



# Evaluating the Effects of Three High Intensity Interval Training Protocols on Maximum Oxygen Consumption and Leg Strength in Recreational Football Athletes

Wirat Sonchan<sup>1ABCE</sup>, Saralee Sonchan<sup>1CD</sup> and Ratanyoo Longrak<sup>1BDE</sup>

<sup>1</sup>Burapha University

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Corresponding Author: Wirat Sonchan, e-mail: wirats@go.buu.ac.th

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## Abstract

**Objectives.** This study aimed to examine the effects of three high intensity interval training (HIIT) protocols on  $VO_{2max}$  and leg strength in recreational football athletes.

**Materials and methods.** Thirty-one participants were recruited and randomly assigned to one of three HIIT protocols: HIIT20/20, HIIT40/10, or HIIT60/5. The training programs spanned 6 weeks with a frequency of 3 sessions per week on non-consecutive days. Baseline testing for  $VO_{2max}$  and leg strength was conducted using an incremental exercise test with blood gas analysis and an isokinetic machine, respectively, at 1 week before the intervention, and post-intervention testing occurred 1 week after the last training session. A two-way repeated measures ANOVA was employed to compare changes between groups and across time points.

**Results.** The results demonstrated that there was a significant increase in  $VO_{2max}$  in both the HIIT40/10 ( $\Delta$  10.4 %, CI 95 % = 1.67-7.42 ml/kg/min, ES = Moderate) and HIIT60/5 ( $\Delta$  12 %, CI 95 % = 2.28-8.84, ES = Moderate) groups, while no considerable changes were observed in leg strength across any group ( $p > 0.05$ ). Additionally, a Weak but substantial correlation between leg strength and  $VO_{2max}$  was found at both pre-intervention ( $r = 0.39$ ) and post-intervention ( $r = 0.38$ ) periods.

**Conclusions.** In conclusion, if the training goal was to improve  $VO_{2max}$  through HIIT, both the HIIT40/10 and HIIT60/5 protocols were more effective than HIIT20/20.

**Keywords:** maximum oxygen consumption,  $VO_{2max}$ , sprint training, leg strength, football.

## Introduction

Football (or Soccer) is a high-intensity, intermittent sport that requires athletes to sustain performance over a 90-minute game (Stølen et al., 2005). Players are constantly engaged in activities like sprinting, jogging, and walking, with frequent changes in direction and pace (Bradley et al., 2015). The physical demands of football necessitate excellent cardiovascular endurance and muscular strength, as athletes must maintain a high level of effort throughout the match. Previous study reported that the professional football players covered the total distances about 9 to 14 km per match (Sarmiento et al., 2014). Without sufficient fitness, players might experience fatigue, which can affect their ability

to make quick decisions and execute skilled movements effectively, especially during the latter stages of the game (Smith et al., 2016).

The maximum oxygen consumption ( $VO_{2max}$ ) during exercise, is widely recognized as a key indicator of cardiovascular fitness (Modric et al., 2020). In football,  $VO_{2max}$  reflects an athlete's ability to perform sustained aerobic work, which is crucial for maintaining high levels of activity throughout the game. The previous study demonstrated that  $VO_{2max}$  values were in the range of 48 to 62 ml/kg/min for male soccer players; especially in professional players, the values were about 57.8 to 61.7 ml/kg/min (Slimani et al., 2019). Athletes with higher  $VO_{2max}$  can recover more efficiently between high-intensity bouts, allowing them to maintain performance during crucial moments (Tomlin et al., 2001). Improving  $VO_{2max}$  through targeted training can enhance an athlete's overall endurance (Scribbans et al., 2016).

High-Intensity Interval Training (HIIT) has garnered significant interest as one of the most effective methods for improving  $VO_2\max$  (Atakan et al., 2021). By alternating between short bursts of intense exercise and recovery periods, HIIT places a greater demand on the cardiovascular and respiratory systems than traditional endurance training (Gibala et al., 2012). Studies have shown that various protocols of HIIT can lead to significant improvements in  $VO_2\max$  (Helgerud et al., 2007; Fernandez-Fernandez et al., 2012; Monks et al., 2017), regardless of differences in the specific protocol.

In addition to cardiovascular endurance, leg strength plays a pivotal role in football performance (Stølen et al., 2005). The ability to generate force in the legs is critical for key actions such as sprinting, jumping, kicking, and clearing long passes (Cometti et al., 2001). Interestingly, HIIT has been shown to elicit multifaceted adaptations, not only improving  $VO_2\max$  but also enhancing maximum leg strength (Caparrós-Manosalva et al., 2023). This increased leg strength contributes to better speed and power while helping athletes sustain high levels of intensity during physically demanding matches.

Given the importance of both aerobic capacity and leg strength in football, the present study aimed to investigate the effects of three HIIT protocols on  $VO_2\max$  and leg strength in recreational football athletes.

## Materials and Methods

### Study Participants

Thirty-one healthy, physically active young men were recruited for this study. The sample size was determined using G\*Power software version 3.1.9.7, with a priori power analysis indicating an effect size of 0.8, an alpha level of 0.05, and a power ( $1-\beta$ ) of 0.95. Eligibility criteria included: 1) healthy male undergraduate students aged 18-24, 2) at least 1 year of recreational football experience, and 3) no pre-existing medical conditions (e.g., hypertension, cardiac disease, diabetes) that could impede participation. A certified hospital physician conducted a comprehensive health assessment to confirm eligibility. Participants were randomly assigned to one of three groups: HIIT20/20 ( $n = 10$ ), HIIT40/10 ( $n = 10$ ), or HIIT60/5 ( $n = 11$ ) using the Research Randomizer website ([www.randomlists.com](http://www.randomlists.com)).

All participants provided informed consent prior to their involvement, and the study adhered to the Declaration of Helsinki. Moreover, approval for the study protocol was obtained from the Institutional Review Board of Burapha University (No. IRB1-015/2565).

### Experimental Design

The study investigated the effects of high intensity interval training (HIIT) protocols on  $VO_2\max$  and leg strength in recreational football athletes. Participants were randomly divided into three groups: HIIT20/20, HIIT40/10, and HIIT60/5. The protocols were applied over 6 weeks using a single-blind design. Eligibility was restricted to recreational footballers who played less than three times per week to ensure they were non-professional and played primarily for leisure.  $VO_2\max$  and leg strength were assessed one week

before and one week after the training intervention, under controlled conditions.

### High Intensity Interval Training

All training groups participated in a 6-week program, engaging in their assigned HIIT protocols three times per week. Each session commenced at the Burapha University football field, where participants were supervised closely throughout session. The session began with a 5-minute warm-up involving dynamic stretching and light jogging to prepare the participants. The HIIT consisted of “all-out” repeated sprints performed at maximum effort of that current state. For the HIIT20/20 protocol, participants completed 20 sets of “all-out” repeated sprinting over a distance of 20 meters, with a 30-second rest interval between bouts. For the HIIT40/10 protocol, participants performed 10 sets of “all-out” repeated sprinting over 40 meters, with a 30-second rest interval between bouts. Last but not least, for the HIIT60/5 protocol, participants performed 5 sets of “all-out” repeated sprinting over 60 meters, with a 30-second rest interval between bouts. After completing the training session, all groups concluded with a 5-minute cool-down period, which included light jogging and static stretching of the total body. Throughout these 6-week training programs, participants were instructed to refrain from engaging in any additional training activities of all kind.

### Leg Strength Assessment

The assessment of muscle strength of dominant leg was conducted by the isokinetic machine (ISOFORCE, Germany), recognized as the gold-standard for evaluating muscular strength (Chamorro et al., 2017). Pre-intervention testing occurred one week prior to the commencement of the training program as well as all post-intervention was on 1 week after last training session. The testing began with a 5-minute warm-up comprising light treadmill walking and dynamic stretching exercises targeting the knee extensor groups. Participants were seated and securely fastened with strap belts to ensure stable positioning of the torso and upper thighs (about 90 degrees of hip flexion). Clear instructions were read out loud to participants that “you have to kick up your legs as hard and fast as possible, with maximal effort against the ankle pad, which was programed to move at the angular velocity of 60 degrees per second, starting from a knee flexion of 90 degrees to full knee extension”. Each participant performed three maximum effort attempts, with a 120-second rest interval between attempts.

### Maximum Oxygen Consumption Assessment

The assessment of  $VO_2\max$  was conducted following the modified Bruce Protocol. This protocol was utilized in previous study for evaluating cardiorespiratory fitness from the treadmill incremental exercise test (Ham et al., 2017). Participants were instructed to wear a specialized mask (Hans Rudolph, Kansas, USA) designed to cover both the nose and mouth with very little dead spaces, enabling the collection of respiratory gases, facilitated by a respiratory gas analyzer (Oxycon Mobile, Germany). Participants were instructed to maintain natural breathing patterns through

the mask during the assessment. The protocol commenced with participants instructed to run on the treadmill (T7-0, Life Fitness, Illinois, USA) at starting speed of 3.6 km/h for an initial duration of 2 minutes. Subsequently, the speed of treadmill constantly increased at 1.2 km/h for every 2 minutes. This modified protocol constantly kept the grade to 0% (Table 1). This incremental exercise test ensured a progressive increase in cardiovascular demand with increased speed, pushing participants towards their maximal aerobic capacity. The test was terminated when participants reached volitional exhaustion, indicated by an inability to maintain the required speed on the treadmill. The heart rate was continuously measured during the test by means of a heart rate monitor (H10, Polar, Finland).

**Table 1.** The modified Bruce Protocol

Speed (km/h)	Time (min)
3.6	0-2
4.8	2-4
6.0	4-6
7.2	6-8
8.4	8-10
9.6	10-12
10.8	12-14
12.0	14-20
13.2	20-22
14.4	22-24
15.6	24-26

Grade (%) remained at 0 throughout the testing period

### Statistical Analysis

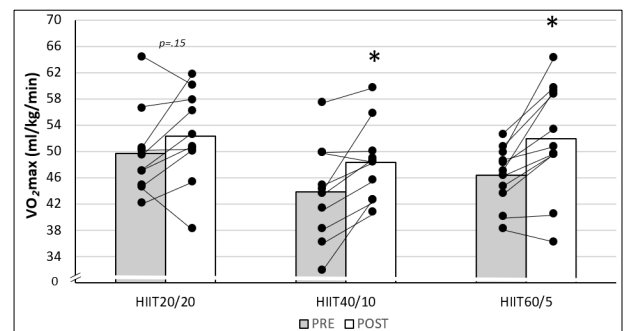
The statistical analysis was calculated to investigate the effects of three different HIIT protocols on leg muscle strength, short-distance sprint performance, and maximum oxygen uptake in football athletes. The Shapiro-Wilk test was analyzed for the distribution of data. Descriptive statistics were used to summarize participants' baseline characteristics. Baseline variables between groups was compared by One-way ANOVA. Levene's test was used to assess the homogeneity of variances. Changes in VO<sub>2</sub>max and leg strength from Pre to Post were calculated and a two-way repeated measured ANOVA was employed to compare the effects between groups (HIIT20/20 vs HIIT40/10 vs HIIT60/5) and times (Pre vs. Post). Cohen's d effect size

was calculated using the following formula: mean change/pooled SD, with being interpreted according to the Hopkins' recommendations: 0.00-0.19: Trivial; 0.20-0.59: Small; 0.60-1.19: Moderate; 1.20-1.99: Large; ≥2.00: Very large (Hopkins et al., 2009). Moreover, the Pearson's correlation coefficient was also calculated to examine the relationships between VO<sub>2</sub>max and leg strength at both pre and post-test, with the interpretation of values according to the previous study: 0.00-0.09 - Negligible; 0.10-0.39 - Weak; 0.40-0.69 - Moderate; 0.70-0.89 - Strong; 0.90-1.00 - Very strong (Schober et al., 2018). Statistical analyses were performed using IBM SPSS Statistics version 20, with a significance level set at  $\alpha = 0.05$ .

### Results

At the beginning of the test, the statistical analysis indicated no significant differences in participants' baseline characteristics ( $p > 0.05$ ) (Table 2). Furthermore, all participants completed the training program with 100% adherence.

A significant time effect was observed VO<sub>2</sub>max ( $F_{(1,28)} = 24.441$ ,  $p = 0.000$ ,  $\eta^2_p = 0.466$ ), indicating changes over time in these variables, while no time effect was observed for leg strength. Additionally, no significant main group or interaction effects were detected ( $p > 0.05$ ) (Table 3).



**Fig. 1.** Maximum oxygen consumption values from pre- to post-intervention with individual analyses. \* indicated significantly different from pre-intervention ( $p < 0.01$ )

Specifically, only HIIT40/10 and HIIT60/5 showed significant increases in VO<sub>2</sub>max from baseline ( $\Delta 10.38\%$ ,  $d = 0.68$ ,  $p = 0.006$ ;  $\Delta 11.98\%$ ,  $d = 0.83$ ,  $p = 0.004$ , respectively) (Figure 1). Conversely, no groups demonstrated a significant increase in leg strength after 6-week HIIT.

**Table 2.** Baselines of participants' characteristics and performance

Variable	HIIT20/20 (n=10) mean ± SD	HIIT40/10 (n=10) mean ± SD	HIIT60/5 (n=11) mean ± SD	F	p
Age (years)	20.30 ± 0.82	20.20 ± 1.14	20.55 ± 1.04	0.33	0.72
Height (cm)	176.70 ± 5.74	176.40 ± 1.14	172.36 ± 7.97	1.53	0.23
Body mass (kg)	64.90 ± 9.09	68.80 ± 8.78	69.45 ± 12.23	0.59	0.56
Leg strength (Nm/kg)	2.84 ± 0.60	2.85 ± 0.45	2.79 ± 0.65	0.09	0.97
VO <sub>2</sub> max (ml/kg/min)	49.72 ± 6.53	43.82 ± 7.41	46.42 ± 4.40	2.29	0.12

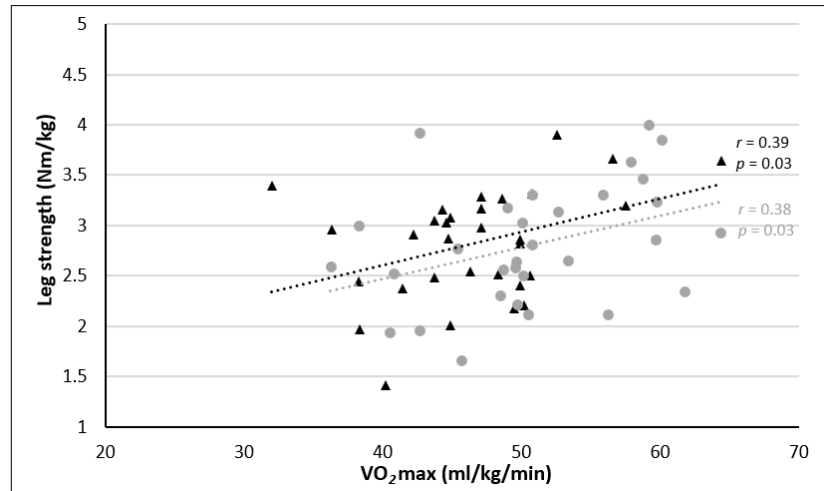
Data were presented as mean ± standard deviation. Abbreviation: VO<sub>2</sub>max

**Table 3.** Change from Pre to Post

Measurement	HIIT20/20 (n = 10)			HIIT40/10 (n = 10)			HIIT60/5 (n = 11)			Effect p
	Pre (mean ± S.D.)	Post (mean ± S.D.)	Δ (95% CI)	Pre (mean ± S.D.)	Post (mean ± S.D.)	Δ (95% CI)	Pre (mean ± S.D.)	Post (mean ± S.D.)	Δ (95% CI)	
VO <sub>2</sub> max (ml/kg/min)	49.72 ± 6.53	52.36 ± 7.08	2.63 (-1.18; 6.44)	43.82 ± 7.41	48.37 ± 5.95*	4.55 (1.67; 7.42)	46.42 ± 4.40	51.98 ± 8.42*	5.56 (2.28; 8.84)	0.380
Leg strength (Nm/kg)	2.84 ± 0.60	2.93 ± 0.60	0.09 (-0.05; .22)	2.85 ± 0.45	2.72 ± 0.69	-0.13 (-.43; 0.17)	2.79 ± 0.65	2.79 ± 0.56	-0.00 (-0.20; .19)	0.309

Data were presented as mean ± standard deviation. Abbreviation: VO<sub>2</sub>max = Maximal oxygen uptake; ES = Effect size; 95% CI = 95% Confidence Interval. \* p < 0.01 compared to Pre.

Moreover, the Pearson's correlation coefficient indicated Weak but significant correlations between VO<sub>2</sub>max and leg strength at both pre-intervention (r = 0.39) and post-intervention (r = 0.38) (Figure 2).



**Fig. 2.** Correlations between maximum oxygen consumption (VO<sub>2</sub>max) and leg strength at pre-intervention (Black triangle) and post-intervention (Light grey circle)

**Discussion**

This study was the first to demonstrate that not all HIIT protocols are equally effective in increasing VO<sub>2</sub>max. We found that the HIIT20/20 protocol was less effective than HIIT40/10 or HIIT60/5 in producing significant improvements in aerobic fitness. However, none of the HIIT protocols in this study led to a significant increase in leg strength after six weeks of training.

The main findings of our study are consistent with previous research demonstrating that short-term HIIT can increase VO<sub>2</sub>max to a certain extent. For example, Milioni et al. (2024) reported that just four weeks of 10 bouts of 1-minute sprints at 90 % of maximum velocity significantly increased VO<sub>2</sub>max by approximately 2.1 ml/kg/min from baseline. Similarly, Raleigh et al. (2018) found that eight 20-second bouts of maximum cycling increased VO<sub>2</sub>max by up to 4.7 ml/kg/min after just four weeks of training. Likewise, Kim et al. (2011) demonstrated that ten 30-second maximum sprint bouts resulted in a significant VO<sub>2</sub>max increase of 3.92 ml/kg/min after eight weeks of training.

Theoretically, the increase in maximum oxygen consumption can theoretically be attributed to improvements in two key areas: 1) central adaptations, which involve an enlargement of left ventricular volume, enhanced contractility, and increased blood volume, all contributing to a greater stroke volume (Hellsten & Nyberg, 2015); and 2) peripheral adaptations, which enhance the muscles' ability to extract oxygen and generate ATP aerobically (Daussin et al., 2007). It is likely that high-intensity interval training can improve both mechanisms within a relatively short time frame.

To support this, previous studies have demonstrated that HIIT can induce various peripheral adaptations, such as increases in mitochondrial numbers (Torma et al., 2019) and oxidative enzymes (Gillen et al., 2014) after a short period of training. Additionally, HIIT has been shown to stimulate the expression of vascular growth factors, like vascular endothelial growth factor (VEGF), which promotes new blood vessel formation (MacInnis & Gibala, 2016). From a physiological standpoint, it is likely that the HIIT40/10 and HIIT60/5 protocols in our study resulted in greater adaptations in these mechanisms. Consequently, the capacity to extract oxygen from the blood and generate ATP aerobically increased significantly in these groups, as evidenced by the significant improvement in VO<sub>2</sub>max (Raleigh et al., 2018). In contrast, the adaptations in the HIIT20/20 protocol may have been suboptimal.

One possible explanation for the results is that the distance covered in each bout of the HIIT20/20 protocol was too short, as participants only sprinted about 20 meters, which took approximately 3 to 3.5 seconds. This short-duration effort may not have been sufficiently taxing to induce the internal stress required, as compared to the

40-meter or 60-meter sprints. The molecular response to interval stress and ATP deficit, such as activation of the AMP-activated protein kinase (AMPK) signaling pathway, might not have been adequately triggered by the shorter sprints (Winder et al., 2006). This signaling pathway is known to enhance several aspects of aerobic capacity, including improved fat oxidation, increased mitochondrial biogenesis, stimulated capillarization, and fiber type transformation (Spaulding & Yan, 2022), all of which are well-established contributors to improved aerobic performance. Therefore, practitioners of HIIT should consider bout duration or distance as critical training factors. However, our study did not examine cellular or molecular responses in detail. Future research should explore our hypothesis regarding these adaptations.

Moreover, we found that the leg strength of our participants did not significantly change after six weeks of HIIT, regardless of the protocol used. It is likely that the participants were not untrained or weak subjects who could benefit from low external load activities, as they only sprinted using their body weight. Therefore, to adhere to the principles of training necessary for inducing physiological adaptations in muscle strength, external moderate to heavy load modalities should be employed (ACSM, 2009).

For instance, high-intensity interval training (HIIT) can be performed on loaded stationary bikes or with weight vests. Additionally, to align with the principle of specificity (Kasper, 2019) for football athletes aiming to increase lower-body strength, it is essential to incorporate resistance training exercises such as the leg press or back squat (Wirth et al., 2016) as the primary modalities for enhancing leg strength. In this study, a Weak but significant correlation was found between leg strength and  $VO_{2max}$  at both pre- ( $r = 0.39$ ,  $p = 0.03$ ) and post-intervention ( $r = 0.38$ ,  $p = 0.03$ ), indicating that improvements in leg strength might positively benefit  $VO_{2max}$  in football athletes. This finding further underscores the necessity of leg strength training in enhancing overall athletic performance.

## Conclusions

In summary, our study clearly showed that not all HIIT protocols are created equal for improving  $VO_{2max}$ . We recommend the HIIT40/10 and HIIT60/5 protocols, as they demonstrated superior results compared to HIIT 20/20. Furthermore, training with HIIT alone, regardless of the protocol used, is unlikely to produce significant increases in leg strength within a short time frame.

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## Conflict of interest

The authors guarantee that no conflicts of interest exist.

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# Оцінка впливу застосування трьох протоколів високоінтенсивного інтервального тренування на показники максимального споживання кисню та сили ніг у спортсменів з рекреаційного футболу

Вірат Сончан<sup>1ABCDE</sup>, Саралі Сончан<sup>1CD</sup>, Ратаню Лонграк<sup>1BDE</sup>

<sup>1</sup>Бурафа університет

Авторський вклад: А – дизайн дослідження; В – збір даних; С – статаналіз; D – підготовка рукопису; Е – збір коштів

Реферат. Стаття: 7 с., 3 табл., 2 рис., 31 джерело.

**Мета дослідження.** Мета дослідження полягала у вивченні впливу застосування трьох протоколів високоінтенсивного інтервального тренування (ВІТ) на показники  $VO_{2max}$  та сили ніг у спортсменів з рекреаційного футболу.

**Матеріали та методи.** До участі в дослідженні було залучено 31 учасника, яких розподілили за методом рандомізації з метою виконання фізичних вправ одного з трьох протоколів ВІТ: ВІТ20/20, ВІТ40/10 або ВІТ60/5. Тренувальні програми тривали 6 тижнів з частотою 3 заняття на тиждень у різні дні. Початкове вимірювання показників  $VO_{2max}$  та сили ніг проводилось за допомогою інкрементного тесту на визначення рівня фізичної підготовленості з використанням аналізу для оцінки рівня кисню та вуглекислого газу в крові та ізокінетичного апарату, відповідно, на етапі за 1 тиждень до проведення інтервенції, а постінтервенційне тестування — через 1 тиждень після останньої тренувальної сесії. З метою порівняльного аналізу змін між групами та часовими точками було застосовано двофакторний дисперсійний аналіз із повторними вимірами (ANOVA).

**Результати.** За результатами дослідження встановлено значне підвищення рівня  $VO_{2max}$  у групах ВІТ40/10 ( $\Delta$  10,4 %, довірчий інтервал, CI 95 % = 1,67-7,42 мл/кг/хв, розмір ефекту, ES = Помірний) та ВІТ60/5 ( $\Delta$  12 %, CI 95 % = 2,28-8,84, ES = Помірний), тоді як істотних змін у показниках сили ніг у жодній з груп не спостерігалось ( $p > 0,05$ ). Крім того, було виявлено слабкий, але суттєвий кореляційний зв'язок між показниками сили ніг та  $VO_{2max}$  як на передінтервенційному ( $r = 0,39$ ), так і на постінтервенційному періодах дослідження ( $r = 0,38$ ).

**Висновки.** Отже, якщо метою тренування було покращення показників  $VO_{2max}$  за допомогою програми ВІТ, застосування обох протоколів ВІТ40/10 і ВІТ60/5 показало більшу ефективність, ніж ВІТ20/20.

**Ключові слова:** максимальне споживання кисню,  $VO_{2max}$ , спринтерське тренування, сила ніг, футбол.

## Information about the authors:

**Sonchan, Wirat:** wirats@go.buu.ac.th; <https://orcid.org/0000-0001-9985-7765>; Faculty of Sport Science, Burapha University, 169 Long Had Bangsaen Rd, Saen Suk, Chon Buri 20131, Thailand.

**Sonchan, Saralee:** saralee@go.buu.ac.th; <https://orcid.org/0000-0002-7545-4328>; Faculty of Sport Science, Burapha University, 169 Long Had Bangsaen Rd, Saen Suk, Chon Buri 20131, Thailand.

**Longrak, Ratanyoo:** addmuscleclinicz@gmail.com; <https://orcid.org/0000-0001-6117-7617>; Faculty of Sport Science, Burapha University, 169 Long Had Bangsaen Rd, Saen Suk, Chon Buri 20131, Thailand.

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