

Article

Handgrip Strength as a Distinguishing Factor of People Training Martial Arts

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Abstract: Jujutsu is a close-contact grappling combat sport. Karate is a long-distance combat sport, primarily using strikes and kicks. Well-designed strength characteristics should be capable of differentiating between participants of martial arts and combat sports, especially if, due to training preferences, they develop particular preferences for grappling or striking that differentiate them, as is the case in jujutsu and karate. One hundred and seventy-eight participants were tested for their age, weight, years of training, style (modern jujutsu, Polish and German groups, karate Kyokushin, karate Shotokan), skill level (Kyu or Dan grade), gender, and handgrip strength (HGS). An analysis of variance utilizing age, weight, years of training, martial art, gender, and skill in explaining HGS showed that variance in skill level and the interaction between skills and weight were significant. Furthermore, a post-hoc Tukey's HSD test based on skills separated practitioners with the second Kyu from those with the sixth Dan grade. There were two groups identified when a similar analysis was conducted for the interaction between skill and weight. The first one encompassed all athletes below the fifth grade, whereas the second one comprised the remaining practitioners. Principal component analysis with gender as a grouping variable showed that women formed a partly separated group of athletes, with the most differentiating factors being age and years of training. When the grouping variable was skill level, the most influential variables were weight, HGS, and age. Finally, utilizing martial arts as a grouping variable showed that age, years of training, and skill were the essential variables. Our study has demonstrated that by utilizing HGS in combination with such characteristics as weight, age, years of training, gender, Dan grade, and martial arts, it is possible to identify differences between people training distinct martial styles, those with varying skills, and those representing opposite sexes. However, the differentiation is only sometimes apparent.

Keywords: HGS; jujutsu; karate; Kyokushin; Shotokan; ANOVA; PCA

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1. Introduction

An indicator of general strength is handgrip strength (HGS) [1]. A sufficient, if not high, level of HGS is necessary among other skills for climbing, golf, hockey, swimming, tennis, weightlifting, and wrestling. Its quick and affordable testing makes evaluating a person's general health status simple [2]. Handgrip strength is related to age, significant differences between genders, hands, and some age groups, and a correlation with height, body mass, BMI, and hand dimensions may exist depending on the gender [3]. It was also suggested that the test is more adequate for men than for women [1]. Generally, grip strength is stronger on the dominant side than on the non-dominant side. However, the difference between the two sides can vary significantly between studies and depends on whether a person is right- or left-handed [4]. Furthermore, sex and hand dominance impact the strength of a person's grip, but not their handedness [5]. However, a person's hand shape and age impact a female's grip strength more than a male's. It was observed that only women had higher values of HGS in their dominant hand than in their non-dominant

hand [6]. As women age, their grip strength weakens, but those with larger hands are less affected than those with smaller hands. Participating in hand sports regularly can increase the strength of a person's non-dominant hand, regardless of sex. Males are more likely to see an impact on grip strength from their occupation, indicating different patterns of hand dominance and function [5]. Discriminant analysis results showed that HGS in male and female judokas is related to practitioner weight and gender [7]. Moreover, hand grip is one of the characteristics capable of differentiating young BJJ athletes [8]. It was also demonstrated that uneven physical exertion of both sides of body in judo may impact directional and absolute asymmetry. This phenomenon seems to be less pronounced in jujutsu competitors [9]. It was demonstrated that judokas did not exhibit greater peak grip force than the non-judokas. However, the judokas showed higher fatigue resistance [10]. Furthermore, univariate ANOVA was capable of identifying significant differences between MMA fighters according to their competitive level and weight class (divided into lightweight professional, lightweight elite, heavyweight professional, and heavyweight elite) using one-repetition maximum (1RM) bench-press weight but not HGS [11]. These findings suggest that measuring practitioner strength may in some instances not be informative. However, the results contrast with the data evaluated for BJJ experts. It was demonstrated that BJJ athletes have significant differences from novices in terms of isometric hand grip strength in both hands [12]. Overall, there was an increase in absolute and a decrease in relative handgrip strength across weight categories. These differences in grip strength between weight categories are probably linked to differences in muscle mass between groups. There was a high correlation between both hands for absolute and relative values, which suggests that assessing only one hand may be enough, and therefore a faster method of evaluation. Similarly, analysis of maximal isometric hand grip strength [13] conducted via one-way ANOVA followed with the Tukey's HSD test on both hands of 406 judo athletes representing varying weight categories showed a large effect of weight category on HGS, with higher values for heavier practitioners. A positive correlation was found between both hands in terms of absolute and relative HGS with an increase in absolute and a decrease in relative HGS across weight categories. The significance of athlete weight was also showed in a study on 546 male judokas of varying ages [14]. It was found that the variations in isometric handgrip strength were primarily due to differences in body mass between the age groups. Furthermore, handgrip strength and lean body mass in professional athletes are correlated, as indicated in studies on MMA athletes [15]. It has been documented that high-level karate athletes have a connection between their body composition and handgrip strength [16], whereas a study on young judo practitioners showed that fat mass, fat-free mass, stature, arm span, and inferior member length mediated the effect on HGS; however, the effects were small [17]. Moreover, tests conducted on Indian judokas revealed that lower-body strength and power are crucial for junior judokas, as demonstrated by their absolute and relative strength (back-squat and bench-press one-repetition maximum [1RM] as well as isometric handgrip) results [18]. However, no similar studies involving karate and jujutsu training athletes have been conducted.

Jujutsu, also referred to as jiu-jitsu and ju-jitsu, is a family of Japanese martial arts and a form of close-contact combat (using no weapons or a small weapon) that can be used either defensively or offensively to kill or subdue one or more opponents who are not carrying weapons or who are armed and wearing armor [19–21]. Hisamori Tenenouchi, who formally founded the first jujutsu school in Japan, invented “jiu-jitsu” in the 1530s. This style of martial arts employs strikes, throws, grips and paralyzing techniques against the opposition while using little to no weapons. Around the 17th century in Japan, jujutsu evolved from the warrior class [22]. It was created to support a warrior's sword use in battle. Many contemporary martial arts and combat sports, such as judo, aikido, sambo, ARB, Brazilian jiu-jitsu, and mixed martial arts, were developed using a subset of techniques from specific jujutsu styles. Jujutsu has recently been updated to fit the modern demands of self-defense and combat sport. It is classified as a grappling style of wrestling. Still, it offers

techniques helpful for fighting at a distance. In Western countries, jujutsu became popular at the end of the XIX century and is commonly known as modern jujutsu [19,23,24].

The most popular Japanese martial art is karate. It was first created on the islands of Okinawa [25]. It emphasizes kata, punches, knee, elbow, and kick attacks. Numerous karate schools also teach Kobudo weapons. Karate has numerous sub-styles; Goju-Ryu, Kyokushin, Shito-Ryu, Shorin-Ryu, Shotokan, and Wado-Ryu are a few of the more popular karate schools (styles). In addition, karate had its debut as an Olympic sport in the summer of 2020 and for the moment will not be continued in the Olympic Games in 2024. Contrary to jujutsu, in karate, the fight is run at a longer distance using strikes and kicks. It is a martial art that has been adopted for sports competitions in many styles. An excellent example of such adaptation is Shotokan, where fights are conducted on a non-contact basis, and actions have assigned scores. Another option is Kyokushin. In contrast to Shotokan, Kyokushin permits vital strikes, and fights follow a knock-down formula. The karate fight rules do not allow any grappling [26,27]. However, in Japan, on Okinawa Island, karate is practiced as self-defense and in many ways resembles jujutsu. In modern Japanese karate, the defense aspect is neglected. The students exclusively learn techniques dedicated to fighting at a distance for sports purposes and kata as the technical forms. As a result, karate has become a style for self-fulfillment, a sport rather than an actual fighting method.

Thus, jujutsu and karate should differ in many aspects concerning the strength of those practicing the two forms of activity. It is not questioned that in many combat sports (wrestling, sambo, judo, sport jujutsu), strong grappling is needed [28–30], whereas in karate, where dynamic actions prevail, grappling is of minor importance [31]. Thus, HGS seems to be an ideal characteristic for analyzing differences between various karate and jujutsu training practitioners.

It is noteworthy that handgrip strength might be affected by external factors. It is a common notion that stretching improves performance and prevents injuries and delayed-onset muscle soreness, although there is no consensus in the scientific literature about these effects [32]. Stretching is usually employed before physical exercises and sports. However, it is negatively correlated with HGS. In fighting sports where grip hand strength is essential, avoiding stretching exercises involving flexor and finger muscles is best [32]. An interesting meta-analysis revealed a small but significant effect of caffeine on HGS and the number of throws performed during a judo fitness test [33]. However, no such effect was observed for factors such as countermovement jump height and the judogi strength-endurance test. Furthermore, caffeine may also affect HGS in judokas [34], but its ergogenic properties are being questioned [33].

HGS measurements need to be practical, inexpensive, transportable, trustworthy, and sensitive to detect significant changes in performance. The maximum isometric HGS can be measured using handgrip dynamometry [35]. There have been several reviews of handgrip dynamometers (HGDs) that address the validity, reliability, and standardization of HGS testing procedures across a variety of populations [35,36]. Obviously, HGS could be a parameter of choice for evaluating differences between people training in martial arts, as demonstrated for judo, sambo, karate, and taekwondo practitioners [37]. However, it is somewhat complicated to measure strength [38–41]. Well-designed strength characteristics should be capable of differentiating between practitioners of martial arts and combat sports, especially if, due to training preferences, they develop particular favorites in grappling and striking that differentiate them, as is the case in jujutsu and karate [20,42–45].

It is hypothesized that individuals training distinct martial arts have developed different HGSs because of preferences in techniques adopted by practitioners of different styles. For example, people training in jujutsu should have greater HGS than those training in karate. Furthermore, it is expected that regardless of the martial art they train and independent of style, women should differ from men in terms of strength measured by handgrip [38]. As HGS is sensitive to age, gender, and body parameters, its use for differentiating people with varying skills and years of training might be advantageous.

The study aims to verify whether (1) people training distinct martial arts develop differences in their strength; (2) there is a difference between individuals with different skill levels (Dan grades); (3) age and years of training impact handgrip strength; (4) there are differences in handgrip strength between men and women.

2. Materials and Methods

The authors of the study conducted the survey personally. All surviving participants attended several independent sports events, including instructor mastery courses and advanced training sessions that took place during 2018–2022 in Poland and Germany. The athletes were asked if they had undergone any surgeries in the past year, specifically involving the upper limbs. We also confirmed that they were free of muscle pain or stress injuries. No other specific criteria except age above or equal to 18 and higher belt ranks (higher skill levels) were used to choose survey participants. Those who did not meet the criteria were excluded from the analysis. Thus, the participants that accepted the invitation were weighed, had their HGS measured, and declared their belt rank, age, and years of training. The data were collected from 178 participants tested for their age, weight, years of training, style (modern Jujutsu—two groups, karate Shotokan, karate Kyokushin), skill level (Kyu or Dan grade), gender, and handgrip strength (HGS).

HGS is a widely used fitness test in judo and karate to evaluate upper-limb strength [46]; it correlates with body mass [47] and composition [16]. However, HGS has been shown to be ineffective in differentiating athletes who train in BJJ [48]. Studies have shown that HGS can differentiate between the skill levels of white and black belt judokas, making it a valuable tool in martial arts [49]. Moreover, experienced athletes practicing arm wrestling seem to have higher handgrip strength [50]. Taken together, these findings suggest that HGS could be useful in differentiating athletes practicing distinct martial arts.

The Kyu and Dan ranks were incorporated into the analysis as they were suggested to be correlated with body mass and HGS [51].

Groups of participants:

- Group 1—Jujutsu 1, athletes from Poland (24 persons)
- Group 2—Jujutsu 2, athletes from Germany (97 persons)
- Group 3—Karate Kyokushin (35 persons)
- Group 4—Karate Shotokan (22 persons)

The HGS test, involving the dynamometric measurement of hand force, was carried out as follows: a KERN MAP 130K1 (manufactured by KERN) palm hand dynamometer was used. The subject squeezes the hand dynamometer with their stronger hand. The wrist should lie along the extension line of the forearm. During this testing, the test hand must not touch any part of the body [31,52]. The strength of the hand is measured in kilograms. The better measurement of the two tests is selected for further analysis. The dynamometer should be adjusted to the size of the hand of the subjects so that the more distal finger joints fit in its handle. Hand swings during measurements are not allowed because they can alter the results. Subjects need to focus mentally on the task since the goal is to measure the maximum HGS force of the subjects [52].

Pearson and Spearman correlation coefficients, analysis of variance, and principal component analysis (PCA) were conducted in XlStat (v. 2020.5.1) software [53]. ANOVA and Tukey's post-hoc test were performed in XlStat (v. 2020.5.1) software [53].

3. Results

One hundred and seventy-eight participants in the survey represented two groups of modern Jujutsu (from Poland and from Germany) and two groups of karate (Kyokushin and Shotokan). The jujutsu groups comprised 24 and 97 participants, whereas the karate groups comprised 35 and 22 members. Only 12 participants were women, equally spread between the two karate groups. Each of the women had grades higher than the second Kyu. The remaining survey members with Kyu grades were spread between the second jujutsu group and the two karate styles. In total, there were 18, 14, 90, 32, 11, 4, 6, 1,

and 2 participants representing first and second Kyu and the first to seventh Dan grades, respectively.

The descriptive statistics of the analyzed variables are arranged in Table 1. There was no missing data for the 178 participants representing three martial arts (two groups of jujutsu and two types of karate). The jujutsu groups trained in the same style, while the karate groups were from two different styles. According to skewness and kurtosis data, deviation from normality for all variables was not high.

Table 1. The arrangement of descriptive statistics for the analyzed variables.

Statistic	Age (Years)	Years of Training	Weight (kg)	Gender	Grade	Martial Arts	HGS
No of observations	178	178	178	178	178	178	178
Minimum	12.000	4.000	43.00	0	0.100	1.000	20.000
Maximum	61.000	56.000	125.00	1	7.000	4.000	106.000
Median	36.000	16.000	80.00	1	1.000	2.000	80.000
Mean	36.140	19.056	79.253	-	-	-	80.298
Variance ($n - 1$)	170.065	100.132	200.054	-	-	-	284.244
Standard deviation (n)	13.004	9.978	14.104	-	-	-	16.812
Standard deviation ($n - 1$)	13.041	10.007	14.144	-	-	-	16.860
Skewness (Pearson)	0.050	1.226	0.256	-	-	-	-1.021
Skewness (Fisher)	0.050	1.237	0.258	-	-	-	-1.030
Skewness (Bowley)	0.000	0.478	-0.164	-	-	-	0.333
Kurtosis (Pearson)	-1.010	1.421	0.978	-	-	-	1.081
Kurtosis (Fisher)	-1.004	1.497	1.040	-	-	-	1.146

Correlation analysis showed that years of training was highly correlated with age ($r = 0.761$). A similar correlation was evaluated between years of training and skill ($r = 0.726$). A moderate correlation was evaluated between the weight and HGS ($r = 0.66$) variables. A moderate correlation was also demonstrated between skill and age ($r = 0.60$). The other correlations were either weak or insignificant (Table 2).

Table 2. Pearson and Spearman (martial arts and Dan grade) correlation coefficient matrix.

Variables	Martial Arts	HGS	Weight (kg)	Age (Years)	Years of Training	Dan Grade
Martial arts	1					
HGS	-0.224	1				
Weight (kg)	-0.224	0.660	1			
Age (years)	-0.135	0.287	0.365	1		
Years of training	-0.074	0.177	0.228	0.761	1	
Dan grade	-0.121	0.128	0.233	0.601	0.727	1

Values in bold are different from 0 with a significance level $\alpha = 0.05$.

The analysis of variance for HGS explained by age, weight, years of training, martial art, gender, and skill proved significant (Table 3). The best model variable selection method retained two variables in the model. The R^2 of the variability of the HGS dependent variable was explained by 61%. Assuming the p -value of the F statistic computed in the ANOVA and given the significant level of 5%, the information provided by the explanatory variables was significantly better than what a basic mean would bring.

Table 3. Analysis of variance for HGS.

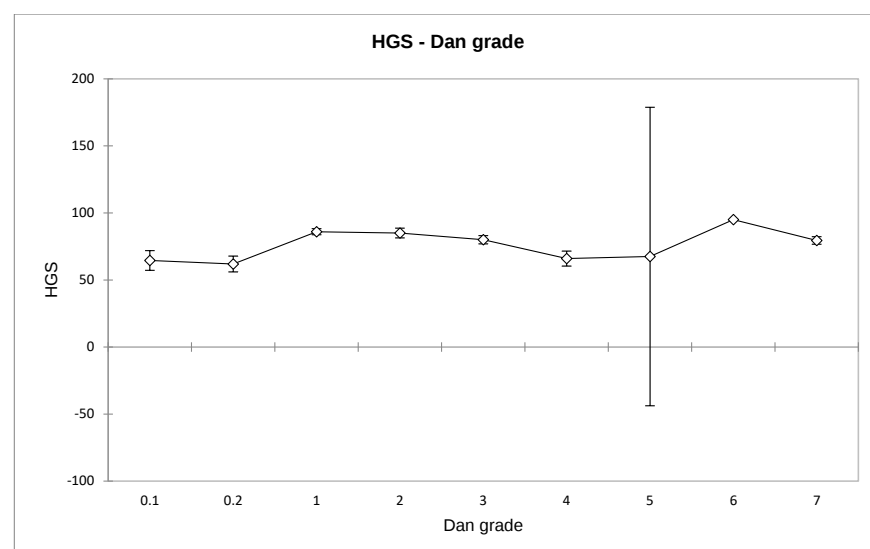
Source	DF	Sum of Squares	Mean Squares	F	Pr > F
Model	15	30,798.581	2053.239	17.047	<0.0001
Error	162	19,512.638	120.448		
Corrected Total	177	50,311.219			

Based on the Type III sum of squares (Table 4), HGS values are explained by skill, followed by the interaction of skill and weight. Based on the Type III sum of squares, the interaction between weight and skill level is the most influential among the explanatory variables.

Table 4. Type III sum of squares analysis for HGS as the dependent variable.

Source	DF	Sum of Squares	Mean Squares	F	Pr > F
Age (years)	0.000	0.000			
Years of training	0.000	0.000			
Weight (kg)	0.000	0.000			
Gender	0.000	0.000			
Skill (Dan grade)	6.000	4271.558	711.926	5.911	0.000
Martial arts	0.000	0.000			
Age (years) × Years of training	0.000	0.000			
Age (years) × Weight (kg)	0.000	0.000			
Age (years) × Gender	0.000	0.000			
Age (years) × Skill (Dan grade)	0.000	0.000			
Age (years) × Martial arts	0.000	0.000			
Years of training × Weight (kg)	0.000	0.000			
Years of training × Gender	0.000	0.000			
Years of training × Skill (Dan grade)	0.000	0.000			
Years of training × Martial arts	0.000	0.000			
Weight (kg) × Gender	0.000	0.000			
Weight (kg) × Skill (Dan grade)	7.000	15,951.704	2278.815	18.919	0.000
Weight (kg) × Martial arts	0.000	0.000			
Gender × Skill (Dan grade)	0.000	0.000			
Gender × Martial arts	0.000	0.000			
Skill (Dan grade) × Martial arts	0.000	0.000			

As indicated in Figure 1, an increase in HGS is observed between Kyu and first Dan. Then, a subsequent decrease is observed through fourth Dan, followed by increase at the fifth Dan and drop in HGS value for participants at the seventh Dan level, independent of the martial arts analyzed. An increase in variance is observed in the group represented by participants with first and second Kyu and fifth Dan.

**Figure 1.** Illustration of the relationship between handgrip strength measurement and Dan grade.

Based on Tukey's HSD post-hoc test, the single participant with the sixth Dan grade was distinct from the other tested martial arts practitioners (Table 5). The participants with the second Kyu formed another separate group. The participants with first Kyu and fourth and fifth Dan grades were typical for the A and B group members. Those with the seventh, third, and second Dan grades were spread across all groups. The first Dan members belonged to groups B and C.

Table 5. Summary of all pairwise comparisons for skill level (Tukey (HSD)).

Grade	LS Means	Groups		
Kyu 2	61.929	A		
Kyu 1	64.556	A	B	
Dan 4	66.000	A	B	
Dan 5	67.500	A	B	
Dan 7	79.500	A	B	C
Dan 3	80.000	A	B	C
Dan 2	85.031	A	B	C
Dan 1	86.000		B	C
Dan 6	95.000			C

The post-hoc test showed that the interaction between weight and years of training grouped the survey participants into two groups (Table 6). The first consisted of participants who achieved a grade lower than the fifth Dan, whereas more experienced participants were in the second group.

Table 6. Summary of all pairwise comparisons for weight and skill interactions based on least squares means.

Category	LS Means	Groups
Weight (kg) $\times$ Kyu -1	-0.061	A
Weight (kg) $\times$ Kyu -2	0.000	A
Weight (kg) $\times$ Dan -1	0.000	A
Weight (kg) $\times$ Dan -2	0.481	A
Weight (kg) $\times$ Dan -3	0.520	A
Weight (kg) $\times$ Dan -4	0.800	A
Weight (kg) $\times$ Dan -5	1.065	B
Weight (kg) $\times$ Dan -6	1.338	B
Weight (kg) $\times$ Dan -7	1.413	B

Principal component analysis (PCA) with gender, Dan grade, and martial art grouping variables showed that in all cases, the first two components explained more than 66% of the variance (Table 7), indicating that the first two components are sufficient to explain data structure.

Factor loadings encompass the first component and are responsible for grouping with the gender variable, as the grouping factor shows that the age of the participants, followed by years of training, followed by Dan grade and participant weight have the greatest effect. In contrast, the second most crucial variable is HGS (Table 8). When the skill variable was a grouping factor, weight, HGS, age, and gender were responsible for the majority of variance explained by the first component. In contrast, years of training was the most influential factor for the second component. Finally, in the case of martial arts used as a grouping factor, the first component's most impactful variables were age, years of training, skill, and weight. In contrast, the second component's most influential variable was HGS.

Table 7. The arrangement of principal component analysis with gender, skill level, and martial art variables used as grouping parameters.

Grouping Factors	Statistics	F1	F2	F3	F4	F5	F6
Gender	Eigenvalue	2.681	1.557	0.814	0.400	0.335	0.213
	Variability (%)	44.688	25.947	13.568	6.664	5.588	3.544
	Cumulative %	44.688	70.635	84.203	90.867	96.456	100.000
Dan grade	Eigenvalue	2.664	1.355	0.835	0.596	0.336	0.214
	Variability (%)	44.407	22.579	13.915	9.928	5.597	3.572
	Cumulative %	44.407	66.987	80.902	90.830	96.428	100.000
Martial Art	Eigenvalue	2.823	1.543	0.690	0.393	0.330	0.221
	Variability (%)	47.053	25.713	11.495	6.555	5.502	3.681
	Cumulative %	47.053	72.766	84.262	90.817	96.319	100.000

Table 8. The arrangement of factor loadings evaluated for the PCA analysis with gender, skill, and martial art used as grouping variables.

Grouping Factors		F1	F2
Gender	Age (years)	0.872	−0.225
	Years of training	0.810	−0.425
	Weight (kg)	0.621	0.581
	HGS	0.555	0.674
	Skill	0.690	−0.514
	Martial art	−0.310	−0.518
Skill	Age (years)	0.719	0.591
	Years of training	0.596	0.731
	Weight (kg)	0.759	−0.232
	HGS	0.744	−0.350
	Gender	0.651	−0.324
	Martial art	−0.488	0.435
Martial art	Age (years)	0.840	−0.307
	Years of training	0.784	−0.467
	Weight (kg)	0.644	0.567
	HGS	0.586	0.662
	Gender	0.539	0.429
	Skill	0.673	−0.535

PCA analysis shows that women formed a separate group (Figure 2). The participants with higher skill levels (fifth Dan grade and higher) are preferentially in a separate group, whereas those with the first to third Dan grades are in the middle part of the PCA. Interestingly, however, two participants with Kyu grades are among the participants with the highest skill levels (Figure 3), indicating their potential strength comparable to that presented by highly skilled survey members. The two cases were the men training jujutsu (the second jujutsu group). Finally, when martial art was used as a grouping factor (Figure 4), it could be seen that jujutsu practitioners (first and the second groups) were mostly clustered in the center. Those training Shotokan karate style (group 4) form slightly separate groups, whereas the members of the karate group are spread more or less equally over the other groups.

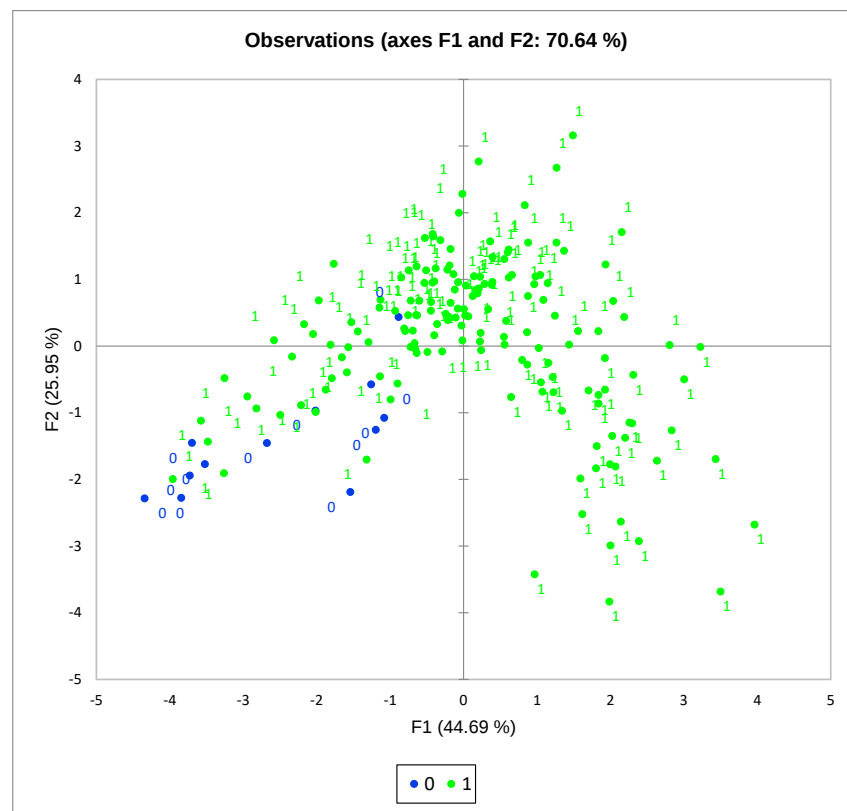


Figure 2. Principal coordinate analysis with the gender variable used as a grouping factor. Females are indicated by zero and males by one.

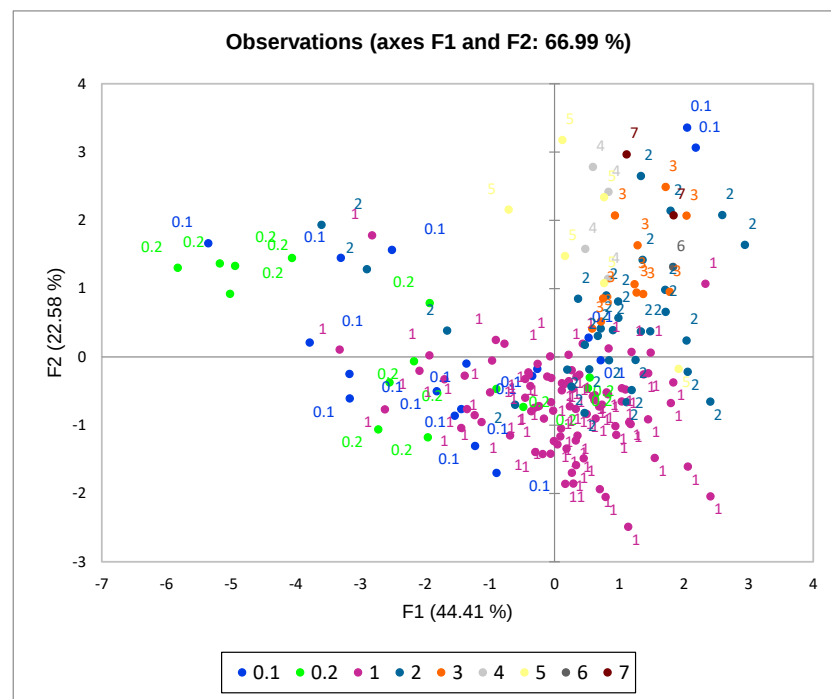


Figure 3. Principal coordinate analysis with the skill variable used as a grouping factor. The labels 0.1 and 0.2 represent the first and the second Kyu, respectively, whereas 1, 2, 3, 4, 5, 6, and 7 represent participants with respective Dan grades.

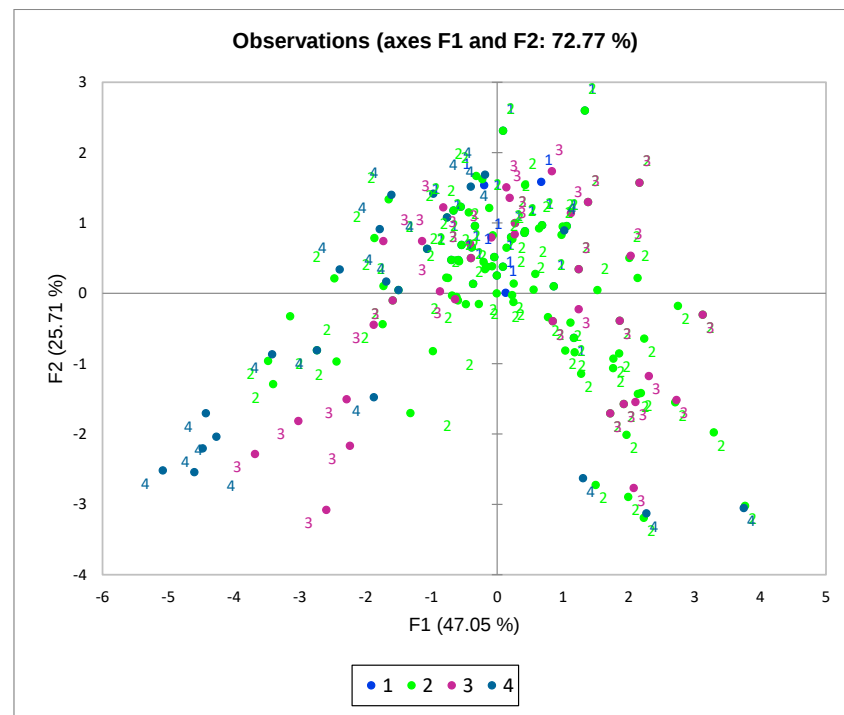


Figure 4. Principal coordinate analysis with the martial art variable used as a grouping factor. The numbers 1 and 2 represent participants training jujutsu, reflecting two separate groups, whereas 3 and 4 are the groups of participants training in karate 3 and 4 styles.

4. Discussion

Despite the survey having a sizable sample size, we still did not have an equal distribution of males and females among the four groups we examined. The two karate forms, however, were representative of all females. Furthermore, recruiting sufficient participants with the best abilities to represent the sixth and seventh Dan grades was impossible. The reason for this is that few people attain the highest dan grade, while women are often less interested in training in martial arts (perhaps except for Aikido).

Some variables exhibit strong correlations. Unsurprisingly, skill and years of trainings are connected with the survey respondents' ages. Additionally, it might be predicted that martial arts students' HGS and weight are related, which is congruent with the data in the literature [8,11,31,54–56]. The same holds true for HGS and age [51,57]. We have also seen comparable results for HGS and skill level. The latter relationships were previously evaluated in terms of skill characteristics for distinct martial arts [58] but were not discussed regarding skill level reflecting grades. Thus, the presented data demonstrate apparent but new facts concerning HGS.

The data meet the criteria for variance analysis, and the model is significant (Table 3). The type III sum of squares indicated that skill and its interaction with weight were important in the model explaining HGS. Tukey's HSD post-hoc test based on skill revealed the existence of a group of second Kyu members. Young people studying any of the examined martial arts make up the group and exhibited the lowest HGS values. In the group, roughly equal representation of each gender is present. Unlike the first Kyu, participants included only a small number of women. To ensure equal sex representation, the issue of the second Kyu group's separation should be addressed. It is also worth mentioning that implementation of HGS for women may not be the best choice and may result in bias [1]. The study also reveals that a single individual who possesses the sixth Dan grade creates a distinct group with the highest HGS value. The grouping may be a statistical issue relating to the individual's attributes rather than the Dan grade because of the group's

thin representation. In general, Tukey's HSD test could not locate any additional distinct groupings of data sufficient for the identification of additional groups based on grade.

Furthermore, Tukey's HSD post-hoc test identified data groups for the interaction between weight and skill level. It should be emphasized, too, that results for the participants in grades 5, 6, and 7 should be interpreted with care. This is so because the groups are not represented by many people. In addition, participants in the fifth dan grade showed significant variation (Figure 1), which could be explained by the fact that they are practicing in the second jujutsu (Germany) group and the Shotokan karate group. Our working hypothesis is that skill level and weight should explain the division of groups. In the current study, the interaction between the skill and participant weight in the case of the highest skill levels has the highest LS mean values.

As was established based on a post-hoc test according to skill, second Kyu and sixth Dan athletes formed separate groups distinct from each other and distinct from other athletes. More pronounced grouping was evaluated based on the interaction between weight and skill. In the first case, the athletes with the fifth Dan grade and higher were separated from the other practitioners, forming a separate group. The results should be evaluated cautiously due to the poor representation of the group containing athletes with the highest skill levels.

According to one of our hypotheses, males and females should have different HGS values. Tukey's post-hoc test taking into account gender and any two-way interactions, however, failed to find such groups. The result might be considered surprising, as in the literature, differences in HGS due to two-way interactions with athlete weight were described earlier [58]. However, in the present study, we have an underrepresentation of women what might explain lack of congruency. The notion seems to be congruent with the principal component analysis using gender as a grouping variable, where it was shown that women generally constituted a homogenous group. Thus, we believe that the survey's underrepresentation of women and the absence of women with higher levels of skill prevented the Tukey's HSD grouping from being determined in the analysis of variance. However, the PCA appears to show this grouping, which is consistent with our working hypothesis.

The individuals with Kyu grades were clearly distinguished from the other survey participants when PCA analysis was carried out using the skill grouping variable. Interestingly, students with the first Dan grade were organized into a group that partially spanned the second Dan group. The third Dan group then went after them. Last but not least, the highest Dan grades overlapped. This conclusion is at least somewhat comparable with the ANOVA findings for weight, corresponding to the available data [58], and skill interaction, where Tukey's HSD test revealed similar grouping.

Post-hoc analyses also failed to divide the participants into martial-art-related groups despite the fact that differences were described in other studies [31,37,55]. In the current situation, PCA analysis using martial arts as a grouping variable is more illuminating. For example, most jujutsu and karate participants mix together. However, Kyokushin and Shotokan participants appear to be divided into two groups. In the first, both styles are represented (bottom left corner of Figure 4); however, there is a little shift between Kyokushin and Shotokan. The second karate group (right bottom, Figure 4) primarily comprises students from Kyokushin, with a few from Shotokan. In addition, group 1 jujutsu training participants (Polish group) cluster together in the middle of Figure 4, whereas group 2 jujutsu participants (Germany) are randomly dispersed throughout all styles. Martial art style thus differentiates participants, although this differentiation may be more prominent. The explanation for categorizing the members of the Kyokushin and Shotokan should be related to particular distinctions in the styles. Their skill level and years of training may explain the divergence of the jujutsu members from the first and second groups. While the presence of the two groups may be related to their skill level, body weight, or years of training, the differences may still be more noticeable.

Based on PCA results, this study has demonstrated that weight, skill level, and gender may help differentiate the analyzed styles, at least to some extent. In addition, analysis of variance has shown that skill level and the interaction of skill and weight could explain differences between participants in HGS. Still, the approach needs to distinguish between styles. Thus, it is crucial to establish the most significant predictors of HGS that could be used in the case of studied martial arts to identify relationships between all variables and to build a theoretically helpful model for practical purposes explaining how each variable affects HGS. It would also be valuable to include similar data representing additional martial arts and more extensive representation of women in each of the arts and athletes with the highest grades.

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