

COMPARISON OF UPPER AND LOWER BODY'S ANAEROBIC POWER IN VISUALLY IMPAIRED JUDO AND GOALBALL ATHLETES

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ABSTRACT

Background and objective

While there are many studies done on goalball and judo athletes, our study focuses on comparing and identifying the upper and lower body's anaerobic power in world-class visually impaired goalball and judo athletes.

Material and methods

The subjects of this study were visually impaired male athletes who had earned a medal in judo ($n = 4$) and goalball ($n = 5$). Anaerobic power of the upper and lower body was measured with the Wingate test. We measured the peak power, peak power/body weight, mean power, mean power/body weight, rate of fatigue, and blood lactate concentration.

Results

Goalball athletes showed a significantly lower all-out lactate concentration than judo athletes ($2.80 \pm 0.33/9.18 \pm 1.18$, $P < 0.05$). Goalball athletes showed a significantly lower rate of fatigue than judo athletes in the upper body (58.1 ± 1.61 , $P < 0.05$), while judo athletes showed a significantly lower rate of fatigue than goalball athletes in the lower body (60.5 ± 1.04 , $P < 0.05$). Goalball athletes showed a significantly higher upper and lower body ratio in the mean power than judo athletes ($0.76 \pm 0.01/0.67 \pm 0.04$, $P < 0.05$). In the upper and lower body ratio on the rate of fatigue, judo athletes showed high fatigue in the upper body, while goalball athletes showed low fatigue (1.24 ± 0.09 , $P < 0.05$).

Conclusions

Visually impaired goalball athletes have higher anaerobic power in the upper body than the lower body whereas visually impaired judo athletes have higher anaerobic power in the lower body than the upper body.

Keywords: *anaerobic power; goalball; judo; Paralympic; visual impairment*

INTRODUCTION

Paralympic Games is a large sporting event globally along with the Olympic Games and the Federation Internationale de Football Association (FIFA) World Cup. It made significant progression regarding the organization and the number of participating countries and athletes. It has grown from a small number of competitors, expanding into regional, national, and international events, and has eventually become known today as the Paralympic Games.¹⁻³

Goalball, developed by Hanz Lorenzen of Austria and Sepp Reindl of Germany in 1946, was initially introduced to visually impaired World War II veterans at rehabilitation centers.⁴ Goalball takes place on a standard volleyball court with three visually impaired players in each team.⁵ The court has tactile indicators for the players to determine their position and direction. The goalball is embedded with bells for the players to use their sound to locate the ball. Thus, the games must be conducted within a silent environment.⁶⁻⁸

After becoming a competitive sport, goalball was successfully featured at the 1976 Montreal Summer Paralympic Games as a demonstration sport. The first goalball world championships occurred in Austria in 1978 and eventually became an official Paralympic sport in the 1980 Summer Games in Arnhem.⁹ Goalball has become the most widely known team sport among the visually impaired athletes.¹⁰

Paralympic judo is exclusively for visually impaired athletes; it became a Paralympic sport at the 1988 Paralympic Games for men and for women at the 2004 Paralympic Games for women.¹¹ Judo is an energetic, high-intensity intermittent sport that

uses both upper and lower body during the match and complex skills and strategic excellence for success.¹² Judo athletes use a short burst of energy system during the match, mainly supplied by anaerobic metabolism.¹³ Meanwhile, the intermittent work performed during a match and the recovery process during the short intervals and between matches are mainly supported by aerobic metabolism.¹⁰

While goalball and judo are typical sports that utilize anaerobic metabolism, goalball mainly uses the upper body during the game, while judo uses both upper and lower bodies together. One research with goalball athletes showed the existence of a correlation between maximal handgrip test and throwing velocity. It found that handgrip strength demonstrates the second highest correlation with throwing velocity.⁵ Alves et al.¹⁴ conducted a study with elite goalball athletes on the relationship between aerobic and anaerobic parameters. The study concluded that goalball could be seen as a high-intensity training sport supplied by the ATP-PCr system, which determines the athletes' performance.

Two separate pieces of research studied visually impaired judo and goalball athletes. Aras et al.¹⁵ focused on the balance skill, while Santos et al.¹⁶ focused on postural control. Aras et al.¹⁵ found that the balance skill for both judo and goalball athletes was lower than visually nonimpaired athletes. The study also found that visually impaired athletes have a higher vestibular system and proprioceptive senses to maintain balance. Santos et al.¹⁶ suggested that goalball athletes performed better postural control than judo athletes. According to a different research on the upper and lower body's energy system contributions in highly trained judo athletes,¹⁷

the higher energy contribution was presented by the glycolytic system in the upper body during the maximum power test. Also, when comparing the upper and lower body with this test, a distinct relationship was presented by mechanical and energy system variables.¹⁸

In most sports events, upper and lower body anaerobic power is highly correlated with athletic performance. It is important to classify components such as physiology, technique, and tactics to conduct effective training.¹⁹ Judo is a representative combat sport, and goalball is a ball game. The purpose of this study is to compare and identify the anaerobic power of the upper and lower body in visually impaired goalball and judo athletes. The findings could provide useful information on the training of visually impaired athletes for improvement in their performance.

METHODS

Subjects

The subjects of this study were visually impaired male athletes who had earned a medal in judo (n = 4) and goalball (n = 5) in the 2016 Rio

Paralympic Games or the 2018 Indonesian Disabled Asian Games. They were selected as players with excellent performance. The study was conducted on athletes who did not receive any medical treatment related to cardiovascular disease (CVD), metabolic disease, autonomic nervous system drug use, and musculoskeletal disorders (MSDs). This study's subjects voluntarily completed the general questionnaire and the consent form after being informed of the purpose, content, method, and precautions of the experiment. Table 1 shows the general characteristics of the study's subjects.

MEASUREMENT

Basic characteristics

Body compositions were measured using the Body Component Analyzer (InBody 770, Biospace, South Korea) based on the Bioelectrical Impedance Analysis (BIA), an indirect measurement method of body composition evaluation, and impedance values automatically calculated the results of the assessment. Subject's height, weight, skeletal muscle, and percentage of body fat were automatically measured

TABLE 1 Characteristics of Participants (n = 9).

No.	Sport	Age (y)	Height (cm)	Weight (kg)	SMM (kg)	BFM (kg)	PBF (%)	BMI (kg/m ²)	TR (y)	VCL
1	Judo	32	179.2	112	43.7	36.3	32.4	34.9	17	B2
2	Judo	29	178.4	83.1	43.8	7.4	8.9	26.1	16	B2
3	Judo	28	171.4	61.8	33.0	4.6	7.4	21.0	8	B2
4	Judo	25	178.9	65.0	34.3	5.2	8.0	20.3	10	B3
5	Goalball	31	182.4	72.7	38.7	5.3	7.3	21.9	5	B3
6	Goalball	25	170.1	75.4	35.4	13.2	17.5	26.1	6	B1
7	Goalball	20	182.6	89.2	42.9	14.4	16.1	26.8	4	B3
8	Goalball	30	184.0	106.8	46.4	25.8	24.2	32.0	12	B2
9	Goalball	23	173.1	90.0	42.9	16.0	17.8	30.0	5	B2

SMM, skeletal muscle mass; BFM, body fat mass; PBF, percent body fat; BMI, body mass index; TR, training experience; VCL, visual classification level; LogMAR, logarithm of the minimum angle of resolution.

B1: visual acuity lower than LogMAR 2.6.

B2: visual acuity ranging from LogMAR 1.5 to 2.6 (inclusive) and/or visual field constricted to a diameter of less than 10°.

B3: visual acuity ranging from LogMAR 1.4 to 1.0 (inclusive) and/or visual field constricted to a diameter of less than 40°.

by standing on the analyzer with legs shoulder width apart.¹⁸ In order to reduce measurement errors, the subjects were prohibited from exercising 24 hours before measurement, restricted food intake 2 hours before measurement, and measured 30 minutes after arriving at the examination room.²⁰

Anaerobic power

The upper body's anaerobic power was measured with a 30-second Wingate upper body test using the arm ergometer (Brachumera Sport, Lode, the Netherlands). The subjects were seated on a chair and secured by their legs. The subjects warmed up for 5 minutes with a 1% load of the weight. The test load was set to 5.5% of the body weight. The subjects performed for 30 seconds, followed by a 2-minute cool down with a 1% load.^{20,21}

The lower body's anaerobic power was measured with a 30-second Wingate lower body test using a cycle ergometer (Excalibur Sport, Lode, the Netherlands). The height of ergometer seat was set for the knee to be flexed approximately 15° in the fully extended pedal position. The subjects warmed up for 5 minutes with a 1% load and maintaining a rate of 60 revolutions per minute (rpm). After a 2-minute break, subjects were instructed to pedal as fast as possible for 30 seconds with the test load set to 7.5% of the body weight. For cool down, the subjects were instructed to pedal for 2 minutes at a rate between 60 and 80 rpm.^{21,22}

The peak power, peak power/body weight, mean power, and mean power/body weight from upper and lower body Wingate tests were calculated based on previous studies.²²⁻²⁴ Upper and lower body Wingate tests were performed in random order with 3-day intervals, and verbal encouragement was given throughout the test to maximize performance.

Blood lactate concentration

The blood lactate concentration was measured by sampling 0.3 uL of blood using the Lansing puncture method at rest, immediately after exercise (all-out), and post-5 minutes using a portable lactic acid analyzer (Lactate Pro 2, Arkray, Japan).²⁴⁻²⁶

Rate of fatigue

The rate of fatigue is the degree of power drop-off during the test. It is calculated by subtracting the minimum power (W) from the peak power (W), then divided by the peak power (W) and expressed as a percentage using the following formula:

$$\% \text{ fatigue} = \frac{\left(\text{Peak power (W)} - \text{Minimum power (W)} \right)}{\text{Peak power (W)}} \times 100\%$$

Statistical analysis

Data processing in this study was analyzed using the SPSS/PC+ 20.0 version. To verify the difference of the upper and lower body anaerobic power and the upper and lower body ratio between judo and goalball athletes, the Mann-Whitney U Test, which is a nonparametric statistical method, was implemented by ranking the initial data without assuming a normal distribution. This data processing method was chosen to enhance the quality of the research using limited world-class athletes as participants. All statistical significance was set at $P < 0.05$.

RESULTS

Anaerobic power of the upper body

In the comparison of upper body anaerobic power between Paralympic judo and goalball athletes, the goalball athletes tend to show a slightly higher level of peak power, peak power/body weight, mean power, and mean power/body weight than judo athletes, but no significant difference was shown (Table 2).

Blood lactate concentration during upper body anaerobic power test

In the comparison of blood lactate concentration during upper body anaerobic power between judo and goalball athletes, the goalball athletes showed slightly lower levels than the judo athletes at rest and

TABLE 2 Upper Body Anaerobic Power of Judo and Goalball Athletes.

Variable	Judo	Goalball	Mann–Whitney U test	P
Peak power (W)	683.3 ± 91.1	753.6 ± 33.7	8.000	0.624
Peak power/body weight (W/kg)	8.7 ± 0.9	8.8 ± 0.3	8.000	0.624
Mean power (W)	426.6 ± 66.6	515.2 ± 17.5	6.000	0.327
Mean power/body weight (W/kg)	5.3 ± 0.4	6.0 ± 0.2	4.000	0.142

Values are mean ± standard error (SE).

post-5 minutes, but no significant difference was shown. Meanwhile, the goalball athletes showed a significantly lower all-out lactate concentration than the judo athletes ($P < 0.05$; Table 3) (Figure 1).

Anaerobic power of the lower body

In the comparison of lower body anaerobic power between judo and goalball athletes, the judo athletes showed a slightly higher level than the goalball athletes in the peak power/body weight

and mean power/body weight. In contrast, the goalball athletes showed a slightly higher level than the judo athletes in the peak power and mean power, but no significant difference was shown (Table 4).

Blood lactate concentration during the lower body anaerobic power test

In the comparison of blood lactate concentration during lower body anaerobic power between judo and

TABLE 3 Blood lactate Concentration During Upper Body Anaerobic Power

Variable	Judo	Goalball	Mann- Whitney U test	p
Rest(mmol/l)	1.17 ± 0.10	1.04 ± 0.05	5.500	0.258
All-out(mmol/l)	9.18 ± 1.18	2.80 ± 0.33	0.000	0.014*
Post-5 min(mmol/l)	10.33 ± 2.16	9.22 ± 0.92	7.000	0.462

Values are mean ± SE. * $p < 0.05$

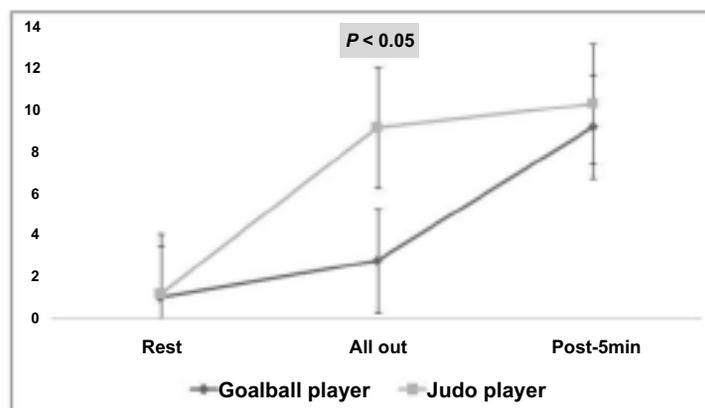


FIGURE 1 Goalball Athletes Showed A Significantly Lower All-Out Lactate Concentration than the Judo Athletes.

TABLE 4 The Difference in Lower Body Anaerobic Power Ability of Judo And Goalball Athletes.

Variable	Judo	Goalball	Mann–Whitney U test	P
Peak power (W)	1034.8 ± 140.6	1151.4 ± 50.7	10.000	1.000
Peak power/body weight (W/kg)	14.2 ± 0.8	13.0 ± 0.9	7.000	0.462
Mean power (W)	633.4 ± 81.3	676.5 ± 17.0	10.000	1.000
Mean power/body weight (W/kg)	7.9 ± 0.5	7.6 ± 0.4	8.000	0.624

Values are mean ± SE.

goalball athletes, the judo athletes showed slightly lower levels of blood lactate at rest, all-out, and post-5 minutes than the goalball athletes, but no significant differences were shown in Table 5 and Figure 2 .

Rate of fatigue

In the comparison between judo and goalball athletes, the goalball athletes showed a significantly lower rate of fatigue than the judo athletes in the

upper body (P < 0.05). Meanwhile, the judo athletes showed a significantly lower rate of fatigue than the goalball athletes in the lower body (P < 0.05; Table 6).

The anaerobic power ratio between upper and lower body

In the comparison of anaerobic power ratio of upper and lower body between judo and goalball

TABLE 5 The Difference in Blood Lactate Concentration during Lower Body Anaerobic Power

Variable	Judo	Goalball	Mann- Whitney U test	p
Rest(mmol/l)	1.17 ± 0.10	1.04 ± 0.05	5.500	0.258
All-out(mmol/l)	9.20 ± 0.76	6.66 ± 1.19	4.500	0.176
Post-5 min(mmol/l)	12.58 ± 1.52	11.66 ± 0.52	8.500	0.712

Values are mean ± SE

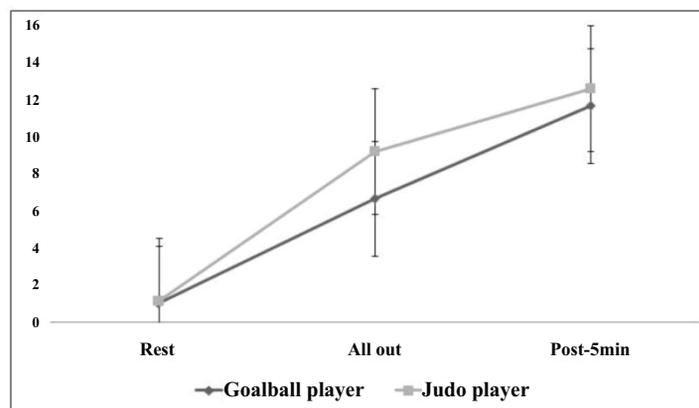


FIGURE 2 Judo athletes showed slightly lower levels of blood lactate at rest, all-out, and post-5 minutes than the goalball athletes.

TABLE 6 Upper and lower Body Rate of Fatigue

Variable	Judo	Goalball	Mann–Whitney U test	P
Upper body rate of fatigue (%)	75.4 ± 5.02	58.1 ± 1.61	0.000	0.014*
Lower body rate of fatigue (%)	60.5 ± 1.04	69.5 ± 1.48	0.000	0.014*

Values are mean ± SE **p* < 0.05

**P* < 0.05.

TABLE 7 Upper and Lower Body Anaerobic Power Ratio and Rate of Fatigue

Variable	Judo	Goalball	Mann–Whitney U test	P
U/L ratio—peak power	0.61 ± 0.04	0.66 ± 0.04	8.000	0.624
U/L ratio—mean power	0.67 ± 0.04	0.76 ± 0.01	0.000	0.014*
U/L ratio—rate of fatigue	1.24 ± 0.09	0.84 ± 0.02	0.000	0.014*

Values are mean ± SE. **p* < 0.05

U/L ratio: Upper body/Lower body ratio (ratio estimation = upper body ÷ lower body). **P* < 0.05.

athletes, there were no significant differences in the peak power. Meanwhile, the goalball athletes showed a significantly higher ratio in the mean power and a significantly lower ratio in the rate of fatigue (Table 7).

DISCUSSION

Anaerobic capacities are crucial factors in determining the physical conditions of athletes. It is important to verify each athlete’s strengths and weaknesses through these measurements, and enhance its skills and potential by applying necessary training.²⁷ During high-intensity exercise, the body’s three energy systems’ relative contribution is determined by the duration of activity.²⁸ The anaerobic energy system is divided into ATP-PCr (adenosine triphosphatophosphocreatine) and glycolysis system components. Under anaerobic conditions, lactate is an end product of glycolysis and feeds into the Cori cycle as a substrate for gluconeogenesis.²⁹ It is known that the ATP-PCr system is the early primary energy source in exercise whereas the glycolysis system starts after approximately 5 seconds.³⁰

In this study, the goalball athletes tend to show a slightly higher level of peak power and mean power than the judo athletes in the upper body’s anaerobic power. Also, the goalball athletes showed a significantly lower all-out lactate concentration than the judo athletes in the blood lactate concentration. According to Fox and Mathews,³¹ energy systems while pitching are 95% ATP-PCr and 5% glycolysis. Similar to pitching, one of the offensive skills in goalball is throwing.³² Goalball athletes seem to enhance ATP-PCr system because of the high-intensity intermittent effort in a short period time. Meanwhile, according to a study conducted by Julio et al.,¹⁸ the estimated relative glycolytic contribution (50 ± 5%) was higher than the ATP-PCr contributions (29 ± 6%) in the energy system with highly trained judo athletes in their upper body (Wingate test).

In comparing lower body anaerobic power between goalball and judo athletes, goalball athletes showed a slightly higher value in peak power and mean power, but no significant difference was presented. On the other hand, there was no significant difference in lactate concentration between the two groups, but the judo athletes showed a slightly

higher value than the goalball athletes in the lactate concentration at all-out and post-5 minutes. The nature of goalball requires a fast and high-intensity movement^{5,10,33} that results in higher energy supply rates by the ATP-PCr system than by the glycolytic system during maximum anaerobic exercise.³⁴ Compared to judo athletes, this difference in energy systems is a significant cause of lower lactate concentration levels of goalball athletes. Lactic acid is produced by metabolizing carbohydrates through the glycolytic system for rapid energy supply in cells during anaerobic exercise, and high accumulation occurs during high-intensity exercise and sports activities. Continued participation in moderate- to high-intensity training increases the monocarboxylate transporter (MCT) 4 protein content of fast-twitch muscle fibers. This facilitates lactic extrusion from muscle to the blood, resulting in a rapid increase in the concentration of lactate in the blood.³⁵⁻³⁷ We believe that this explains the high level of lactate concentration observed in judo athletes during maximum anaerobic exercise in the present study.

The lower body's rate of fatigue appears to be significantly higher in goalball, which uses the upper body's muscle power to perform more than 100 pitches per game.^{8,10,31} In comparison, judo predominantly utilizes the lower body's muscle power, using techniques such as *seoi-nage*, *hari-gosh*, and *o-uchi-gari*.^{35,36} The lower body's rate of fatigue is significantly lower in judo because of the continuous performance of training the lower body and lower back, which improves the tolerance of muscle fatigue in the lower body.³⁵⁻³⁷

The upper and lower body anaerobic power ratio between judo and goalball athletes showed a significant difference in the mean power and the rate of fatigue. In the Wingate test, mean power indicates power endurance.³⁸ Goalball showed a higher dependency of mean power than judo, with goalball being 76% and judo 67% in the upper and lower body anaerobic mean power ratio ($P < 0.05$). Goalball's higher mean power results by maintaining a constant

pitching speed to improve performance which executes over 100 pitches per game at an average speed of 35 km/h using a 1.3-kg ball.^{32,39,40} As such, training is needed to improve the upper body performance, since the maintenance of fast and powerful pitches could be a determinant of winning the game.^{32,33} On the other hand, judo is a highly complex sport that uses both upper and lower bodies, thus requiring an evenly developed upper and lower body power endurance training.^{27,41,42}

The upper and lower body rate of fatigue was 84% for goalball and 124% for judo and showed conflicting results. Judo showed high fatigue in the upper body and low fatigue in the lower body, while goalball showed low fatigue in the upper body and high fatigue in the lower body ($P < 0.05$). These results indicate that anaerobic power development is higher in the lower body for judo and higher in the upper body for goalball. Based on this research with world-class athletes, judo should focus on training to improve the lower body muscle fatigue, and goalball should focus on training to improve the upper body muscle fatigue when developing programs to enhance performance.

The results from this study provide useful information to the upper and lower body training for goalball and judo. Furthermore, athletes and coaches can improve performance by applying the energy system analysis to their training programs.

CONCLUSIONS

In this research, we compared and identified the upper and lower body's anaerobic power in visually impaired goalball and judo athletes. The following results were obtained in this study.

First, goalball athletes showed a significantly lower all-out lactate concentration than judo athletes.

Second, goalball athletes showed a significantly lower rate of fatigue than judo athletes in the upper body, while judo athletes showed a significantly lower rate of fatigue than goalball athletes in the lower body.

Third, goalball athletes showed a significantly higher upper and lower body ratio in the mean power than judo athletes.

Fourth, in the upper and lower body ratio of the rate of fatigue, judo showed high fatigue in the upper body whereas goalball showed low fatigue.

In the future research, anaerobic and aerobic capacities should be identified through profile analysis and used as basic data when designing training programs for various sports to improve and maximize athletes' performance.

DECLARATION OF CONFLICT OF INTEREST

The authors have no potential conflict of interest to declare with respect to the research, authorship, and publication of this article.

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