7．柔道試合中の心拍測定からみる運動強度の解明

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キーワード：柔道、運動強度、心拍数、試合

7．Clarification of exercise intensity through measurement of heart rate during judo matches

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Key words : judo, exercise intensity, heart rate, during a match

要　約

本研究は，柔道競技中の運動強度を正確に評価するために，試合中の心拍数を測定することを目的とした．また，危険性が低く，競技パフォーマンスに影響を及ぼさない心拍数測定方法についても検討した．装着部位では，腕・胸・脚での装着テストを行った結果，脚部が最も安定して測定できると判断された．また，事前の予備測定により，競技中の安全性も確認された．

試合中の最高心拍数は個人差があり，190bpm以上を記録したのは２名（C選手：196bpm，M選手：191bpm），180bpm以上を含めると５試合（約15.6%）にとどまった．多くの試合では140～170bpmで推移し，常に最大強度で動くスポーツではないことが示唆された．特に軽量級の選手は心拍数が高い傾向があり，速い動作の連続が要因と考えられ，対照的に中量級や重量級では比較的安定した心拍数で推移することが確認された．

試合の結果やゴールデンスコアの有無と心拍数の関係を分析したが，有意な差は認められな

かった．ただし，ゴールデンスコアに突入した試合では平均心拍数が本戦決着試合よりも約10bpm高い傾向があり，試合時間の延長により運動負荷が増すことが示唆された．

本研究の成果は，柔道の運動強度の基礎データとして有用であり，競技力向上のためのトレーニング設計に十分貢献できると考えられる．しかし，被験者数の少なさや，対戦相手のレベルによる影響，戦術や心理的要因の影響分析など，さらなる研究が必要である．今後，非接触型センサーの活用や，大規模なデータ収集を通じて，より精緻な運動強度評価が求められる．

I. Introduction

Kodokan Judo (hereinafter referred to as “Judo”) is a martial art systematized by Jigoro Kano in 1882, evolving from traditional Jujutsu to achieve a high level of safety, competitiveness, and educational value. Its guiding principles, “Seiryoku-Zenyo” (Maximum Efficiency) and “Jita-Kyoei” (Mutual Benefit), indicate that Judo is not merely a combat sport or performance activity but a discipline aimed at human development. Internationally, Judo has established itself as a performance sport, leading to extensive research focused on improving competitive performance. These studies include investigations into the physical characteristics of Judo athletes [1,8,19,26], evaluations of movement and techniques [10,11,12,15,17,20], and match analyses [18,22,23,31], covering a wide range of topics.

From the perspective of exercise intensity, many sports quantify intensity accurately by directly measuring heart rate during matches, applying this data to the development of training methodologies and practice programs [5,6,9,24,25,33]. In Judo, Mazuchi and Matsui’s group studied the effects of endurance training using Uchikomi in male university Judo athletes [38], while Franchini et al. examined the effects of high-intensity interval training (HIIT) on Olympic Judo athletes, both using heart rate measurements [36]. Although these studies provide valuable insights into the physiological responses and workload conditions of Judo athletes, reports on heart rate measurements during Judo matches remain limited. Most existing studies focus on measurements taken during practice or specific controlled conditions [3,4,14]. A previous study attempted to analyze exercise intensity during matches by measuring pulse rate via palpation immediately after the match [1], but this approach does not strictly reflect real-time match intensity.

There are two primary reasons why heart rate measurement during matches has been challenging. First, the International Judo Federation’s competition regulations prohibit wearing hard or metallic objects [31], restricting the use of conventional wearable measurement devices. Second, the intense and dynamic movements, constant physical contact, and complex sequential techniques characteristic of Judo may compromise the accuracy of traditional chest-strap heart rate monitors [13,30]. Since heart rate serves as a crucial indicator for assessing continuous workload and fluctuations in physical exertion, establishing an appropriate measurement method could significantly contribute to evaluating exercise intensity in Judo matches.

Recent advances in sensor technology have led to miniaturized and lightweight devices,

making it possible to conduct measurements with minimal risk during competition. This study aims to verify a low-risk, non-intrusive heart rate measurement method that does not interfere with performance while analyzing workload fluctuations during matches. The findings of this study are expected to contribute to understanding continuous exercise intensity in Judo matches and provide fundamental data for the development of training programs.

II. Research Methods

2.1 Participants

Fourteen male Judo club members from T University (age: 20.6 ± 1.0 years, weight: 75.3 ± 10.2 kg, rank: Shodan to Sandan) without injuries or health issues participated in this study (Table 1). All had over ten years of competitive experience and trained at least six days a week. This competitive level was deemed sufficient to achieve the research objectives. The study was approved by the Research Ethics Committee of Toin Yokohama University (Approval No. I-47, review details: Safe heart rate measurement in Judo matches and evaluation of exercise intensity).

Table 1. Subject Profile

Subject	Category	Age	Height	Weight
A	60	19	165	60
B	60	21	163	60
C	66	21	170	66
D	66	21	164	66
E	73	21	172	72
F	73	19	170	73
G	81	21	168	81
H	81	19	175	80
I	90	21	180	87
J	90	19	177	90
K	100	21	177	97
L	100	21	177	99
M	100+	20	178	107
N	100+	19	179	105

2.2 Attachment of Optical Heart Rate Sensors

Heart rate measurements were taken using the optical heart rate sensor Polar OH1 (diameter: 29.85 mm, thickness: 9.5 mm, weight: 5g). To enhance measurement accuracy and stability, an assessment was conducted regarding sensor placement at three body sites: arm (midpoint between biceps and triceps), chest (upper third of the sternum), and leg (midpoint between anterior superior iliac spine and superior-medial edge of the patella). Participants rated comfort, device displacement, and presence of discomfort using a three-point scale (3 = good, 2 = neutral, 1 = poor). The highest-rated site for all factors was the leg (Figure 1).

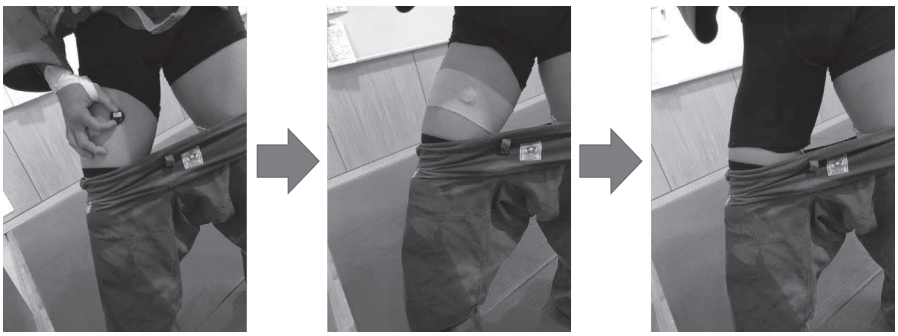


Figure 1. Measurement device attachment position

2.3 Preliminary Measurement to Ensure Safety

To confirm the safety of measurements, preliminary tests were conducted using test matches. The study protocol was explained to the opposing team's coaches and athletes beforehand, and consent was obtained. Post-match surveys were conducted with six participants wearing the device and 16 opponents to assess safety perceptions (Table 2). Based on the results, the method was deemed safe. Additionally, data reliability and device durability under Judo movements were confirmed.

Table 2. Participants' and Opponents' Perceptions of the Device

Question Category	Question Content	Response Options	Number of Responses
Participant Feedback	Perception of Device Comfort	Noticed Discomfort	0
		Slightly Noticed Discomfort	1
		Did Not Notice Discomfort	5
	Device Fit During Measurement	Significantly Displaced	0
		Slightly Displaced	1
		No Displacement	5
Opponent Feedback	Perception of Device During Match	Felt Uncomfortable	0
		Slightly Felt Uncomfortable	1
		Did Not Feel Uncomfortable	15
	Sensation of Device When Executing Techniques	Felt the Device	0
		Slightly Felt the Device	0
		Did Not Feel the Device	16

2.4 Target Tournament and Competitive Level

The study targeted the 31st National Physical Education University Judo Weight Class Championships (individual competition) held in February 2019. This official national tournament for university students specializing in physical education and sports was deemed appropriate for measuring exercise intensity, as past competition results indicated that finalists generally ranked between 4th and 8th place in the All Japan Student Judo Championships (individual intercollegiate competition).

2.5 Approval for Heart Rate Measurement During Matches

In accordance with the tournament's objectives—to enhance the competence of Judo practitioners, foster mutual friendship, recognize the importance of research, and contribute to the promotion and development of Judo [40]—detailed explanations of the study's purpose, methodology, and safety measures were provided to the tournament director, executive committee, and university coaches. Written and verbal consent was obtained.

2.6 Validation of Heart Rate (HR) Measurement in Relation to Sensor

Leg placement of the optical heart rate sensor measures pulse rate rather than direct heart rate [33]. To compare the data with conventional heart rate measurements, correlation analysis was conducted between pulse rate from the optical sensor and heart rate obtained from a three-electrode chest ECG (TL3435: Nihon Kohden). Participants underwent a 30-minute resting period, followed by three minutes of rest on a cycle ergometer and an incremental exercise test using a 20-watt/min ramp protocol (pedaling rate: 60–70 rpm). A strong correlation (r = 0.97678) was observed between pulse rate and ECG-derived heart rate (Figure 2). Based on these findings, the measured values were referred to as heart rate (HR) in this study.

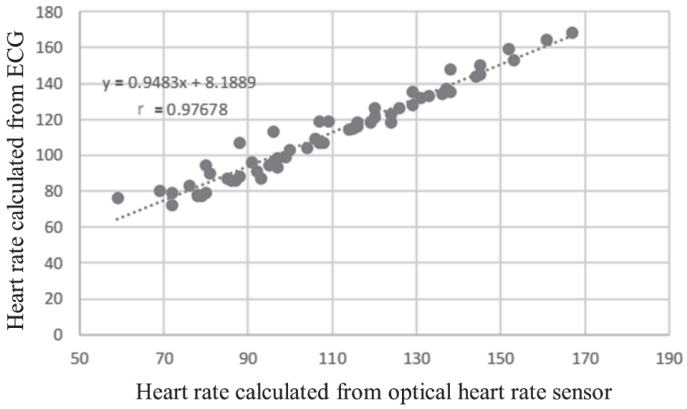


Figure 2. Relationship between ECG and optical heart rate sensor

2.7 Heart Rate Measurement During Matches

Sensors were attached by an examiner before matches. The measurement variables were heart rate fluctuations during the match and peak heart rate. Measurement started at the referee's "Hajime" command and ended at the "Sore made" signal.

2.8 Comparison Parameters

Peak heart rates were extracted from heart rate trends and analyzed based on match outcomes, the presence or absence of Golden Score (GS), and weight categories.

2.9 Statistical Analysis

Levene's test was used to verify variance homogeneity across comparison groups (match outcomes, GS presence, weight categories). If variance was homogeneous, an independent t-test was used for peak heart rate comparison based on match outcome and GS presence. One-way ANOVA was performed to compare peak heart rates across three weight categories: Lightweight (60–66 kg), Middleweight (73–90 kg), and Heavyweight (100–100+ kg). Statistical analysis was conducted using IBM SPSS Statistics 27.0.1.0, with significance set at $p < 0.05$.

III. Results

3.1 Maximum Heart Rate and Heart Rate Trends During Matches

Table 3 presents the maximum heart rate recorded for each of the 14 participants during their matches. The highest recorded value was 196 bpm, observed in Participant C (66 kg category) during the fourth round, while the lowest value was 128 bpm, recorded in Participant H (81 kg category) during the first round. Figure 3 illustrates the heart rate trends of Participant C, who advanced to the finals. In the first and second matches, the heart rate remained stable at approximately 140 bpm. However, in the fourth round and final match, a gradual increase in heart rate was observed in the latter half of the match. In contrast, during the third and semifinal matches, the heart rate exhibited a declining trend from the beginning of the match, decreasing to 117 bpm and 118 bpm, respectively.

Table 3. Maximum heart rate of 14 subjects

Subjects	Category	First	Second	Third	Fourth	Semi-final	Final
A	60	*176*	*174*	*185*	174		
B	60	*183*					
C	66	*143*	*149*	*162*	*196*	*164*	174
D	66	134	143				
E	73	134					
F	73	149					
G	81	*160*	141				
H	81	128	*129*	133			
I	90	138	147				
J	90	142					
K	100	160	153	*161*			
L	100	*143*					
M	100+	158	188	191			
N	100+	*134*	142				

Italic：Matches that went into the GS

Shaded：Matches lost

3.2 Comparison Based on Match Outcomes

The average maximum heart rate for matches that resulted in victory was 155.6 ± 19.3 bpm, whereas for matches that ended in defeat, it was 154.1 ± 18.9 bpm. No statistically significant

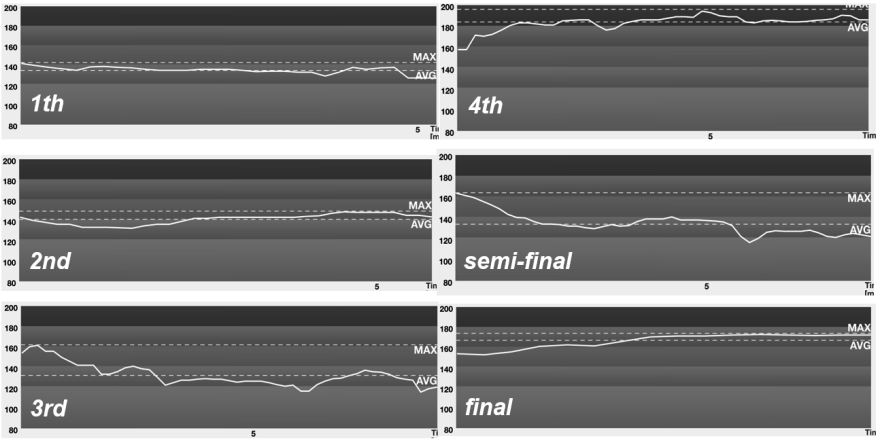


Figure 3. Subject C's heart rate variability during the match

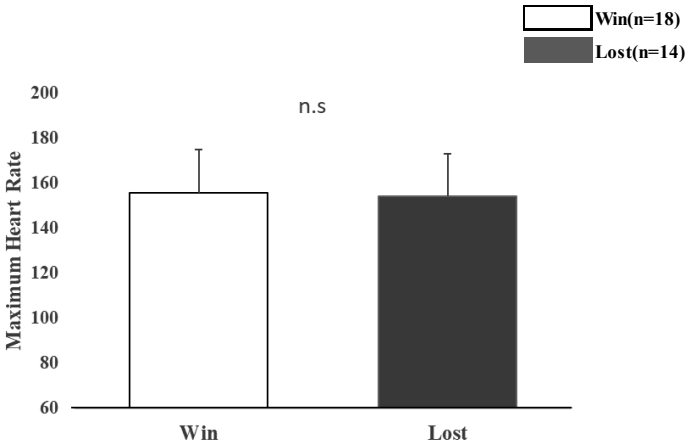


Figure 4. Comparison by Match Result

difference was observed between the two groups (p = 0.18; Figure 4).

3.3 Comparison Based on Golden Score (GS) Entry

The average maximum heart rate for matches decided in regular time was 151.7 ± 18.8 bpm, while for matches that entered the Golden Score (GS) period, it was 161.4 ± 20.1 bpm. A difference of approximately 10 bpm was observed, but no statistically significant difference was found between the two groups (p = 0.7; Figure 5).

3.4 Comparison Based on Weight Category

The average maximum heart rate for the lightweight group was 165.9 ± 18.8 bpm, for the middleweight group was 140.1 ± 9.9 bpm, and for the heavyweight group was 158.9 ± 19.6 bpm (Figure 6). One-way ANOVA analysis revealed a significant difference among the three

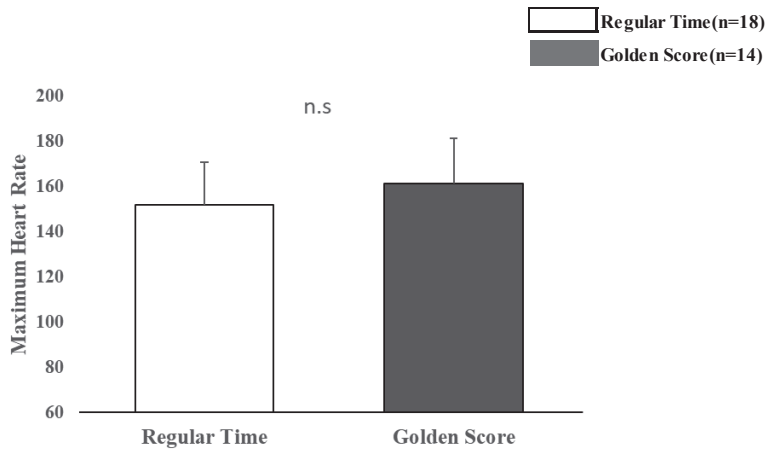


Figure 5. Comparison with and without Golden Score entry

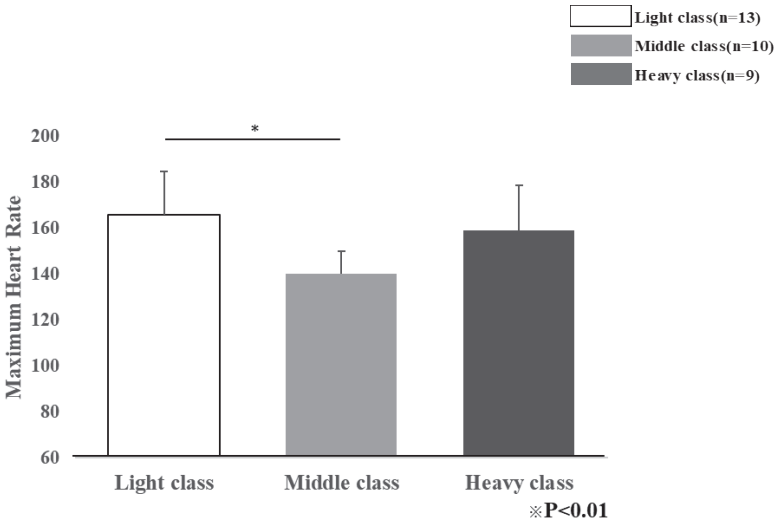


Figure 6. Comparison by weight

groups (p = 0.0036). Furthermore, the middleweight group showed a significantly lower value compared to the lightweight group (p = 0.0029).

IV. Discussion

4.1 Reliability of Heart Rate Measurement During Matches

In this study, no data loss or incidents related to the sensor attachment were observed due to adjustments in the attachment position of the optical heart rate sensor and taping techniques. This demonstrates the feasibility of this method for real-time heart rate measurement without interfering with the athlete's performance. However, the validity of attaching the sensor to the lower limb, chosen to avoid interference from intense upper-body movements and contact

in judo, should be re-examined through comparisons with other attachment sites in future studies.

4.2 Maximum Heart Rate and Heart Rate Trends During Matches

In the obtained data, only about 15.6% (5 out of 32 matches) recorded heart rates exceeding 190 bpm. Given that the estimated maximum heart rate based on age (220 - age) for the participants was approximately 200 bpm, this indicates that athletes were not continuously performing at maximal intensity (≥90% HRmax). Although judo involves frequent bursts of high-intensity movements, many matches showed heart rate trends in the 140–180 bpm range, suggesting a strong aerobic component throughout the match.

The limited number of matches exceeding 90% HRmax may be attributed to strategic variations based on match progression. Athletes may adopt different tactics, such as assessing the opponent's strength in the early stages and increasing aggression in the latter half or employing endurance strategies to exhaust the opponent.

Examining Participant C's heart rate trends across six matches (Figure 3), the fourth-round match recorded the highest value among all participants (196 bpm). Additionally, a consistently high heart rate trend with an increasing tendency toward the end was observed, suggesting a match characterized by sustained intense exchanges. Conversely, in the subsequent semifinal match, a marked decline in heart rate was observed after the match began, likely reflecting energy conservation (pacing) following the exertions of the fourth round.

From the 32 recorded matches, three primary heart rate trend patterns were identified: (1) consistently stable, (2) increasing in the latter half, and (3) high at the beginning. However, further investigation with a larger sample size is necessary. Factors influencing these patterns may include match progression, tactical approaches, athlete personality, and judo style. For example, offensive athletes who actively initiate attacks may exhibit higher heart rates, while defensive athletes who evade and wait for opportunities may maintain relatively stable heart rates.

4.3 Relationship Between Match Outcome and Maximum Heart Rate

The average maximum heart rate for victorious matches was approximately 155.7 bpm, while for defeated matches, it was approximately 154.1 bpm, showing almost identical results (Figure 4). Typically, in disadvantageous matches where the opponent dominates, the athlete remains under sustained high-load conditions, leading to insufficient heart rate recovery. Consequently, it was expected that losing matches would exhibit higher heart rates than winning matches; however, this trend was not observed in this study.

Athletes exert their best effort regardless of match outcomes, meaning a certain level of load is naturally incurred in both winning and losing matches. Additionally, offensive movements are necessary to secure victory, which could have influenced the observed results. Factors such as psychological state, motivation, and tactical maneuvers during the match may explain the lack of a difference in maximum heart rate between wins and losses. For example, athletes

highly focused on winning may aggressively attack, leading to increased heart rates, whereas those adapting to the opponent's strategy may deliberately withhold attacks and wait for an opportunity.

4.4 Relationship Between Golden Score Entry and Maximum Heart Rate

The average maximum heart rate for matches concluded in regular time was approximately 151.8 bpm, whereas it was about 161.4 bpm for matches that entered the Golden Score (GS) period, exhibiting a trend toward a 10 bpm increase, though not statistically significant (Figure 5).

During GS periods, athletes are subjected to sustained high-intensity exertion, leading to progressive fatigue accumulation and increased heart rates. However, in this study, data collection beyond two minutes into the GS period was not possible due to the tournament's special rules (regular match duration: 4 minutes + GS: 2 minutes). Matches exceeding six minutes are common in closely contested situations, suggesting an increased exercise intensity. On the other hand, matches extending beyond 10 minutes are also observed occasionally. Given the finite duration for maintaining high- or mid-power outputs, exercise intensity may not necessarily increase significantly in such prolonged matches.

Possible reasons for the observed increase in maximum heart rate during GS periods include not only match duration but also psychological stress and fatigue accumulation specific to GS scenarios. In GS, athletes attempt to secure an "Ippon" victory by executing more aggressive techniques, potentially elevating heart rates. Additionally, as match duration increases, accumulated fatigue may lead to a gradual rise in heart rate.

4.5 Relationship Between Weight Category and Maximum Heart Rate

In this study, the lightweight group exhibited the highest values (Figure 6). The highest average maximum heart rate observed in the lightweight group aligns with the demand for continuous rapid movements and the increased relative workload for lighter athletes.

The difference between the middleweight and heavyweight groups may be attributable to Participant H in the middleweight group, who recorded the lowest maximum heart rate among all participants, averaging 130 bpm across three matches (including one GS match). This value represents only about 50% of the heart rate reserve, suggesting that these matches were conducted at moderate or lower intensities. Possible reasons for Participant H's lower heart rate include individual personality traits, judo style, match strategies, and the strength differential between opponents. Participant H (81 kg category) is typically reserved and remains composed during matches but tends to engage passively, leading to minimal intense exchanges.

4.6 Challenges of This Study

This study provided valuable foundational data by attempting to measure heart rate during Judo matches. However, several challenges remain, including the limited sample size, the

need for improved measurement accuracy of devices, and the simultaneous measurement of multiple physiological indicators under competition conditions. In particular, integrating advanced non-contact heart rate measurement technologies, such as facial image analysis, with deep body temperature measurement presents a promising future research direction. Such advancements could enable data collection at high-level competitions, including the Olympics and World Championships, thereby contributing to a more precise understanding of exercise intensity in Judo.

Despite improvements over conventional methods, biometric data obtained through non-contact vital sensors remain unstable depending on measurement conditions. While facial image analysis enables measurement in static conditions, acquiring accurate data in dynamic sports settings remains a challenge. To overcome these obstacles, future research must consider approaches such as utilizing high-performance cameras and multi-angle recording systems to enhance data reliability.

Another limitation of this study was the absence of data from extra-large athletes weighing over 130 kg. The heaviest participant in this study's over-100 kg category weighed less than 110 kg, making him relatively light for his division. While the study observed a general trend in which lighter-weight athletes exhibited higher heart rate fluctuations, Participant M exceeded 90% HRmax in two out of his three matches. Future research should not only increase the sample size but also include larger athletes in the over-100 kg category to examine potential correlations between body weight and exercise intensity.

Furthermore, it is necessary to analyze heart rate variations based on behavioral changes during matches. It is important to identify specific phases of the match that impose greater physical stress, examine differences in heart rate responses between standing techniques (nage-waza) and groundwork techniques (katame-waza), and evaluate how heart rate fluctuates depending on whether a competitor adopts an offensive or defensive fighting style. One approach to addressing these questions could involve video analysis of athletes' actions, categorizing techniques such as throwing, groundwork, attack, and defense, and investigating their relationships with heart rate fluctuations.

Comparing heart rate variations based on the skill level of opponents is also an essential aspect. Since Judo is a one-on-one combat sport, exercise intensity may differ depending on whether an opponent is superior, equal, or inferior in skill level. Additionally, competition involves significant psychological pressure, which is distinct from training, as athletes experience a strong fear of losing. However, psychological responses vary based on individual personality traits, which were not examined in this study. Future research could classify participants based on their opponent's Judo rank or past competition history and divide them into groups such as superior, equal, or inferior opponents, allowing for a comparison of heart rate variations among these groups.

Conducting more detailed analyses of heart rate fluctuations according to weight class, tactical approach, and opponent skill level could further clarify the physiological characteristics of Judo. Such findings would provide valuable insights for developing training programs and

refining tactical strategies.

V. Conclusion

This study aimed to accurately assess exercise intensity in Judo by measuring heart rate during matches. Additionally, it examined a heart rate measurement method that is safe and does not interfere with competitive performance.

Regarding sensor placement, tests were conducted on the arm, chest, and leg, and the leg was determined to be the most stable site for measurement. Preliminary safety testing also confirmed that the device could be used without compromising match safety.

In terms of heart rate trends during matches, there was individual variation in maximum heart rate values. The highest recorded value was 196 bpm, observed in Participant C (66 kg category) during the fourth round, while Participant M (over-100 kg category) recorded 191 bpm. However, in most matches, heart rates remained in the range of 140–180 bpm. These results suggest that while Judo involves frequent explosive, high-intensity movements, athletes do not continuously perform at maximum intensity throughout the entire match. Instead, aerobic activity appears to play a dominant role in overall match performance.

Notably, lightweight athletes recorded relatively higher heart rates than athletes in other weight categories. This may be attributed to the demands for rapid, continuous movements in lighter weight divisions.

Additionally, while no statistically significant differences were found when comparing match outcomes (win vs. loss) or the presence or absence of Golden Score (GS), a trend was observed in which GS matches resulted in an average maximum heart rate approximately 10 bpm higher than matches concluded in regular time. These findings suggest that cumulative fatigue and strategic decision-making during extended matches may influence exercise intensity.

The findings of this study provide fundamental data on the exercise intensity of Judo and can contribute significantly to the development of training programs aimed at improving athletic performance. However, further research is needed to address limitations such as the small sample size, the influence of opponent skill level, and the effects of tactical and psychological factors on heart rate fluctuations. Future studies should incorporate non-contact sensors, large-scale data collection, and multivariate analysis to refine exercise intensity assessment methods in Judo.

Acknowledgments

The authors would like to express their sincere gratitude to the tournament president and the chair of the organizing committee for granting permission to conduct this study. The authors also extend their appreciation to the coaches and athletes from participating universities for their understanding of the study's significance and their cooperation throughout the research process.

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