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Original Article

Performance analysis considering the technical-tactical variables in female judo athletes at different sport skill levels: optimization of predictors

ARTUR KŁYS[1], KATARZYNA STERKOWICZ-PRZYBYCIEŃ[2], MAREK ADAM[3], CRISTINA CASALS[4]
[1]Department of Theory of Sport and Kinesiology, Institute of Sport Sciences, University of Physical Education in Krakow, POLAND,
[2]Department of Gymnastics and Dance, Institute of Sport Sciences, University of Physical Education in Krakow, POLAND,
[3]Department of Combat Sports, University of Physical Education and Sport in Gdansk, POLAND
[4] MOVE-IT Research group, Department of Physical Education, Faculty of Education Sciences, University of Cádiz, SPAIN
[4]Biomedical Research and Innovation Institute of Cádiz (INiBICA) Research Unit, Puerta del Mar University Hospital, University of Cádiz, SPAIN

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Abstract:
Performance evaluation of female judokas during judo bouts is crucial for their training. The aim of this study was to 1) Compare level of achievement to relevant technical-tactical variables based on the indices of the course of fight and time spent between grip contact and technique application in senior Polish female judo athletes 2) Try to optimize sport skill level predictors using Probabilistic Neural Network (PNN). The sample of 87 Polish senior female judo athletes from all weight categories was divided into Group 1 (n=29) and Group 2 (n=58) using Polish Judo Association ranking places 1-5 and 6-23 respectively. The fights were recorded during 4 national judo tournaments. Group 1 was characterized by significantly better results expressed in indices of activity in attack, efficiency of attacks, efficiency of defense, effectiveness of attacks, and effectiveness of defense, than Group 2 ($p<0.05$). Moreover, Group 1 significantly predominated over Group 2 ($p<0.05$) in number of attacks performed in all analyzed ranges of time (1-3s, 4-8s, over 8s), measured from grip contact to technique application. The optimized PNN model of fight using patterns from effectiveness of defense, efficiency of attacks, efficiency of defense, grip time to throw 4-8s showed overall accuracy prediction of 79.3% and accuracy classification for Group 1 and Group 2 of 82.3% and 77.6% respectively. The analyzed variables were able to discriminate between higher and lower performance in elite female judo athletes. Specifically, we found significant differences in analyzed variables of attack and defense actions, and time spent from grip contact to throw action according to sport skill level. These results can be useful in setting standards that should be gradually met during training for competition.
Key Words:Combat Sports, Martial Arts, Match Analysis, Models,Evaluation.

Introduction

Since female judo tournaments were included in the Olympic program in Seoul (1988), important studies have been published regarding these athletes (Adam &Majdan, 2011; Adam &Szczepańska, 2011; Laskowski, 2006; Sterkowicz-Przybycień, Miarka& Fukuda, 2017), as the analysis of technical actions during the course of combat that was started by Sterkowicz&Kęsek (1983). Analysis of female tournaments, including a diagnosis of the temporal structure of fights, resources, and quality of actions, is relevant since it allows coaches to predict sports results and to develop, modify and better adjust training programs of female judokas (Miarka, Sterkowicz-Przybycień& Fukuda, 2017; Dal Bello,Aedo-Muñoz, Brito&Miarka, 2019).

Therefore, the assessment of such variables as activity, efficiency and effectiveness in both attack and defense actions, is necessary for providing information about the individual or group level of technical and tactical preparation of judokas (Adam, 2012). The efficiency of attacks and efficiency of defense indices were used for comparing the courses of fights between Japanese and Russian national judo teams in three World Championships (Adam &Sterkowicz-Przybycień, 2018). Moreover, indices of the course of fight can be also used to compare elite female athletes across different weight categories and variable fight conditions caused by updated competition regulations (Calmet et al., 2017a; Calmet et al., 2017b; Stanković et al., 2015). Specifically, analysis of the frequency of used techniques is popular (Sterkowicz, Sacripanti&Sterkowicz-Przybycień, 2013;

Corresponding Author: KATARZYNA STERKOWICZ-PRZYBYCIEŃ E-mail: katarzyna.sterkowicz@awf.krakow.pl

Miarka et al., 2014, Miarka et al., 2016), whereas analyses that take into consideration grip needed to perform throws are scarce, especially in women (Courel et al., 2014, Miarka et al., 2017, Baretto et al., 2019).

The grip is crucial to transfer forces caused by actions performed during attack or defense, and to control an opponent's focus of attention, posture, and balance (Ohlenkamp, 2006). Soriano et al. (2019) analyzed the duration of time gripping in male and female judo athletes in two stages: 1) Time of approach to the grip, 2) Time of established grip. Women spent more time with a real grip (kumi kata) on their opponents than men: 7.3 ± 4.0s vs. 6.1 ± 3.5s, respectively (Soriano et al., 2019). The time from grip application to performing a throw is differentiated and can be correlated with sports skill level (Sacripanti, 2010). In the present study we ring-fenced three ranges of time in which the grip is established. In the first, from 1s to 3s, the (typically pre-planned) attack is performed immediately after grip application, during which time the athletes are able to generate maximal power. In the second time period, from 4s to 8s, performing the attack is determined by athletes' abilities to maintain maximal power. During this time, judo athletes try to find the optimal solution and move together with the opponent to perform the attack at the adequate moment. In the third time period, longer than 8s, the successful attack is correlated with the athlete's strength endurance preparedness. Keeping the grip for a long gives the time for preparing attack, but generating maximal power is more difficult due to increasing fatigue (Kenney et al., 2011, Franchini 2017).

The Probabilistic Neural Network (PNN) is a classification of data analysis method that can be employed in sport-science research. Success in competitive sports is determined by interrelations between different variables, and in this case the PNN method has been chosen (Pfeiffer &Hohman, 2012). This statistical method encompasses Bayesian decision rule in classifying data (Soldić-Aleksić, 2011) and Parzen's nonparametric technique for probability function estimation (Parzen, 1962). Previous research studies used neural networks for predicting the success of basketball teams in the NBA (Loeffelholz et al., 2009), blocking prediction for volleyball (Chen et al., 2013), discriminating level of achievement in Olympic volleyball teams (Sterkowicz-Przybycień, Sterkowicz& Zak, 2008), and applied in cricket team selection (Iyer&Sharda, 2009). Sterkowicz-Przybycień et al. (2019) employed PNN to show predictors of high skill level in all-round events at a national competitive level in male artistic gymnasts. In the field of judo, Miarka, Sterkowicz-Przybycień& Fukuda (2017) created optimized a probabilistic neural network model using technical-tactical indicators from the gripping, attack, groundwork, and pause phases for discrimination between men and women.

Previous studies of the temporal structure of fights have not analyzed the indices of the course of the fight (Adam, 2012) and time spent between grip contact and throw action in elite female judokas. Thus, the aim of this study was to 1) Compare level of achievement to relevant technical-tactical variables based on the indices of the course of fight and time spent between grip contact and technique application in senior Polish female judo athletes; 2) Try to optimize sport skill level predictors using Probabilistic Neural Network. This information could help coaches to better program, adjust training, and achieve greater results in female judo competitions.

Material & methods

In this descriptive cross-sectional study, several variables during judo competitions have been analyzed and compared according to performance level of elite female athletes. Specifically, the analyzed variables in *Tachi-waza* were activity, efficiency and effectiveness of both attack and defense actions, points scored, and time spent between grip contact and technique application. The fights were recorded during 4 national-level judo tournaments in Poland in 2015.

Participants

The sample consisted of 87 Polish senior female judo athletes from all weight categories. The performance level of judo athletes was determined according to the official ranking of the Polish Judo Association, establishing two judokas' groups (Group 1: places from 1 to 5, n=29, Group 2: places from 6 to 23, n=58). Similar to a group of men (Stanković et al., 2015),our group of female athletes represented weight categories aggregated into subgroups (light: two lightest categories; medium: next three categories; heavy: two heaviest categories). Distributions and characteristics of subjects, number of fights and points scored acrosssports skill level and weight categories are presented in Table 1.

Table 1. Number of fights, attacks, and scoring points of elite female judo athletes according to sports skill level and weight category.

	Light		**Medium**		**Heavy**	
	Group 1	**Group 2**	**Group 1**	**Group 2**	**Group 1**	**Group 2**
Number of fights	69	31	90	135	43	36
Number of attacks	297	101	463	564	142	71
Scoring points	315	117	501	462	287	87
n	*9*	*9*	*12*	*39*	*8*	*10*

Light: 48kg and -52kg, Medium: from -57kg to -70kg, Heavy: -78kg and +78kg.

Distribution of group sizes did not differ significantly between Groups 1 and 2 (Chi^2=5.456, df=2, p=0.065, Cramer's V=0.250). Therefore, sports skill level did not depend on the number of players across weight categories.

The present study was connected to a scientific project that was approved by the Council of the Faculty of Physical Education and Sport of the University of Physical Education in Krakow and was in accordance with the Helsinki declaration(WMA, 2013). All judokas signed written consent forms to participate in the study. The results were obtained in secondary form and not generated by experimentation. Additionally, the athletes' personal identification has not been reported as only final results were considered. Such ethics approach has been affirmed in similar works (Calmet et al., 2017a; Calmet et al., 2017b; Morley & Thomas, 2005).

Procedure

The bouts registration was done by the Polish Judo Association. All involved records were of high quality in order to analyze the fights' variables. The contest area, competitors, referee, judges, timers and scoreboard were in landscape view. During playback of the recording, technical actions in attack both effective (point-scoring) and ineffectivewere counted, after which the information was recorded in an EXCEL spreadsheet according to a previously reported protocol (Sterkowicz-Przybycień, Miarka& Fukuda, 2017). Points scored were registered as *yuko* 5 points, *wazaari* 7 points, *ippon* 10 points for the *Tachi-waza* combat. The signalization of referee was also observed. Gripping was defined as the moment of physical contact between the competitors, which continued until an attack was initiated (Calmet, Miarka&Franchini, 2010; Sterkowicz-Przybycień, Miarka& Fukuda, 2017). Attack was identified as the initiation of a throwing technique, as indicated by a reduction in distance/space between athletes ("tsukuri"), until completion of the technique or cessation of the throwing attempt (Franchini et al., 2008; Sterkowicz, Sacripanti&Sterkowicz-Przybycień 2013; Sterkowicz-Przybycień, Miarka& Fukuda, 2017).

Indices of the course of fight

Detailed analysis concerned *Tachi-waza*, with indices of the course of fight computed based on the following formulae (Adam, 2012):

Activity in attack (Aa) was calculated as Aa= Σ of attacks recorded for the athlete / N; where N is the number of fights analyzed for the athlete.

Activity in defense (Ad) was calculated as: Ad= Σ of attacks recorded for the athlete's opponents / N; where N is the number of fights analyzed for the athlete.

Efficiency of attacks (Ea) was calculated as: Ea= (a*5+a*7+a*10) / N; where a is the number of point-scoring attacks performed by the athlete, and N is the number of fights analyzed for the athlete.

Efficiency of defense (Ed) was calculated as: Ed= (d*5+d*7+d*10) / N; were d is the number of point-scoring attacks performed by the athlete's opponents, and N is the number of fights analyzed for the athlete.

Effectiveness of attacks (E%a) was calculated as: E%a= (Σ of effective attacks performed by the athlete/ Σ of attacks performed by the athlete)*100.

Effectiveness of defense (E%d) was calculated as:E%d= 100 - (Σ of sum of effective attacks performed by the athlete's opponents/ Σ of attacks performed by the athlete's opponents)*100.

The number of fights analyzed for the athlete and the athlete's opponents were recognized and counted.

Furthermore, the number of attacks were counted and grouped according to the time spent between grip contact and technique application into three ranges of time:from 1s to 3s, from 4s to 8s, and over 8s.

Reliability Testing

In order to assess the reliability of observations, intra and inter-expert agreement protocols were conducted. Two experts with more than ten years of experience as professional coaches were employed. The first expert repeated the procedure after more than 48 hours with the same 20 athletes in randomized order. Intra and inter-expert reliability was examined using Cohen's kappa coefficient (Miarka, Sterkowicz-Przybycień& Fukuda, 2017). The following classifications of kappa values and strength of agreement were used: 0.0-0.2 (poor); 0.21-0.40 (fair); 0.41-0.60 (moderate); 0.61-0.80 (substantial); 0.81-1.00 (almost perfect). The significance level of $p<0.05$ was used.

All analyzed variables essential for calculating indices of the course of fight were classified in almost perfect kappa values range for both intra and inter-expert agreement, respectively: 0.970 and 0.939 for sum of attacks, 1.000 and 1.000 for number of point-scoring attacks: 5 points, 7 points, 10 points, 1.000 and 1.000 for sum of effective attacks; and variables concerning frequency of attacks in three ranges of time: 0.958 and 0.917 for 1-3s, 1.000 and 0.955 for 4-8s, 1.000 and 1.000 for over 8s.

Statistical analysis

After verification of distributions of the above variables by using the Shapiro-Wilk's Normality test, medians and ranges were computed for Groups 1 and 2. Intergroup comparisons used the U-Mann Whitney test adopting the level of significance of $p<0.05$. The r effect size was computed based on the equation: $r= z/ \sqrt{N}$, where z is the value of z statistic, and N is the group size. Friedman's test was used to compare ranked data of number of attacks performed according to the time spent between grip contact and technique application into three time

ranges: 1-3s, 4-8 and over 8s. The synthesis of comparisons was performed using the PNN, with all variables qualified initially. Moreover, the model was optimized through limitation of the number of variables to those which had a very high statistical significance for intergroup differences ($p<0.001$), medium and high effect size (considering small effect for $r=0.10$; medium for $r=0.30$; and high for $r=0.50$ or higher).

Based on the general and two optimized PNN models, we developed a classification table and computed independence Chi^2 test and Cramer's V effect size (small 0.1, medium 0.3, and large 0.5) for accurate classification of the Group 1 of top athletes compared to the lower ranked Group 2. Odds ratio (OR) were also computed for Group 1 and Group 2. The classification plot of PNN used to gain better understanding of the region defined by chosen variables (in optimized models) was divided into areas that would result in two groups classifications as belonging to higher or lower ranked groups. Statgraphics Centurion XVII software was also employed.

Results

The comparison of fights' variables according to performance level of elite female judo athletes are presented in Table 2, showing statistically significant differences for all studied variables, except for the Ad Index, which was approaching significance. Overall number of attacks performed from the moment of gripping to performing a throw in the time range of 1 to 3s was the highest (rank=2.79) and decreased significantly for consecutive ranges (4 to 8s and over 8s), being 2.03 and 1.18, respectively (Friedman's test=122, $p<0.001$). Comparison of average values in pairs demonstrated the highest rank difference between duration of actions from 1 to 3s and over 8s (1.61), followed by those between 4 to 8s and over 8 s (0.86), and between 1 to 3s and 4 to 8s (0.75).

Table 2. Comparison of indices between high and lower ranked female judokas median (min-max).

Index	Group 1	Group 2	U	p	r-effect size
Aa	4.43 (1.29-7.40)	3.10 (0.50-9.67)	589.0	0.023	0.242
Ad	3.30 (0.50-8.43)	3.67 (1.50-9.00)	639.0	0.069	-0.195
Ea	5.80 (1.00-11.00)	1.88 (0.00-10.25)	344.0	0.001	0.484
Ed	1.88 (0.0-88.0)	5.0 (0.0-22.0)	426.5	0.001	-0.401
E%a	17.39 (3.85-44.44)	16.81 (0.00-100)	529.0	0.005	0.304
E%d	93.55 (50-100)	81.10 (40-100)	488.0	0.001	0.342
Grip time to throw (1-3 s) number of attacks	20.0 (2.0-48)	6.5 (0-27)	311.5	0.001	0.479
Grip time to throw (4-8 s) number of attacks	8.0 (2-19)	3 (0-22)	301.5	0.001	0.523
Grip time to throw (over 8s) number of attacks	1 (0-11)	1 (0-6)	611.5	0.038	0.231

Note: Aa = activity in attack; Ad= activity in defense; Ea= efficiency of attacks; Ed= efficiency of defense; E%a= effectiveness of attacks; E%d= effectiveness of defense; Grip time to throw= time from gripping to performing an attack.

The PNN models for predicting judo performance in elite female athletes relating to the analyzed fight variables is presented in Table 3. The general model (with 9 predictors) produced an overall prediction accuracy of 74.7% for discrimination between Group 1 and Group 2 of Polish female judokas. The optimized models are based on 4 indicators with the greatest effect sizes from the Group 1 and Group 2 comparisons. The 1st optimized PNN model showed higher overall accuracy and similar, but lower, accuracy classifications for Group 1 than Group 2 athletes.

The second optimized PNN model, developed using patterns from E%d, Ea, Ed and Grip time to throw (4-8s), showed highest overall accuracy and especially higher accuracy classifications for Group 1 than Group 2 athletes. The difference of prediction between the groups was insignificant ($Chi^2=0.315$, df=1, $p=0.015$, Cramer's V=0.060 [small effect], but OR=1.39, Cl's=0.442 to 4.350). The odds ratio between Group 1 and Group 2 was 1.39 (Cl = 0.442 to 4.35). This means that the OR of the predicted Group 1 to Group 1 was 1.39 times as great as the odds ratio of the predicted Group 2 to Group 2.

Table 3. Classification tables from the Probabilistic Neural Network Models using the 6 indices of the course of fight and 3 time ranges from gripping to performing a throw.

Classification Tables from PNN using 9 characteristics of fight					
Actual Ranking	**Group Size**	**Predicted**			**Indices (9)**
		Group 1	**Group 2**	**Accuracy (%)**	
Group 1	29	17	12	58.60	Aa
Group 2	58	10	48	82.80	Ad
Overall Accuracy				74.70	Ea
					Ed
					E%a
					E%d
					Grip time to throw (1-3 s)
					Grip time to throw (4-8 s)
					Grip time to throw (over 8s)
The first optimized model including the best four predictors					
Actual Ranking	Group Size	Predicted			Indices (4)
		Group 1	Group 2	Accuracy (%)	
Group 1	29	22	7	75.90	E%d
Group 2	58	13	45	77.60	Ea
Overall Accuracy				77.00	Ed
					Grip time to throw (1-3 s)
The second optimized model including the best four predictors					
Actual Ranking	**Group** Size	**Predicted**			**Indices (4)**
		Group 1	Group 2	Accuracy (%)	
Group 1	29	24	5	82.76	E%d
Group 2	58	13	45	77.59	Ea
Overall Accuracy				79.31	Ed
					Grip time to throw (4-8s)

Note: Aa = activity in attack; Ad= activity in defense; Ea= efficiency of attacks; Ed= efficiency of defense; E%a= effectiveness of attacks; E%d= effectiveness of defense; Grip time to throw= time from gripping to performing a throw.

Discussion

We found significant differences in the analyzed technical-tactical variables according to the performance level of the elite female judo athletes. Thus, those female judokas with higher sport skill level were characterized by greater value of Aa and lower value of Ad, compared with judokas with lower performance level. Similarly, higher-ranked female athletes were characterized by higher value ofEa and lower value of Ed in comparison with lower-ranked judokas. It should be emphasized that the lower values of Ad and Ed based on opponents' activities, indicate better results. E%a and E%d indices were greater in the higher-ranked group compared to the lower-ranked one. Moreover, in all three intergroup comparisons, the time spent between the grip contact and throw application was shorter in higher-ranked athletes than in lower-ranked athletes. The greater number of attacks was performed in the time range of 1-3s by athletes from Group 1 than Group 2, with the same being observed in time ranges 4-8s and above 8s.

A study by Laskowski (2006) demonstrated that during the fights of Polish female judokas in 2001-2004, the most successful actions were throws (63.3%), followed by penalties (22.8%), and grips (13.9%). Regarding to these variables, in the present study, the time spent between the grip and the throw action has been established as a key performance factor in judo female athletes, since it was able to discriminate between higher and lower ranked athletes according to the National Judo Association Rank. Pierantozzi, Nerozzi and Piras (2009) analyzed the 2007 World Championship and found that during a fight, both women and men initially attempt to use a collar grip (51%). The next type of grip used by female judokas was leg grip (forbidden according to current judo fight regulations), whereas men strove more for the wrist grip. The third grip used by both female and male athletes was the sleeve grip. From the *hajime* command (beginning of the judo bout), it

took on average 13 seconds for the athletes to perform the grip. Miarka et al. (2016), who analyzed female fights during the 2012 Summer Olympics in London, found the approach time of 7.0 ± 5.1s and grip time of 4.4 ± 2.3s, similarly to the results presented by Calmet, Miarka and Franchini (2010). The time-motion and technical-tactical analysis demonstrated significantly longer duration of total combat time, standing combat time, displacement without contact, gripping time and technique time in seniors' matches in comparison with other age groups. No differences in groundwork combat time and pause time were observed. Senior athletes significantly less frequently applied ashi-waza in each combat than younger athletes (Miarka et al., 2014). Furthermore, female judo athletes showed higher attack frequency and pause occurrence than males, and were characterized by using higher frequencies of techniques with different biomechanical levers for attacks (Dal Bello et al., 2019).

This study demonstrated that the time spent between grip and the throw action was significantly shorter in athletes from Group 1 compared to Group 2 in all time ranges (1-3s, 4-8s, and over 8s). In an important study (Kłys, 2017), 3-way ANOVA was used to analyze two intergroup factors (sport skill level and weight category) and a variable with repeated measurement i.e. time of using grip before attack. In this more complex experimental design, a significant correlation was demonstrated between sport skill level and the time range of 1-3s. In the present study, we found intergroup differences for time ranges of 1-3s, 4-8s and over 8s. Furthermore, we identified differences between performance groups for selected aspects of fights what can have important application in improving the training process.

Based on the results of our study, we developed a model of top female Polish competitors in judo using PNN. The first PNN model shows higher accuracy of overall classification than the general model. Also, we found that the second optimized model showed more accurately the 29 best athletes (accuracy 82.8%) than the 58 lower ranked group (accuracy 77.6%) using patterns of E%d, Ea, Ed and time between grip and attack action (4-8 s).

The Classification Plot was used to gain a better understanding of how the region defined by the Ea and period of 1-3s (Fig. 1. Panel A) or 4-8s is divided into areas that would result in samples being classified as belonging to different groups (Fig. 1. Panel B).

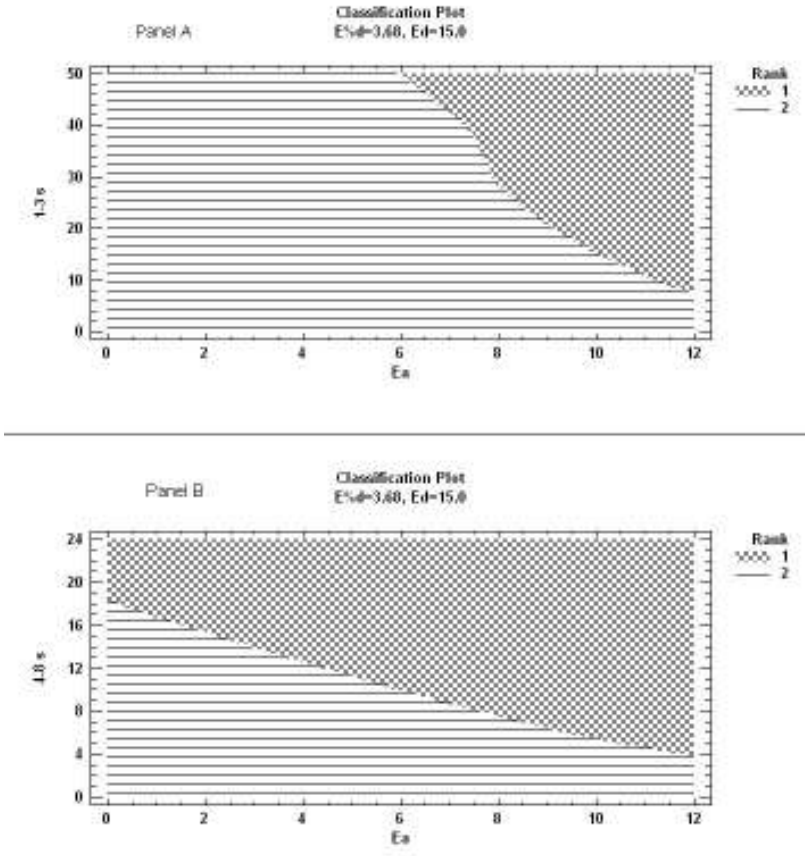

Figure 1. Classification Plot. 1 – Group 1, 2 – Group 2. Each fill type-coded region corresponds to a different group. Efficiency of attacks (Ea) and throws in ranges of time (1-3 s for Panel A and 4-8 s for Panel B) are used to define the horizontal and vertical axes, while effectiveness of defense (E%d) and efficiency of defense (Ed) are held at fixed values.

Conclusions

The analyzed variables were able to discriminate between higher and lower performance in elite female judo athletes. Specifically, we found significant differences in analyzed variables of attack and defense actions, and time spent from grip contact to throw action, according to sport skill level. The PNN method demonstrated that a higher ranking at a national competitive level can be achieved if the judo athlete is characterized by adequate activity in attack, choice of the right moment for attack, effectiveness of defense, and efficiency of defense.

Therefore, quantification of the differences that occurred in elite female judo athletes according to performance level can help set standards in lower ranked athletes that should be gradually met during training and competition. For higher ranked female judokas, such standards should be expected rather during international competition. Moreover, lower-ranked female judo athletes who were not classified in their group (Group 2) had individual characteristics similar to the group of higher-ranked athletes, consequently, they could be considered reserves. These results can be useful for coaches to plan combat strategies and in setting standards that should be gradually met in training for competition. Furthermore, coaches can use video to analyze indices of the course of fight that are discriminant between higher and lower ranked judo athletes to provide training methods focused on improving technical-tactical preparation. Observation of potential athlete's opponents and analysis of their indices of fight can be used by coaches in training organization before competition.

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