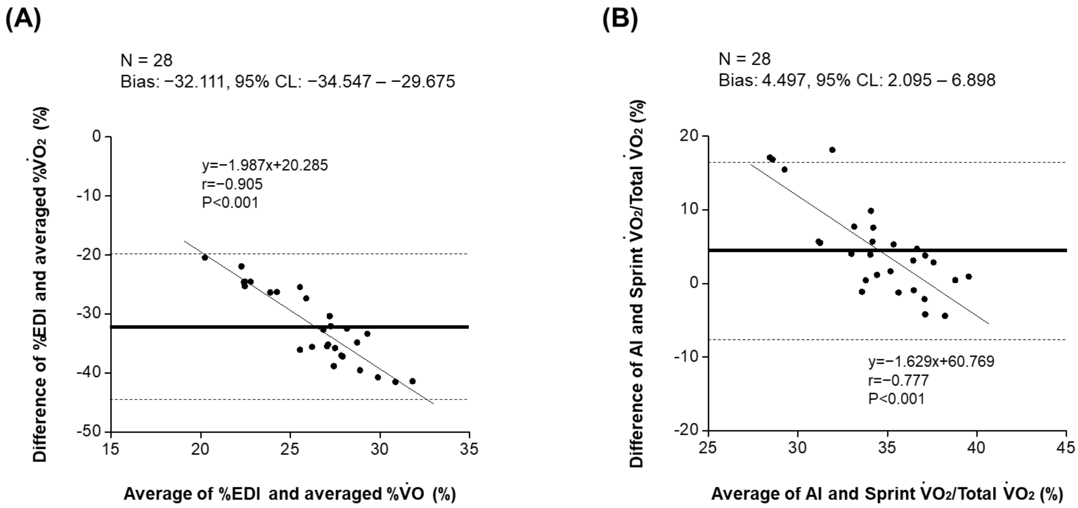

Fig. 2. Bland–Altman plots of the equivalent distance index (%EDI) of the GPS data and the average of percent relative oxygen uptake to peak value ($\%\dot{V}O_{2peak}$) for the total exercise (A), and Bland–Altman plots of the anaerobic index (AI) from GPS data and the ratio of $\dot{V}O_2$ for sprinting of the total $\dot{V}O_2$ (sprint $\dot{V}O_2$/total $\dot{V}O_2$) (B) from the 1st to the 4th period of the game. The solid line represents the mean difference, whereas the dashed lines represent the 95% upper and lower limits of agreement (mean difference ± 1.96 standard deviation).

Similarly, a significant difference in O_2 demand for walking, running, sprinting and total exercise among players was observed (P=0.006, P=0.002, P<0.001 and P<0.001, respectively) (Table II); however, the average O_2 demand for walking, running, sprinting and total exercise in all players was unchanged from the 1st to the 4th period of the game (P=0.292, P=0.05, P=0.645 and P=0.912, respectively). The ratio of the sprint O_2 demand to the total O_2 demand, as an index of the ratio of anaerobic exercise to the total exercise, has a significant variation among players (P<0.001); whereas this average value of all players ranging from 30% to 33% was unchanged from the 1st to the 4th period of the game (P=0.247). This value should be matched with the AI in the GPS data; however, a significant relationship between the AI and sprint/total O_2 demand was not observed in the analysis of ICC ($ICC_{(2,1)}$, absolute agreement=−0.031, P=0.596, 95%Cl: −0.247–0.249) and Bland–Altman plots (Fig. 2B).

IV. Discussion

In this study, we calculated the time-to-time changes in aerobic (walking and running) and anaerobic (sprint) exercise intensities during a football game using laboratory experimental and GPS data. This analysis demonstrated a difference in exercise intensity during a football game among players; importantly, the index of the sprint strength over the game provided by GPS (%EDI and AI) did not provide the actual exercise intensity because the individual fitness level (different sprint speed at V_T) was not included in these indexes. The findings of this study suggest that individual physiological fitness data and running speed at the anaerobic threshold are needed to assess the actual aerobic and anaerobic exercise intensities.

The energy (O_2) required for exercise can be broadly classified into aerobic (endurance) and anaerobic (including muscle strength) exercise energies. Aerobic exercise capacity is important as a long-time exercise capacity, whereas anaerobic exercise capacity greatly affects the high-intensity exercise capacity, which determines the sprint and recovery times from fatigue (Wasserman *et al.*, 1973). A football game consists of many repeated sprints (high intensity) rather than long-term continuous exercise, despite a long game time (90 min). This high-intensity exercise (sprinting) is performed using anaerobic energy but causes fatigue and consequently attenuates exercise performance. Whether aerobic or anaerobic energy metabolism depends on exercise intensity (Wasserman *et al.*, 1973). Against this background, preventing anaerobic energy metabolism-induced fatigue related to sprint exercise is important for maintaining high performance during a game. This is because of limited anaerobic energy expenditure, and the following sprints need recovery time. Therefore, particularly knowing how anaerobic energy is used during a football game is important. Furthermore, individual anaerobic energy capacity and the individual usage

European Journal of Sport Sciences
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characteristics in energy metabolism during a game are essential physiological factors that determine the performance of competitive football players (Ulupinar *et al*., 2021).

Under this background, a physical evaluation method that matches the complexity of exercises peculiar to soccer competitions is indispensable and significant for improving competitive performance during a football game. Thus, some studies have attempted to assess individual exercise performance during a football game (Bangsbo *et al*., 1991; Helgerud *et al*., 2001; Mohr *et al*., 2003; Mohr *et al*., 2004; Rienzi *et al*., 2000). However, the previous studies may not represent aerobic and anaerobic exercise intensities or metabolism accurately because the analysis of the previous study did not include physiological factors (using only a player's running speed or distance during a football game).

During exercise, HR is used as an index of the physical load because HR is related to $\dot{V}O_2$ during dynamic exercise (Marini *et al*., 2022). Some studies (Ali & Farrally, 1991; Mohr *et al*., 2004) have attempted to assess physical strength during a football game using HR and demonstrated that the average percentage of the maximal HR (%HR_{max}) during a 90-min soccer match is close to the anaerobic threshold (80%–90% of %HR_{max} in soccer players) (Stolen *et al*., 2005). However, HR measurement may not be suitable for assessing time-to-time exercise intensity during a football game (Stolen *et al*., 2005) because the relationship between HR and $\dot{V}O_2$ is inaccurate during acute and short-term high-intensity exercises (i.e. sprint running or intermittent exercises). The time to reach $\dot{V}O_2$ or steady-state HR is necessary (Medbo *et al*., 1988; Ogoh *et al*., 2009) as an index of exercise intensity ($\dot{V}O_2$ response to changes in exercise intensity is much slower than that of HR). Additionally, HR peak is delayed in sprint running exercises, and HR recovery from the sprint running exercise is changed by the autonomic function associated with fatigue (Storniolo *et al.*, 2019). Thus, HR measurement may not be adequate for identifying acute changes in physical strength or metabolism during a football game.

The GPS can measure the %EDI and its ratio to total exercise (AI), whereas the definition of sprinting is determined by the absolute running speed on the GPS. However, individual exercise strength cannot be determined by the absolute running speed because GPS data do not include information on individual physical fitness. Indeed, in this study, individual V_T running speeds ranged from 9.8 km/h to 12.9 km/h. This finding indicates that individual V_T is different among players, and thus, the same running speed does not represent the same sprint strength among players. For example, for the individual who has a 12.9 km/h V_T running speed, 9.8 km/h is not an anaerobic (sprint) level of intensity, whereas, for the individual who 9.8 km/h V_T running speed, 9.8km/h is an anaerobic (sprint) level of intensity. Indeed, %EDI as an index of exercise intensity during a football game analysed using the GPS using running speed or acceleration did not provide the actual individual exercise intensity calculated in this study (Fig. 2). This finding indicates that GPS data (running speed) only are inadequate to estimate individual exercise intensity during a soccer game. In this study, the correction of the laboratory respiratory factors during an incremental intensity exercise test can estimate exercise strength using running speed considering individual physical fitness levels. The individual variation in parameters calculated using O_2 was significant among players (Table II). These findings also indicate the importance of including individual physical fitness in GPS data. While physical improvement that matches athletic characteristics in football competition games is important for improving performance, current training is not specifically based on scientific evidence on in-game energy consumption (e.g., in GPS data, fatigue is not considered). Thus, a method that individually assesses actual physiological strength throughout the game should be established to improve football performance for the game.

To analyse the anaerobic energy required, the actual O_2 uptake is needed (Medbo *et al*., 1988). Anaerobic energy can be analysed using the actual O_2 uptake during a football game and O_2 demand at each running speed calculated from the data of the laboratory experiment; however, O_2 uptake measurement during a football game is unrealistic because of the large stress it may cause the participants if they wear a gas mask. Thus, in this study, exercise intensity was identified using the O_2 demand at each moving speed.

V. Conclusion

The indexes of the GPS data (%EDI and AI) did not accurately provide the exercise intensity and anaerobic ratio of the total exercise during a game. This finding suggests that individual physiological fitness should be considered to identify individual exercise intensity at each running speed using GPS data during a game. Thus, a new method should be established to individually assess the actual physiological strength throughout the game to improve the performance of each football player.

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CONFLICT OF INTEREST

No conflicts of interest, financial or otherwise, are declared by the authors.

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