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Comparison of energy consumption and excess post-exercise oxygen consumption according to Taekwondo Taegeuk Poomsae performance in Taekwondo players

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[Purpose] We compared and analyzed energy consumption and excess post-exercise oxygen consumption (EPOC) following Taekwondo Taegeuk Poomsae performances.

[Methods] Forty-two healthy men who could perform Taegeuk Poomsae 1–8 Jangs were enrolled in this study. To reduce the impact of Poomsae, a random cross-design was used. The washout time was set to at least three days. Oxygen consumption (VO_2) was monitored after performing each Poomsae until a reference line was resumed. Each Taegeuk Poomsae was performed at a speed of 60 bpm.

[Results] There was no significant difference in VO_2, carbon dioxide excretion, and heart rate after performing the Taegeuk Poomsae once; however, all variables increased significantly in combined results of EPOC metabolism ($F<45.646$, $p<0.001$, and $\eta^2<0.527$). Taegeuk 8 Jang had the highest levels of all the factors. There were noticeable variations in the oxidation of fat and carbohydrates throughout the Taegeuk Poomsae ($F<9.250$, $p<0.001$, $\eta^2<0.184$). Taegeuk 8 Jang demonstrated the greatest rate of carbohydrate oxidation, and 4–8 Jangs demonstrated much greater rates of fatty acid oxidation. Compared to 1 Jang, the energy consumption showed significant differences in all the variables and peaked in Taegeuk 8 Jang.

[Conclusion] The energy consumption during the Poomsae performances was the same. When the EPOC metabolism was coupled, it was evident that more energy was substantially used in each chapter of Poomsae. Consequently, it was determined that when performing Poomsae, not only should energy metabolism during exercise be taken into account but also EPOC metabolism, which can increase by 10-fold.

[Keywords] Taekwondo, Taegeuk Poomsae, energy consumption, excess post-exercise oxygen consumption, Taekwondo players

INTRODUCTION

Many individuals now have higher calorie diets than did those in the past; however, less physical activity and lack of exercise in daily life have led to an imbalance in the body's energy supply and consumption. Consequently, lifestyle diseases, such as hypertension, diabetes, hyperlipidemia, and obesity are emerging social problems[1,2]. Increasing energy metabolism is an effective method for preventing and treating lifestyle-related diseases. Therefore, there is significant interest in increasing energy metabolism through increased physical activity[3,4].

Energy consumption during physical activity is generally expressed as a function of oxygen consumption (VO_2) during exercise[5]. However, this does not describe the entire process because VO_2 also increases to promote homeostasis by reversing increased metabolic activity caused by physical activity to a stable level; this is called excess post-exercise oxygen consumption (EPOC)[6].

Excess post-exercise VO_2 is active within an hour of exercise, thereby leading to the recovery of adenosine triphosphate-phosphocreatine (ATP-PCr) in muscles, re-supplementation of blood and muscle oxygen, re-distribution of ions (elevated sodium-potassium pump activity), repair of damaged tissues, normalization of elevated heart rate (HR) and body temperature, and removal of lactic acid[6,7]. The EPOC was found to account for a large part of energy consumption, and the necessity of research is emerging because of high EPOC variability among various conditions. In particular, some studies have shown that the amount of EPOC varies, depending on exercise conditions, such as exercise duration, intensity, type of exercise, central body temperature, and nutritional status[8]. Therefore, the VO_2 during exercise is relatively small compared to dietary intake, but it can still be significant if applied to include EPOC and increased metabolic rate after exercise; thus, further research on met-

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abolic differences according to exercise is urgently needed[9]. Exercise programs to maintain, enhance, and improve general health frequently employ energy expenditure during exercise as a physiological indication, and many kinds of training programs have been designed based on this characteristic. However there isn't enough information available on Taekwondo Poomsae programs.

Taekwondo is a martial art that anyone can practice, and it is practiced for various purposes, including health promotion, weight loss, and confidence gain. Most Taekwondo training consists of basic movements, such as the mitt kick, Poomsae, and Gyeorugi[10]. Beginner students of Taekwondo first receive basic instruction in Poomsae, a combination of hand and foot skills, and are then organized to gradually acquire a variety of techniques, including diverse assaults and defense. The most fundamental training technique for Taekwondo is called Taekwondo Poomsae; this training is required to make sure that participants have the athletic physiological foundation of Taekwondo Poomsae to effectively achieve various training goals[11-13].

Prior studies related to Poomsae performance have occasionally reported changes in HR, oxygen intake, and lactic acid levels based on single and repeated Poomsae performances. According to one performance of Taegeuk Poomsae, although exercise intensity, energy consumption, and relative exercise intensity varied slightly depending on the research participants' ages, in general, the average HR reached around 65-85% of maximum VO_2. One study investigating energy consumption following repeated Poomsae performance showed that the higher the number of repetitions, the higher the HR, exercise intensity, and energy consumption[14-16].

Taekwondo Poomsae, as previously stated, is an exercise that anyone can learn, and it is important to understand the physiological underpinnings that manifest when exercising. Most researchers have focused on the energy expenditure that occurs during Taegeuk Poomsae when it is performed once or repeatedly. However, because energy consumption after exercise makes up a higher share of the energy consumption during exercise, it is crucial to examine EPOC post-exercise energy consumption features; however, studies on this topic are limited. To examine the physiological basis of energy consumption during Taekwondo Taegeuk Poomsae and to obtain thorough baseline information on energy consumption during Taegeuk Poomsae, it is crucial to assess both energy consumption and EPOC during exercise. Therefore, in this study, energy consumption, according to Taekwondo Taegeuk Poomsae performance and EPOC, was compared and analyzed.

METHODS

Participants

In this study, we enrolled 42 major Taekwondo players that are men, in their 20s, with >5 years of Taekwondo practice. Inclusion criteria were: those who were good at implementing Taegeuk Poomsae (1–8 Jangs), and had no diseases of the muscle or skeletal system, no heart- or blood-related diseases, and no neurological or psychiatric diseases. Informed permission was gained from each participant following a thorough explanation of the study's purpose, content, and methods, which was approved by our Institutional Review Board (IRB; 7001355-202004-HR-372). Table 1 shows the participants' physical characteristics.

Table 1. Baseline characteristics of the subjects.

Variables	Male (*n*=42)
Age (years)	21.2±3.5
Height (cm)	173.5±4.9
Weight (kg)	69.3±7.7
BMI (kg/m^2)	23.0±2.2
Free fat mass (kg)	59.0±5.7
Body fat mass (kg)	10.3±4.5
Body fat percentage (%)	14.6±4.9

Note. BMI = body mass index.

Experimental design

The participants visited our laboratory eight times for measurement purposes. After evaluating the participant's height, weight, and body composition during the initial visit, energy consumption during the Taegeuk Poomsae performance was measured. The participants were engaged in Taegeuk Poomsae from 1 to 8 Jangs while wearing an HR monitor (Garmin, USA) and a gas analyzer (COSMED K5, Italy). The participants were randomly cross-designed from 1 to 8 Jangs of the Taegeuk Poomsae, and the washout time was set to at least three days to minimize the influence of the Poomsae. To collect constant data for 1 to 8 Jangs, each Taegeuk Poomsae exercise was performed at a speed of 60 bpm, and EPOC was measured after performing the Poomsae exercise once until return to baseline. The experimental design is illustrated in Figure 1.

Body composition

Participants were dressed simply after taking off their socks, jewelry, and other accessories in order to use a bioelectric impedance analyzer (Inbody 770, Biospace, Korea) to measure their physical attributes and body composition. The variables were measured body weight, height, body mass index (weight [kg]/square of height [m^2]), body fat mass, fat mass percentage, and free fat mass.

Measurement of taegeuk poomsae energy consumption

In this study, the participants wore an automatic respiratory gas analyzer (COSMED K5, Italy) on their backs, HR monitor (Garmin, USA) on their chests, and a mask on their faces, while performing Taegeuk Poomsae. Energy expenditure was continuously measured until the EPOC measurement was completed by starting the Taegeuk Poomsae performance. Immediately after the Taegeuk Poomsae was performed, the participant's EPOC was measured in a comfortable sitting position. The measured variables in-

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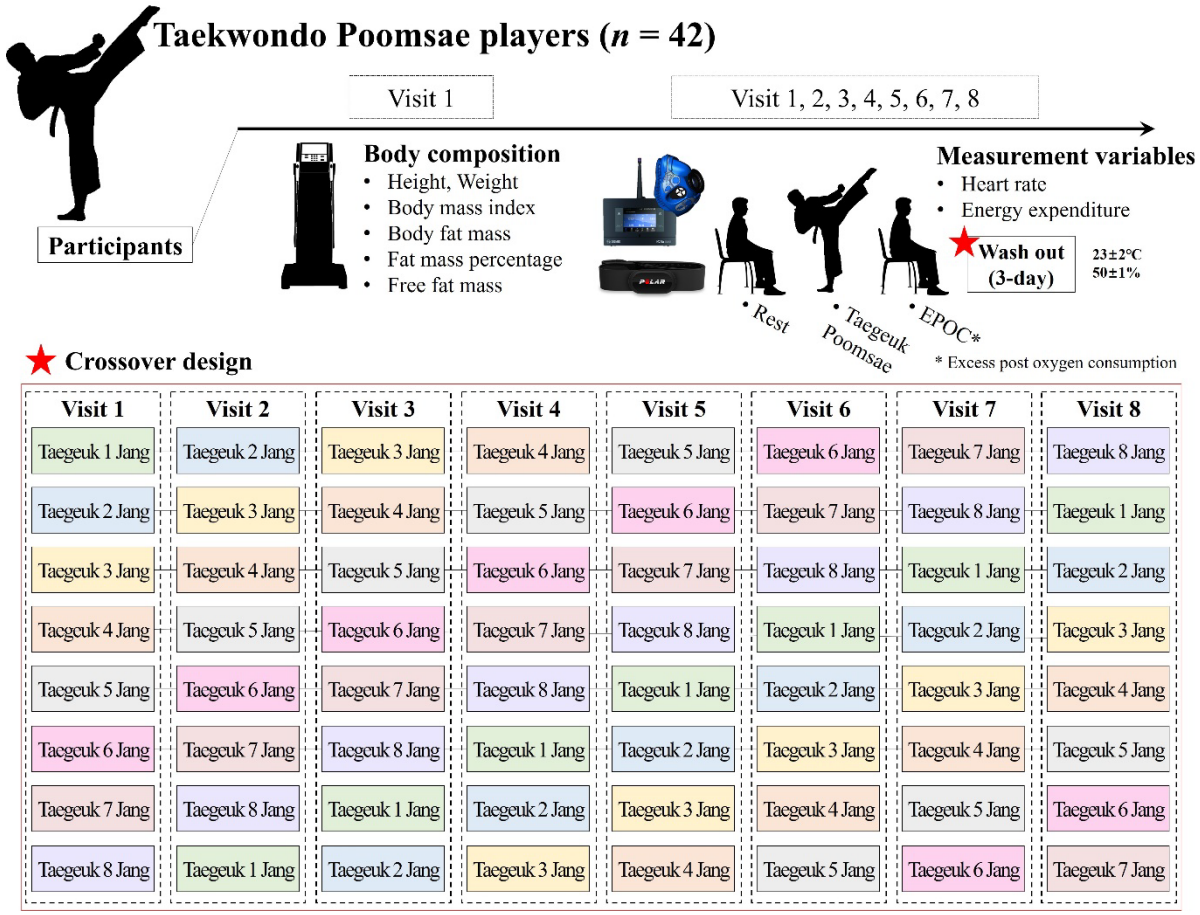

Figure 1. Experimental design.

cluded VO_2, carbon dioxide excretion (VCO_2), HR, energy consumption, and substrate oxidation. Using the Jeukendrup and Wallis[17] formula, substrate oxidation was determined.

$$\text{Carbohydrate (CHO) oxidation (g)} = 4.210 \times VCO_2 - 2.962 \times VO_2$$

$$\text{Fat oxidation (g)} = 1.695 \times VO_2 - 1.701 \times VCO_2$$

$$\text{Energy consumption (kcal)} = 4.07 \times \text{CHO} + 9.75 \times \text{FAT}$$

Statistical analysis

Using SPSS software (version 25.0; IBM Corp., Armonk, NY, USA), all data collected for this study were analyzed, and mean and standard deviation were calculated to show descriptive statistics. Using the Shapiro-Wilk test, the assumptions of normality and homoscedasticity were confirmed. In order to clarify the interaction effects between the Taegeuk Poomsaes (1–8 Jangs) and energy consumption, including EPOC, a two-way analysis of variance (ANOVA) with repeated measurements was performed. The differences in the dependent variables between all Tae-geuk Poomsaes and energy consumption, including EPOC, were assessed using repeated one-way ANOVA. The Bonferroni test was used as a post-hoc analysis. The threshold for significance was determined at 0.05.

RESULTS

Metabolic function of taegeuk poomsae

We observed a significant difference in VO_2 (F=157.636, p=0.000, and η^2=0.794), VCO_2 (F=100.343, p=0.000, and η^2=0.710), and HR (F=41.621, p=0.000, and η^2=0.504) after performing multiple Taegeuk Poomsaes. Conversely, after performing the Taegeuk Poomsae once, there was no significant difference in VO_2, VCO_2, or HR, but all these variables increased significantly in the combined results of EPOC metabolism. The VO_2, VCO_2, and HR variables were higher in Taegeuk 1 Jang under all conditions and were highest in Taegeuk 8 Jang (Figure 2).

Energy consumption of taegeuk poomsae

The Taegeuk Poomsae showed significant differences in CHO oxidation (F=9.250, p=0.000, and η^2=0.184), fat oxidation (F=45.646, p=0.000, and η^2=0.527), and energy consumption (F=93.419, p=0.000, and η^2=0.695). Taegeuk 8 Jang showed the highest CHO oxidation, and fatty acid oxidation was significantly higher in Taegeuk 4–8 Jangs. Compared to Taegeuk 1 Jang, energy consumption showed significant differences in all the variables and was highest in Taegeuk 8 Jang (Figure 3).

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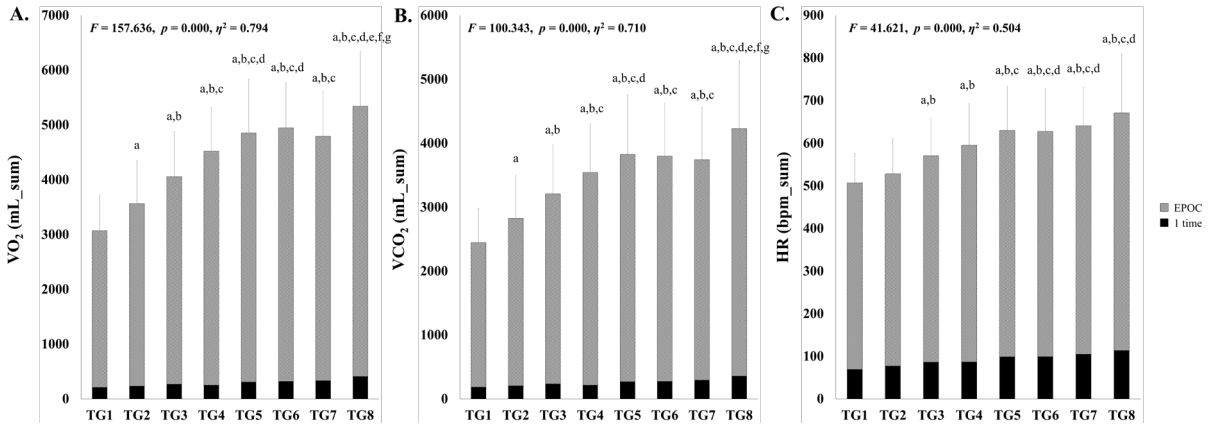

Figure 2. Metabolic function of Taekwondo Taegeuk Poomsae (mean ± standard deviation): The (**A**) Change in VO_2, (**B**) Change in VCO_2, (**C**) Change in HR are shown.
TG: Taegeuk; VO_2: oxygen uptake; VCO_2: carbon dioxide excretion; HR: heart rate. a = Taegeuk 1 Jang vs.; b = Taegeuk 2 Jang vs.; c = Taegeuk 3 Jang vs.; d = Taegeuk 4 Jang vs.; e = Taegeuk 5 Jang vs.; f = Taegeuk 6 Jang vs.; g = Taegeuk 7 Jang vs. Taegeuk 8 Jang mean statistically significant differences, respectively.

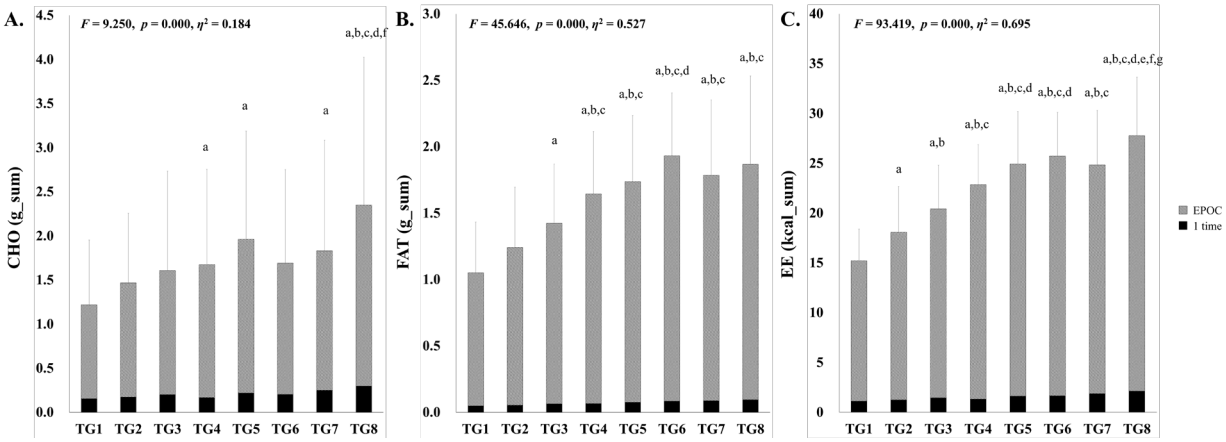

Figure 3. Energy expenditure of Taekwondo Taegeuk Poomsae (mean ± standard deviation): The (**A**) Change in CHO oxidation, (**B**) Change in fat oxidation, and (**C**) Change in EE are shown.
TG: Taegeuk; CHO: carbohydrate; EE: energy consumption. a = Taegeuk 1 Jang vs.; b = Taegeuk 2 Jang vs.; c = Taegeuk 3 Jang vs.; d = Taegeuk 4 Jang vs.; e = Taegeuk 5 Jang vs.; f = Taegeuk 6 Jang vs.; g = Taegeuk 7 Jang vs. Taegeuk 8 Jang mean statistically significant differences, respectively.

DISCUSSION

Taekwondo Poomsae involves training in basic attack and defense skills, such as kicking, punching, and blocking in a certain stride. This sport was selected as the official event of the 2006 World Championship, highlighting the value and importance of Poomsae training[10,12,13]. Taekwondo Poomsae training begins with "Taegeuk," and is divided into eight Jangs. Each Jang progresses by adding additional offensive and defensive postures, one step apart. Taekwondo Poomsae is an exercise that people of all ages can perform, and to bring about continuous expansion and activation of the base, it is necessary to develop effective programs for promoting daily sports and health and scientific verification[11,18,19]. In this study, to verify the scientific effect of Taekwondo Poomsae for use as basic data, metabolic function and energy consumption during and after Taegeuk Poomsae performance were measured, compared, and analyzed.

Taekwondo Poomsae is divided into Taegeuk 1–8 Jangs, with increasing complexity and difficulty of movement at each stage. In this study, metabolic function (VO_2, VCO_2, and HR) increased during a single Taegeuk Poomsae performance, but there were no significant differences between the different Poomsaes. In contrast, it can be seen that the data obtained by combining metabolic function and EPOC during the performance increased significantly at Taegeuk 8 Jang compared to Taegeuk 1 Jang. Excess post-exercise VO_2 varies with exercise intensity and duration and has been reported to last up to ≥8 h[19,20]. The higher the exercise intensity, the higher the EPOC, which has been reported to be effective in reducing total body fat[21,22]. In particular, the concept of increased EPOC is used as an important data to support the maintenance or reduction of body mass while creating exercise programs that maximize energy consump-

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tion during recovery.

Energy consumption is calculated as the amount of oxygen used in physical or metabolic activities combined with the contraction and relaxation processes of the skeletal muscles used during exercise. For oxygen to be used as an energy source, breathing, circulation, nerves, and muscles must work together[21,23,24]. Excess post-exercise VO_2 can restore ATP-PCr in muscles immediately after exercise, replenish oxygen in the blood and muscles, redistribute ions, normalize elevated HR and body temperature, and remove lactic acid. Therefore, energy metabolism after exercise plays an important role in determining the amount of energy consumption[20,25,26]. In this study, the energy consumption of each Taekwondo Taegeuk Poomsae is insignificant, ranging between 1.1–2.1 kcal on average per measurement, but the EPOC used after completion added up to 14.1–25.6 kcal, indicating a 10-fold or more increase in energy consumption. This movement of Poomsae is believed to be due to significant stress on the muscles and immediate and long-term appearance of symptoms related to motor-induced muscle damage during unfamiliar activities. Jung et al.[15] reported that the average energy consumption of Taekwondo Poomsae was 3.1–6.4 kcal/min, which differed from other exercises, such as walking 5.4 ± 0.9 kcal/min[27], stair climbing 8.5 ± 0.1 kcal/min[28], fast walking 4.7–6.7 kcal/min[29], and golf 3.3–8.2 kcal/min[30]. Because most of the Taekwondo Poomsaes are completed within minutes, if calculated in minutes for one measurement, it appears at around 4 kcal/min, which can be seen as a similar number. However, there is currently no research on EPOC during Taekwondo Poomsae, which prevents direct comparisons. Considering that the EPOC consumes 10 times more energy than during exercise, Taekwondo Poomsae can be used as a basic material for public health.

As shown in a previous study by Jung et al.[14], the energy consumption of repeatedly performed Taekwondo Poomsae is similar to or greater than that of medium-intensity exercise, and when considered in combination with EPOC, more energy consumption is shown. The American College of Sports Medicine[31] states that to maximize the effect of exercise, people should perform moderate-intensity exercise for 30–60 min for ≥5 days, or 20–60 min of high-intensity exercise for ≥3 days, or concurrent moderate-intensity and high-intensity exercise for 3–5 days a week[32]. In most cases, medium to high-intensity aerobic exercises are recommended for weight loss and health promotion. When it comes to how different types of exercise affect the body, long-term mild exercise lowers blood lipids and body fat while short-term vigorous exercise enhances cardiovascular function. Continuous moderate-intensity exercise may drop heart rate, reduce blood pressure, raise blood volume, reduce blood catecholamines, and boost thyroid hormone[5,11,20,33,34]. The results of this study showed that Taekwondo Poomsae is effective in promoting energy consumption and positively changing the metabolism of EPOC, and could therefore be used in programs to promote health. Additionally, developing and distributing programs in the order of Taegeuk 1 Jang with low intensity to Taegeuk 8 Jang gradually increased, according to various age groups. Exercise levels can be recommended as an effective exercise program.

This study has several limitations. Although the generalizability of our results is unclear, we have attempted to increase the reliability for many individuals. However, future studies with larger sample sizes are needed to investigate whether energy consumption and EPOC still increase, and controls should be used to further reduce the risk of type I error. We acknowledge that our study is limited because we did not monitor dietary intake during data collection. However, we instructed the participants to maintain a similar energy intake throughout the study, and to complete and participate 2 h before the experiment.

Overall, the energy consumption of Taekwondo Taegeuk Poomsae conducted in this study increased in Taegeuk 8 Jang rather than Taegeuk 1 Jang. In particular, there was no significant difference in one performance, but there was a significant difference in the combined results with the EPOC measured after the end of the exercise. The total energy consumption was higher in Taegeuk 4–8 Jangs than in Taegeuk 1 Jang. Given the short duration of single Taekwondo Poomsae performances, there was no variation in the amount of energy used in each chapter. However, considering the entire EPOC and the fact that the energy consumed during the exercise was approximately 10 times more than the energy consumed during the exercise, it is possible to consider strategies to enhance energy metabolism by engaging in Taekwondo Poomsae. Additionally, because energy consumption increases in the order of Taegeuk 1 to 8 Jangs, these protocols can be used as exercises for men and women of all ages. Taekwondo Poomsae is known to be an effective exercise for improving the range of joint movement and body composition, as well as mental training, and it is considered a suitable exercise to develop an individual's body evenly because it can be performed alone in a small place. Future research suggests a regression model that predicts energy consumption based on the energy metabolism and EPOC of Taekwondo Poomsae, so that it can be easily used in exercise programs and physical activity guidelines that are effective in improving health and preventing obesity. Additionally, these data could be used to develop various programs that utilize the exercise intensity and energy consumption of Taegeuk 1–8 Jangs and to construct effective exercise programs for public health.

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REFERENCES

1. Zobel EH, Hansen TW, Rossing P, von Scholten BJ. Global changes in food supply and the obesity epidemic. *Curr Obes Rep.* 2016;5:449-55.
2. Blüher M. Obesity: global epidemiology and pathogenesis. *Nat*

Rev Endocrinol. 2019;15:288-98.
3. Okely AD, Kontsevaya A, Ng J, Abdeta C. 2020 WHO guidelines on physical activity and sedentary behavior. *Sports Med Health Sci.* 2021;3:115-8.
4. Fukumoto Y. Nutrition and cardiovascular diseases. *Nutrients.* 2021;14:94.
5. Su X, McDonough DJ, Chu H, Quan M, Gao Z. Application of network meta-analysis in the field of physical activity and health promotion. *J Sport Health Sci.* 2020;9:511-20.
6. Børsheim E, Bahr R. Effect of exercise intensity, duration and mode on post-exercise oxygen consumption. *Sports Med.* 2003;33:1037-60.
7. Baker JS, McCormick MC, Robergs RA. Interaction among skeletal muscle metabolic energy systems during intense exercise. *J Nutr Metab.* 2010;2010:905612.
8. LaForgia J, Withers RT, Gore CJ. Effects of exercise intensity and duration on the excess post-exercise oxygen consumption. *J Sports Sci.* 2006;24:1247-64.
9. Larsen I, Welde B, Martins C, Tjønna AE. High- and moderate-intensity aerobic exercise and excess post-exercise oxygen consumption in men with metabolic syndrome. *Scand J Med Sci Sports.* 2014;24:e174-9.
10. Pieter W. Combat sports medicine: Taekwondo. *Springer.* 2009; 263-86.
11. Bridge CA, Ferreira da Silva Santos J, Chaabène H, Pieter W, Franchini E. Physical and physiological profiles of taekwondo athletes. *Sports Med.* 2014;44:713-33.
12. Kim YJ, Baek SH, Park JB, Choi SH, Lee JD, Nam SS. The psychosocial effects of Taekwondo training: a meta-analysis. *Int J Environ Res Public Health.* 2021;18:11427.
13. Choi CH, Joo HJ. Motion recognition technology based remote Taekwondo Poomsae evaluation system. *Multimed Tools Appl.* 2016;75:13135-48.
14. Jung WS, Moon HW, Kim JW, Park HY, Park JB, Choi SH, Lee JD, Nam SS. Analysis of cardiopulmonary function, energy metabolism, and exercise intensity and time according to the number of repetitions of Taekwondo Taegeuk Poomsae in Taekwondo players. *J Mens Health.* 2022;18:87.
15. Jung KC, Kwon K, Choi DH, Cho JY, Yang DS. An analysis on exercise intensity and blood physiological components of Taekwondo Beegak Poomsae. *Taekwondo J Kukkiwon.* 2019;10:217-33.
16. Chung J, Nam SS, Park HY, Lee CH, Kwon KT, Sunoo S. Comparative analysis on the exercise intensity and energy expenditure of Taekwondo Poomae for black belts. *Korean J Sport Sci.* 2013;22:809-16.
17. Jeukendrup AE, Wallis GA. Measurement of substrate oxidation during exercise by means of gas exchange measurements. *Int J Sports Med.* 2005;26:S28-37.
18. Yoo SH, Jung KH, Ryu JS. Suggestion of new terminology and classification of the hand techniques by angular momentum in the Taekwondo Poomsae. *Korean J Sport Biomech.* 2016;26:51-69.
19. Shin YS, Yang SM, Kim MY, Lee LK, Park BS, Lee WD, Noh JW, Kim JH, Lee JU, Kwak TY, Lee TH, Park J, Kim J. Differences in respirogram phase between taekwondo poomsae athletes and nonathletes. *J Phys Ther Sci.* 2016;28:2495-500.
20. Campos EZ, Bastos FN, Papoti M, Freitas Junior IF, Gobatto CA, Balikian Junior P. The effects of physical fitness and body composition on oxygen consumption and heart rate recovery after high-intensity exercise. *Int J Sports Med.* 2012;33:621-6.
21. Panissa VLG, Fukuda DH, Staibano V, Marques M, Franchini E. Magnitude and duration of excess of post-exercise oxygen consumption between high-intensity interval and moderate-intensity continuous exercise: a systematic review. *Obes Rev.* 2021;22:e13099.
22. Laforgia J, Withers RT, Gore CJ. Effects of exercise intensity and duration on the excess post-exercise oxygen consumption. *J Sports Sci.* 2006;24:1247-64.
23. Speakman JR, Selman C. Physical activity and resting metabolic rate. *Proc Nutr Soc.* 2003;62:621-34.
24. Jung WS, Hwang H, Kim J, Park HY, Lim K. Effect of interval exercise versus continuous exercise on excess post-exercise oxygen consumption during energy-homogenized exercise on a cycle ergometer. *J Exerc Nutrition Biochem.* 2019;23:45-50.
25. Yoo S, Park SK, Yoon S, Lim HS, Ryu J. Comparison of proprioceptive training and muscular strength training to improve balance ability of Taekwondo Poomsae athletes: a randomized controlled trials. *J Sports Sci Med.* 2018;17:445-54.
26. Gaesser GA, Brooks CA. Metabolic bases of excess post-exercise oxygen. *Med Sci Sports Exerc.* 1984;16:29-43.
27. Gonzales JU, Wiberg M, Defferari E, Proctor DN. Arterial stiffness is higher in older adults with increased perceived fatigue and fatigability during walking. *Exp Gerontol.* 2015;61:92-7.
28. Halsey LG, Watkins DA, Duggan BM. The energy expenditure of stair climbing one step and two steps at a time: estimations from measures of heart rate. *PLoS One.* 2012;7:e51213.
29. Ulupınar S, Özbay S. Energy pathway contributions during 60-second upper-body Wingate test in Greco-Roman wrestlers: intermittent versus single forms. *Res Sports Med.* 2022;30:244-55.
30. Creighton A, Cheng J, Press J. Upper body injuries in golfers. *Curr Rev Musculoskelet Med.* 2022;15:483-99.
31. Liguori G. American College of Sports Medicine (ACSM). ACSM's guidelines for exercise testing and prescription. 11th ed. *Lippincott Williams & Wilkins.* 2020.
32. Bull FC, Al-Ansari SS, Biddle S, Borodulin K, Buman MP, Cardon G, Carty C, Chaput JP, Chastin S, Chou R, Dempsey PC, DiPietro L, Ekelund U, Firth J, Friedenreich CM, Garcia L, Cichu M, Jago R, Katzmarzyk P, Lambert E, Leitzmann M, Milton K, Ortega FB, Ranasinghe C, Stamatakis E, Tiedemann A, Troiano RP, van der Ploeg HP, Wari V, Willumsen JF. World Health Organization 2020 guidelines on physical activity and sedentary behaviour. *Br J Sports Med.* 2020;54:1451-62.
33. Conn VS, Hafdahl AR, Cooper PS, Brown LM, Lusk SL. Meta-analysis of workplace physical activity interventions. *Am J Prev Med.* 2009;37:330-9.
34. Fong SSM, Ng GYF. Does Taekwondo training improve physical fitness? *Phys Ther Sport.* 2011;12:100-6.