JKES
Journal of Kinesiology and Exercise Sciences

E-ISSN: 2956-4581
Journal of Kinesiology and Exercise Sciences

105 (34): 46-59, 2024 ORIGINAL RESEARCH

(1.5) DOI: 10.5604/01.3001.0054.3260

TESTING FACTORS INFLUENCING HANDGRIP STRENGTH AND REACTION TIME TO VISUAL STIMULUS IN SELECTED MARTIAL ARTS

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Authors' contribution:

A. Study design/planning
B. Data collection/entry
C. Data analysis/statistics
D. Data interpretation
E. Preparation of manuscript
F. Literature analysis/search
G. Funds collection

Received: 23.10.2023
Revised: 18.11.2023
Accepted: 30.12.2023
Published: 15.01.2024

Keywords: Handgrip strength, HGS, reaction time, hierarchical linear regression, classification and regression tree, martial arts, karate, jiu-jitsu

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Abstract:

Background: Handgrip strength (HGS) is essential in sports, including martial arts, as it can be used to evaluate general athletes' performance and physical fitness. Reaction time (RT) is another characteristic that is of value in sports based on fast reaction instead of strength. The two measures belong to the same group of coordinative energetic abilities analyzed in sports theory. The available literature suggests that handgrip strength may depend on body weight but can also be affected by other parameters. Additionally, the athlete's age and martial arts training can impact reaction time. Still, verifying whether the characteristics could be applied to martial arts athletes is crucial.

Materials and Methods: Several characteristics, such as athletes' body weight, age, years of training, and skills, were evaluated during a survey of 166 male jiu-jitsu athletes (modern jiu-jitsu) and karate (Shotokan, Kyokushin). HGS was measured based on the dynamometric approach, whereas reaction time was evaluated using Ditrich's rod method. The data were analyzed using the hierarchical multiple regression method to identify the variables influencing HGS and RT. Furthermore, the classification and regression tree method was implemented to illustrate how variables used in the study influenced HGS or RT.

Results: The present study demonstrated that athletes' body weight is the most significant factor affecting the handgrip strength of male athletes trained in martial arts. It can explain 61% of the HGS variance. Regression analysis of factors influencing reaction time showed that martial arts are the factor that affects the characteristic. However, martial arts can explain up to 17% of the reaction time variance. Based on the classification and regression tree approach, it was shown that HGS depends primarily on athletes' body weight rather than on their age, skills, and years of training. For reaction time, martial arts were the most significant factor distinguishing between jiu-jitsu and karate participants. The next factor affecting athletes' classification was years of training.

Conclusion: Based on the hierarchical multiple linear regression method and classification and regression tree approach, it was found that athletes' body weight is the most influential factor affecting the handgrip strength of martial arts practitioners. Reaction time is affected by martial arts. However, using the classification and regression tree approach revealed that additional factors such as athletes' age, years of training, or skills should be considered. Similarly, reaction time is also affected by years of training. Although our study showed that handgrip strength and reaction time are functions of other variables that can be easily evaluated in trainers' practice, the two statistical methods cannot reveal the relationships between the variables, suggesting further studies in the field.

Introduction

Martial arts styles have unique features related to the specific drills developed during training. Measurements frequently used in sports can assess those characteristics. According to the literature, the measurements fit numerous martial arts differently, reflecting their specificity i.e., anthropometric measurements, physical characteristics, or motor skills. Furthermore, the measurements can be applied to distinguish between training methods for the athletes of the style of fighting discussed in the present study, i.e., Brazilian jiu-jitsu (BJJ) [1,2]. Studies using discriminant analysis have shown that anthropometric measurements (body mass, body height, and body fat), physical performance characteristics, and motor skills can differ between athletes practicing taekwondo, judo, and karate across two age groups [3]. Judo athletes tend to have the highest scores for sit and reach, handgrip, countermovement jump, and balance beam activities, while taekwondo practitioners typically score the highest for sit-ups, sprints, and jumping sideways. Handgrip strength (HGS) and reaction or response time (RT) are particularly noteworthy among the many essential characteristics in sports. The two, including coordination and resistance, form a concept of motor characteristics [4]. According to the concept, reaction time encompasses five variables but only three of them (perception, processing, and reaction) can be improved through training. Moreover, RT depends on athletes' skills, age, and years of training. It is also linked to body mass and associated with strength. [5]. Furthermore, in sports theory, HGS and RT are classified in the same group of coordinative energetic abilities [6].

The highest force generated during the voluntary flexion of the person's thumbs, wrists, and finger joints under typical biokinetic circumstances determines his or her handgrip strength. Handgrip strength is a reliable indicator of an individual's overall muscle strength and function. It has been found to be a useful predictor of various health factors and physical performance for both genders [7]. Although it is frequently neglected, this aspect of strength is crucial in medical diagnostics [8] and sports such as climbing, judo, weightlifting, wrestling, tennis, and field hockey [9]. Handgrip strength can vary depending on age, sex, hand size, and expertise in a particular sport. In addition to body height, body mass [10] and its composition [11], and lean body mass [12], HGS is also related to the body mass index (BMI) [11,13]. A study conducted on 546 male judokas of different ages showed that athletes' body weight significantly impacts handgrip strength [14]. It was observed that the differences in isometric handgrip strength were mainly due to variations in body mass between the age groups [14]. Additionally, handgrip strength is linked to lung function [15], and testosterone biomarkers in MMA athletes [12].

Experienced arm wrestlers have higher handgrip strength [16]. HGS is a fitness test that has been widely used in judo and karate to evaluate upper limb strength [17], with results correlated with body mass [10] and composition [11]. However, as body mass is a significant factor, it may not be the most effective method to distinguish between judokas and non-judokas. An alternative index called HGSINDEX has been suggested [18]. Additionally, it has been shown to be ineffective in showing differences between BJJ athletes [19]. Nonetheless, HGS is successful in distinguishing between male judokas and karatekas, with judokas demonstrating higher HGS values in both hands [17]. HGS was also partially useful in finding differences between some martial arts [20].

Studies have shown that HGS can distinguish between the skill levels of white-belt and black-belt judokas, making it a valuable tool in martial arts [2]. Furthermore, research has found that aikidokas tend to have weaker handgrip strength compared to athletes in other combat sports and martial arts [21]. Moreover, a discriminant analysis revealed that young male judo athletes with higher body weight tend to have higher maximal handgrip strength than their lighter peers [22]. Furthermore, increased HGS across body weight categories was evaluated in sambo athletes of both genders [23]. Women are better suited to take the test than men [7]. Additionally, a person's dominant side typically has a stronger handgrip, however, this can change depending on whether he or she is right- or left-handed [24]. According to recent studies, women typically have greater HGS values in their dominant than non-dominant hands [25,26]. Regardless of gender, consistent participation in hand sports helps increase strength in a person's non-dominant hand. The occupation of men is more likely to affect their grip strength, indicating different patterns of hand dominance and function [27]. According to discriminant analysis, the HGS of male and female judokas depends on their body weight and gender [22]. Furthermore, elite judo athletes usually develop higher levels of HGS [10]. The handgrip strength of young BJJ competitors can also be an identifying feature [28]. Uneven physical exertion on both sides of the body can also affect directional and absolute asymmetry in judo, but this impact is less noticeable in jiu-jitsu athletes [29].

Interestingly, based on ANOVA, HGS failed to differentiate between MMA competitors at various competitive levels and weight classes [30]. This implies that HGS can be informative only occasionally. According to BJJ experts, the power of an isometric handgrip varied significantly between novices and specialists in both hands [31]. Across weight categories, there is an overall tendency toward rising absolute handgrip strength and decreasing relative handgrip strength, probably caused by muscle mass variations. Because each hand's absolute and relative values have a strong association, it is possible to evaluate just one hand. Furthermore, a study using ANOVA utilizing the maximum isometric handgrip strength of 406 judo athletes of different body weights showed that the weight category had a more significant effect on HGS, with higher values for heavier practitioners [32]. Similarly, isometric lumbar strength showed differences between MMA athletes according to their competitive level and weight class [30]. These studies controlled for chronological age and body mass and investigated the mediating role of anthropometric variables [33]. Among mediators, arm span, stature, fat mass, fat-free mass, and inferior member length showed that the relationships between characteristics influencing HGS might be complex. However, the effects were relatively small. Unfortunately, whether the same complexity is valid across both genders' whole lifespans is still being determined, as is whether it is typical for other martial arts.

The other characteristic used in medicine and sport is the time between perceiving something and reaction, known as reaction/response time (RT). This process involves detecting, processing, and responding to a stimulus, depending on the type of perception (such as seeing, hearing, or feeling a stimulus), processing the stimulus, and responding with motor agility. If any part of this process is altered, RT will be affected. A good reflex is necessary for the motor component of RT. The processes involved in RT take place in milliseconds, but the complexity, familiarity, preparation, expectations, body status, and stimulated sensory modality of the stimulus affect RT. Additionally, the type of stimulus, whether simple, choice, or selection, also affects RT [34].

In combat sports, attacks occur quickly and last for a short time, making effective defense difficult. It may seem logical to assume that high-level athletes react faster to an attack than those of a lower level. This assumption is based on the belief that high-level athletes have a shorter time between the stimulus and the onset of their response and move their limbs faster when responding. Such reasoning likely accounts for why RT was historically a significant concern for trainers, psychologists, and sports scientists [35]. The role of RT was recognized as a secret aspect of Yang's legendary spear-turning-stab technique [36].

Sport and physical activity play a significant role in developing motor reaction time [37]. There have been efforts to investigate if reaction time (RT) correlates with an athlete's success within a specific sport. These studies usually compared novices with experts or athletes at different levels. Some studies have discovered that higher-level athletes are characterized by a faster RT [38,39], while others have found no difference [40] or even the opposite effect [41]. In addition, results could have been more consistent when multiple RT tasks had been used in the same study. These studies suggested that RT solely influences sports performance in particular tasks [42]. Still, in combat sports, including some karate styles, reaction time is crucial to success [43]. The ability to strike or counter-strike quickly can significantly impact performance and chances of success. [44, 45].

In martial arts, RT depends on an optimal location for gaze anchoring. One must account for the cost, namely that the further a stimulus is presented in the periphery, the more time is needed to initiate a response. [46]. Despite what coaches believe, there is no widespread agreement that reaction time accurately predicts success in combat sports. However, studies have shown that experienced combat sports athletes are adept at anticipating their opponent's actions based on information they gather before and during an attack. These experts likely use the gaze fixation strategy, which helps them pick up important information more easily [35]. Thus, RT serves as a vital diagnostic tool for combat sports. It has been confirmed that the reaction speed of taekwondo athletes varies by age and training experience. As athletes get older and gain more experience, their reaction speed improves. This trend is particularly evident when comparing junior and senior athletes, indicating that RT could be used to monitor the performance of martial arts athletes [47].

Research on taekwondo athletes suggests that RT can be enhanced through various training modes [48] and methods [49]. Core strength training has been found to be particularly effective in improving RT in taekwondo athletes [50]. However, it is important to note that fatigue can negatively impact RT, as observed in MMA athletes [51]. Elite MMA athletes have demonstrated preserved or improved cognitive performance, including RT, immediately after exhaustive exercise. Therefore, MMA athletes should consider incorporating cognitive-motor programs [52]. With a well-planned training program, motor proficiency in martial arts can be achieved at a level comparable to that of older athletes and surpassing that of athletes of the same age [53]. Overall, RT is a crucial indicator of performance in martial arts. Among many parameters studied, athletes of technical martial arts (judo, sambo) demonstrated the best results, i.e., in simple visual-motor reactions. However, the worst results of athletes practicing strength-based sports (Greco-Roman and freestyle wrestling) show that the reaction speed to different irritators is not the leading predictor of their success [54]. On the other hand, comparing the reaction times of athletes from various martial arts has proven highly informative. Athletes of ITF taekwondo, WTF karate, and hand-to-hand combat performed better than those from Greco-Roman and freestyle wrestling (including sambo and judo) [55].

There are many RT tests including those developed to be performed in virtual reality [56] or the real world [57,58]. The value of VR tests is still being investigated. However, RT tests for karate kumite athletes performed in virtual reality are similar to those in the real world [56]. They proved to be correlated with conventional computer tests in the case of MMA athletes [59]. On the other hand, the position of the conventional tests including the ruler drop test assessing visual reaction time (i.e., Ditrich's rod) is well-grounded in martial arts [53,57]. It has been found that different tests to evaluate reaction time (RT) results can lead to varying outcomes [35]. A study that compared athletes in boxing, gymnastics, judo, karate, taekwondo, and wrestling [60] showed that while boxers had the best results in simple RT, they were weaker in other RT tasks. Other studies have also attempted to rank sports based on reaction time [61], with fencers ranked as the fastest, followed by tennis players, boxers, and table tennis players. Evidently, the interpretation of different RT tests or comparison of RT tests based on distinct methodologies should be taken with caution. Thus, there is no clear consensus on whether RT differences exist between and within groups of combat athletes. RT per se is not a variable that can reliably predict combat sports performance or potential for success.

Analysis of the factors linked to handgrip strength and reaction time to visual stimulus can help identify those most critical and can be useful for the evaluation of the athlete's potential. Furthermore, the analysis of how the factors classify athletes according to HGS and RT can benefit coaches by helping them implement the most effective training programs for individual athletes. Additionally, utilizing these factors can also aid in predicting which abilities can be developed based on the available information. The classification tree and linear regression methods are recommended statistical techniques for this purpose.

This study aims to select the variables (body weight, age, years of training, skills, and martial arts) that significantly impact HGS and RT and classify athletes using linear regression analysis and classification trees.

Materials and Methods

Selection criteria

The authors of the study personally surveyed participants of various independent events such as instructor master courses and advanced training sessions held between 2018 and 2022 in Poland and Germany. Participants aged 18 years or older and with higher belt ranks were invited to participate in the survey. Moreover, athletes were inquired regarding putative surgical interventions within the last year, including upper limb interventions. Furthermore, it was verified whether athletes experienced muscle pain or overload injuries. Those who met the exclusion criteria were excluded from the analysis.

Surveyed and measured characteristics

The others had their body weight measured, handgrip strength (HGS) assessed, and declared their belt ranks, age, and years of training. A total of 166 male participants were tested across different styles (modern jiu-jitsu (groups from Poland and Germany), Shotokan karate, Kyokushin karate), skill levels (Kyu or Dan grades), with their age, body weight, years of training, reaction time, and HGS recorded (Table 1). The kyu and Dan ranks were incorporated into the analysis as they were suggested to be correlated with body mass, and HGS [62] Furthermore, studies have shown that HGS can differentiate between the skill levels of white-belt and black-belt judokas, making it a valuable tool in martial arts [2].

Table 1. Survey athletes' classification to respective martial arts

Classification	Athletes
	men
Participants	166
Jiu-jitsu (Poland)	24
Jiu-jitsu (Germany)	97
Kyokushin	29
Shotokan	16

Handgrip strength measurement

To measure handgrip strength, we conducted the HGS test using the KERN MAP 130K1 palm hand dynamometer. The test involves pressing down on the dynamometer with a firm grip, ensuring that the forearm extension line is parallel to the wrist, and keeping the test hand from touching the body. Hand strength is measured in kilograms, and we chose the measurement that yielded the best results for further assessment. We selected the appropriate grip size for each participant based on the size of their hands so that their distal finger joints could fit comfortably within the dynamometer. We instructed participants to maintain concentration and avoid swinging their hands during the test to ensure accurate results. The goal was to determine the athletes' maximum HGS strength [59].

Reaction time measurement

The participant sits astride a chair, facing the rest, where he or she places the forearm (resting it halfway down); four fingers are straightened and tightened, and the thumb is abducted. The tester holds a stick with a diameter and length of 50 cm, on which a centimeter scale is marked along its entire length. The lower end of the cane (0 cm) is at the level of the lower edge of the patient's hand, approximately 1 cm from his or her hand. The participant's task is to grasp the cane by clenching the hand. The distance from point 0 to the grip point (bottom edge) is measured. The study participants performed the procedure five times, and two extreme results were rejected. The arithmetic mean was calculated from the remaining trials. The present experiment followed the procedure developed by Ditrich [63].

Statistical methods

Descriptive characteristics (min, max, mean, standard deviation, variance, skewness and kurtosis), Pearson and Spearman correlation coefficients were conducted in XlStat v. 2020.5.1 software [64]. A regression tree using the C&RT method with a maximum depth of 9 and a complexity parameter (CP) of 0.0001 was accomplished in XlStat software v. 2020.5.1 [64]. Multiple linear regression analysis (stepwise) was performed in SPSS v. 28 [65].

Results

A total of 166 male athletes took part in a survey to measure their HGS and RT. The participants practiced jiu-jitsu (Poland and German groups), Kyokushin, and Shotokan (Table 1). However, the jiu-jitsu (Germany) group had the highest number of participants, making the representation unequal. The survey collected all the data (Table 2). The athletes' handgrip strength ranged from 20 to 106, with an average value of 82.2. RT ranged from 0 to 24 with a mean value of 12.67.

Moreover, their body weight varied from 49 to 125 kg while age and years of training ranged from 12 to 61 and 4 to 56, respectively. The athletes differed in their experience (1Kyu to 7 Dan) in four martial arts groups. As indicated by skewness and kurtosis, quantitative variables exhibited normal or close to normal distribution.

Table 2. Descriptive statistics of quantitative variables employed in analysis

	Min	Max	Mean	SD	Var	Skew	Kurt
HSD*	20	106	82.22	15.08	227.56	-1.04	1.73
Ditrich's rod	0	24	12.67	4.13	17.1	0.34	0.1
Body weight	49	125	80.71	13.16	173.13	0.46	1.53
Age	12	61	37.01	12.84	164.86	0	-0.99
Years of training	4	56	19.57	10.08	101.54	1.21	1.34
Skills (grade)	0.1	7	1.45				
Martial arts	1	4	2.31				

* HGS stands for handgrip strength; Ditrich's rod reflects reaction time, Body weight is the athletes' weight in kg; Age is the athletes' age in years; Years of training illustrates the number of years the athlete has practiced martial art; Skills is the grade the athletes achieved; Martial arts included jiu-jitsu (Poland, Germany) and karate (Kyokushin and Shotokan) styles; Min – minimum; max – maximum values. Mean is the mean value; S.D - Std. Deviation; Var – variance; Skew – skewness; Kurt – kurtosis.

After analyzing the correlations (Table 3), it was found that handgrip strength (HGS) had a strong correlation with HGS and athletes' age. Reaction time expressed by results of Ditrich's rod experiments was correlated with martial arts. Furthermore, body weight was correlated with athletes' age and years of training, years of training was correlated with age, and age and years of training were correlated with skills. Additionally, martial arts showed a significant correlation with reaction time measured by Ditrich's rod. Notably, there was no correlation between handgrip strength and reaction time.

Table 3. Pearson's correlation coefficients (Pearson's for quantitative and Spearman's nominal variables).

	HGS	Ditrich's rod	Body Weight	Athletes' age	Years of Training	Skills	Martial arts
HGS	1						
Ditrich's rod	0.085	1					
Body Weight	0.601**	-0.035	1				
Athletes' Age	0.185*	0.038	0.292**	1			
Years of Training	0.086	0.043	0.165*	0.757**	1		
Skills	-0.06	-0.071	0.081	0.579**	0.638**	1	
Martial arts	-0.063	0.414**	-0.073	0.060	0.082	-0.001	1.000

****.** Correlation significant at 0.01 (2-tailed).

***.** Correlation significant at 0.05 (2-tailed).

We used a hierarchical multiple regression analysis to see if adding factors such as athletes' body weight, age, years of training, skills, and martial arts they practice would improve the accuracy of predicting HGS compared to body weight alone (Table 4). A similar approach was undertaken in the case of RT (Table 5).

The results of the multiple linear regression analysis showed that only athletes' body weight was a significant predictor of HGS (Table 4). The model accounted for 61% of the variation in HGS ($F(1, 164) = 92.49$, p-value < 0.001, and $R^2 = 0.61$).

Table 4. Hierarchical multiple linear regression predicting HGS from athletes' body weight, and martial arts.

Handgrip strength			
Statistics	**B**	**p-value**	**β**
Constant	26.66	<0.01	
Body weight	0.688	<0.01	0.601
R^2(male)	0.61		
F	92.49		

Linear regression results showed that only martial arts was a significant predictor of RT ($F(1,164) = 33.464$, p-value < 0.001, $R^2 = 0.169$). Martial arts explained 6.9% of the reaction time variance (Table 5). Adding other variables (skills, years of training, age, and body weight) resulted in insignificant models (not shown).

According to the classification tree analysis, an athlete's body weight is the most critical factor in determining handgrip strength (HGS) (Figure 1, Table 6). The analysis showed that athletes with a body weight below 74.5kg (25.9%) were separated from those above that body weight (74.1%). Young athletes under 21.5 (8.4%) and older athletes over that age (17.5%) made up the first group. The latter group was then divided according to their skills. The group of athletes with a body weight above 74.5kg was then again divided by their body weight. The athletes with body weight less than 91 kg (56.6%) were then divided by their skills, with one group including 24.1% and the other 32.5% of athletes. The smaller subgroup was then separated by the years of training, whereas the bigger one had a body weight with an impact of years of training relating to the athletes with a body weight above 78.5 kg. The athletes classified in the group above 91 kg were divided into two groups with a breaking point at body mass equal to 98.

Table 5. Hierarchical multiple linear regression predicting RT from body weight and martial arts

Reaction time			
Statistics	**B**	**p-value**	**β**
Constant	8.431	<0.01	
Martial arts	1.842	<0.01	0.318
R^2(male)	0.169		
F	33.464		
Reaction time			

Table 6. Tree structure illustrating the improvement each node introduces to the classification explaining HGS

Nodes	Objects	%	Improve-ment	Split variable	Values	Parent node	Sons	Predicted values
Node 1	166	100	0.29				2; 3	82.22
Node 2	43	25.90	0.34	Weight	<= 74.5	1	4; 5	68.60
Node 3	123	74.10	0.16	Weight	> 74.5	1	6; 7	86.98
Node 4	14	8.43		Age	<= 21.5	2		53.36
Node 5	29	17.47	0.29	Age	> 21.5	2	10; 11	75.97
Node 6	94	56.63	0.18	Weight	<= 91	3	12; 13	84.71
Node 7	29	17.47	0.16	Weight	> 91	3	14; 15	94.34
Node 10	15	9.04		Skills	0.1; 0.2; 2; 4; 5;	5		68.33
Node 11	14	8.43		Skills	1; 3; 6; 7;	5		84.14
Node 12	40	24.10	0.11	Skills	0.1; 0.2; 2; 3; 4; 5; 7;	6	24; 25	79.95
Node 13	54	32.53	0.06	Skills	1; 6;	6	26; 27	88.24
Node 14	15	9.04		Weight	<= 98	7		91.33
Node 15	14	8.43		Weight	> 98	7		97.57
Node 24	19	11.45		Years_of_training	<= 23.5	12		82.79
Node 25	21	12.65		Years_of_training	> 23.5	12		77.38
Node 26	14	8.43		Weight	<= 78.5	13		84.29
Node 27	40	24.10	0.09	Weight	> 78.5	13	54; 55	89.62
Node 54	27	16.27		Years_of_training	<= 16.5	27		87.78
Node 55	13	7.83		Years_of_training	> 16.5	27		93.46

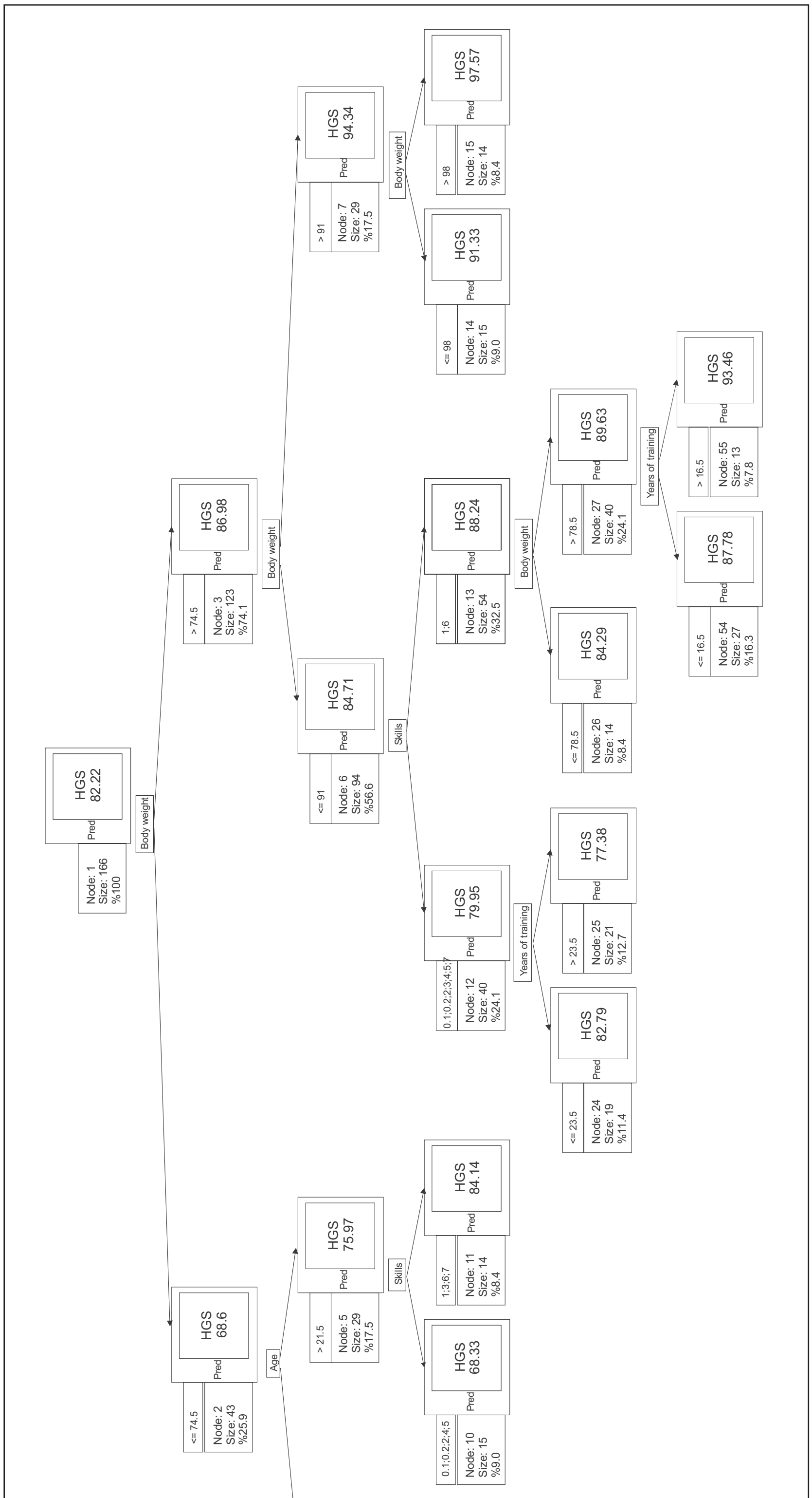

Figure 1. Regression Tree using the C&RT method illustrating how HGS is affected by other variables

According to the classification tree analysis, martial arts is the most crucial factor when determining their RT (Figure 2, Table 7). The analysis showed that all jiu-jitsu athletes were separated from those training karate. Then, the group of JJ athletes was divided according to their years of training. The larger group was further divided according to age, with a breaking point around 41.5 years.

Table 7. Tree structure illustrating the improvement each node introduces to the classification explaining RT

Nodes	Objects	%	Improvement	Split variable	Values	Parent node	Sons	Predicted values
Node 1	166	100	0.13				2; 3	12.67
Node 2	121	72.89	0.06	Martial arts	1; 2;	1	4; 5	11.74
Node 3	45	27.11		Martialarts	3; 4;	1		15.156
Node 4	38	22.89		Years_of_training	<= 14.5	2		12.97
Node 5	83	50.00	0.02	Years_of_training	> 14.5	2	10; 11	11.18
Node 10	43	25.90		Age	<= 41.5	5		10.72
Node 11	40	24.10		Age	> 41.5	5		11.67

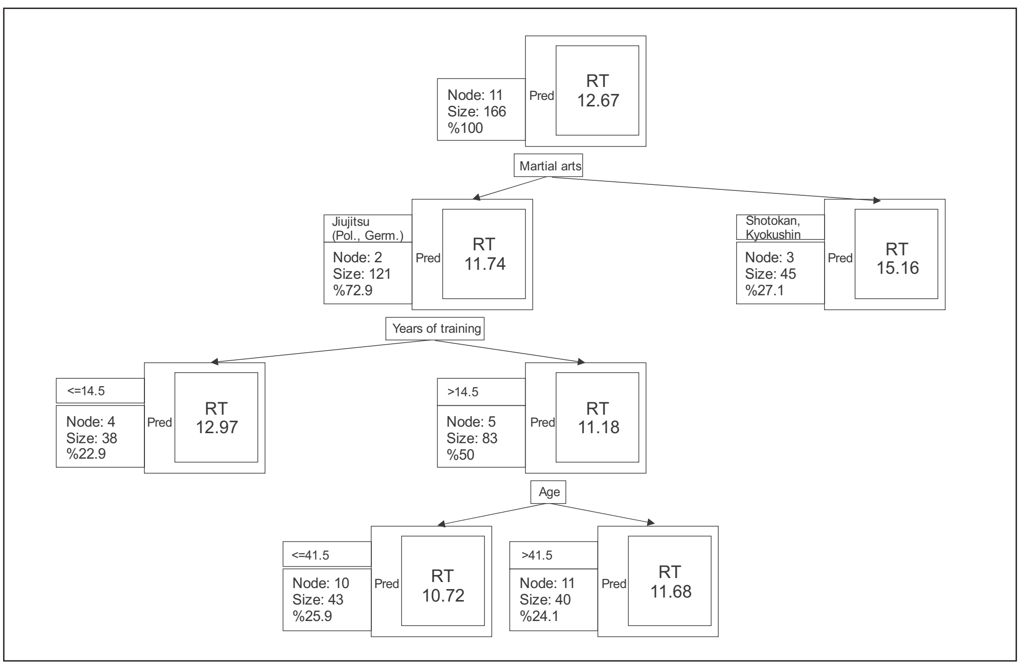

Figure 2. Regression Tree using the C&RT method illustrating how reaction time (RT) is affected by other variables.

Discussion

Handgrip strength is an important variable used in sports [9], including martial arts, to test athletes' fitness or evaluate their physical fitness. It is usually applied to persons practicing judo [18,66,67], MMA [12], karate [3,11,17,68,69], or BJJ [1,19,25,31,62,70,71]. However, HGS may only sometimes be a good choice [18]. HGS is linked to body mass and BMI [10-14]. Furthermore, it may discriminate between skilled and inexperienced judokas [2], men and women [23], and athletes' age [14]. However, more information is needed about the effect years of training have on HGS. Our findings indicate a correlation between HGS and body weight. Additionally, we observed a correlation between HGS and age. Thus, these variables may have an impact on HGS.

Current results based on linear regression analysis have demonstrated that athletes' body weight was the only predictor of HGS. The regression analysis has shown that increasing an athlete's body weight by one kilogram is expected to increase his or her HGS by 0.69.

The role of body weight was confirmed by classification regression analysis, with body weight being the primary factor responsible for athletes' classification based on HGS, which is in accordance with linear regression analysis. Furthermore, classification and regression tree analysis indicated that years of training, athletes' age, and skills may also affect HGS. Interestingly, both linear regression and classification trees failed to demonstrate that HGS might depend on martial arts. Thus, our results agree with data published earlier concerning the role of body weight in HGS but indicate that athletes' age, years of training, and athletes' skills might also impact HGS. The role of skills in HGS is consistent with the analysis of BJJ athletes [62].

Another characteristic used in sports and martial arts is reaction time [38,39,72]. RT solely influences sports performance in particular tasks [42]. Still, reaction time is crucial in combat sports, including some karate styles [43-45]. Despite coaches' belief, there is no agreement that reaction time predicts success in combat sports. Thus, the value of RT in other martial arts and the variables it depends on need to be evaluated. A study using correlation analysis found that RT is somewhat correlated with martial arts, indicating that martial arts may have a potential impact on RT.

Linear regression analysis showed that among all variables used in the study, only martial arts were significant. However, this can explain a minor part of the variance of RT (ca 17%), which suggests that additional variables not investigated by us are needed. The presented data are congruent with results indicating that RT is crucial in differentiating martial arts; however, RT is explained by martial arts only to a small extent, possibly making it quite inconvenient in some cases.

On the other hand, classification analysis confirmed that RT may differentiate between martial arts. Kyokushin and Shotokan were separated from the remaining arts in the current study. Interestingly, karate requires fast reaction time, unlike the other arts tested in the study, which rely on grappling. Possibly, RT should be used only in the case of such styles. The notion is confirmed by the fact that RT is useful in taekwondo [48-50].

The other outcome of the classification regression tree analysis is the importance of years of training and athletes' age in grouping athletes. The effect of age on RT is prominent and well-documented in taekwondo [47,53]. However, classification tree analysis indicated that years of training and athletes' age are the other factors used in classification. Therefore it is likely that with years of training and age, RT may progress, as indicated by previous studies [73].

A correlation analysis showed no correlation between HGS and RT. This lack of correlation can be explained by the hierarchical concept of essential motor characteristics, which group strength and reaction time as conditional but distinct abilities [6,74]. Therefore, HGS and RT should not be considered variables that directly interact with each other. Moreover, our results did not identify any relationships between RT and skills, in contrast to the analysis of BJJ athletes [62].

Study Limitations

A limitation of this study was the limited number of participants. Furthermore, an unequal representation of the athletes with different ranks was surveyed. Another limitation was that only four groups of athletes of modern jiu-jitsu and karate styles were surveyed.

Conclusions

Based on a combination of regression analysis and classification tree, it was found that athletes' body weight plays a significant role in determining handgrip strength, whereas martial arts impact reaction time. The linear regression analysis results are congruent with the classification regression tree where martial arts allowed the grouping of Shotokan and Kyokushin into one and jiu-jitsu practitioners into another group. Furthermore, the classification tree indicated that RT depends on martial arts, years of training, and age. Our results also demonstrated that in contrast to RT, HGS is somewhat linked to skills expressed by belt ranks and that HGS and RT follow the hierarchical concept of essential motor characteristics belonging to the same group of conditional abilities but being distinct.

Practical implications.

Athletes' body weight can be a good predictor of HGS in athletes trained in martial arts. On the other hand, martial arts explain a small fraction of reaction time, and, therefore, it is not clear whether martial arts can be a good predictor of reaction time. More studies involving distinct practitioners in varying martial arts are needed to solve this problem. However, the presented results determined some variables affecting HGS and RT, but specific relationships between each other still need to be evaluated before practical implications for trainers are provided.

Conflicts of Interest: The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

Funding: This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Ethics Committee of the Idokan Poland Association, Committee of Scientific Research (Opinion No. A2/2023).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

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Citation:
Bajkowski DS, Cynarski WJ: Testing factors influencing handgrip strength and reaction time to visual stimulus in selected martial arts. Journal of Kinesiology and Exercise Sciences. 2024; 105 (34): 46-59.