applied sciences

MDPI

Article

The Impact of Effective Mass on the Strength of Side and Turning Kick in Taekwon-Do Male Practitioners

Tomasz Góra [1], Dariusz Mosler [1,*], Robert Podstawski [2] and Jacek Wąsik [1,*]

[1] Institute of Physical Culture Sciences, Jan Dlugosz University in Częstochowa, 42-200 Częstochowa, Poland; t.gora@ujd.edu.pl
[2] Department of Physiotherapy, University of Warmia and Mazury in Olsztyn, 10-720 Olsztyn, Poland; podstawskirobert@gmail.com
* Correspondence: d.mosler@ujd.edu.pl (D.M.); j.wasik@ujd.edu.pl (J.W.)

Abstract: Background: One of the elements of improving the striking power of combat sports athletes is the ability to use their body mass in an efficient manner; this can improve movement technique and thus increase combat effectiveness. Therefore, the aim of this study was to gain knowledge about the influence of the effective mass obtained on the strength of turning and side kicks in the context of lateralization. Material and methods: The study involved four adult taekwon-do ITF (International Taekwon-do Federation) competitors. Acceleration and force data were obtained by mounting a wireless IMU sensor manufactured by Noraxon, which was synchronized with a force plate. Results: The median force pressure values amounted to 2661.53 N for the turning kick and 4596.15 N for the side kick, with foot acceleration of 150.56 m/s^2 and 74.34 m/s^2, respectively. The calculated median effective mass for the turning kick was 20.12%, and for the side kick, it was 73.09% of the total body mass. The conducted analysis indicates a lack of statistically significant differences between the right and left leg in the obtained kinetic variable values ($p > 0.05$). Conclusions: Our research suggests that the side kick achieves, on average, higher force values than the turning kick. The noted correlation between the three variables informs us that the greater the effective mass, the greater the force pressure and the smaller the foot acceleration, which is consistent with other studies. The lack of lateralization in the limbs performing the kicks is consistent with another study.

Keywords: turning kick; side kick; roundhouse kick; taekwon-do; effective mass; strength kicks

check for updates

Citation: Góra, T.; Mosler, D.; Podstawski, R.; Wąsik, J. The Impact of Effective Mass on the Strength of Side and Turning Kick in Taekwon-Do Male Practitioners. *Appl. Sci.* **2024**, *14*, 2339. https://doi.org/10.3390/app14062339

Academic Editor: Mark King

Received: 22 January 2024
Revised: 29 February 2024
Accepted: 7 March 2024
Published: 11 March 2024

1. Introduction

Strength is a fundamental element of many sports disciplines. It is a key factor influencing efficiency, the ability to generate power, and overall athletic performance. Its significance is noticeable in various sports contexts [1–4]. It depends on a number of factors, including distance, speed, and the involvement of the right body segments in the movement [1,2]. Determining the impact force for a uniformly shaped block of mass is a simple product of the mass and its acceleration [3]. In such a situation, the effective mass is simply equal to the mass of the whole body. However, the mass of a human being is not homogeneous. It consists of many moving segments, which include bones, muscles, tendons, ligaments, etc. Moreover, after an impact, they can deform, reducing the force of the impact [4]. Therefore, one of the elements of improving the striking power of combat sports athletes is their ability to use their body mass in an efficient manner; this can improve movement technique and thus increase combat effectiveness [5,6]. This mass is often referred to as "effective mass". In the case of boxing, judo, or taekwon-do, effective mass is a key element in combat. Boxers, for example, utilize their body mass by shifting weight from one leg to the other, which allows them to generate greater striking force [7]. In judo, effective mass is utilized for throws and incapacitating maneuvers. Understanding how to use the opponent's body mass and manipulate it is crucial in the techniques of throws [5]. In the case of kicks in taekwon-do, body mass is used to generate force in the kicks. By properly utilizing body mass and hip rotation, the force of a kick can be increased. It is suggested that the more body segments an athlete can engage in a movement, the greater the potential effective use of mass [8]. Interestingly, there is no linear correlation between effective mass and the total body mass of an athlete [9]. This suggests that well-trained and experienced martial arts competitors can achieve a higher effective mass through proper muscle contraction just before contact with the target [10]. Moreover, achieving the appropriate value of effective mass is crucial, as maximum speed or acceleration alone cannot guarantee high force values behind a strike [11]. From physics, we know that force is directly proportional to both mass and acceleration [12,13]. However, the maximum striking force in combat sports depends on many factors, including the distance, speed of the limb, and proper coordination of the kinematic chain during the strike [14–16].

Technological advancements have significantly influenced biomechanical studies in taekwon-do, particularly using load cells and force platforms, along with advanced motion measurement systems featuring accelerometer arrays. This technology has been critical in dissecting the dynamics of taekwon-do techniques, providing invaluable insights into the forces and movements involved [17]. The application of force platforms in taekwon-do biomechanics is essential for accurately measuring motion parameters and the forces exerted during various taekwon-do moves, enhancing our understanding of the mechanics behind these movements. This understanding is crucial for refining techniques and improving training methodologies. Accelerometers, or inertial measurement units (IMU), play a pivotal role in measuring accelerations and velocity changes, thereby offering a deeper analysis of taekwon-do's dynamic movements [18]. In biomechanical research on taekwon-do, combining force plates with motion analysis systems, such as stereophotogrammetric methods with cameras or IMU units, is common. Synchronizing these devices is key to minimizing measurement errors and accurately capturing all variables at specific moments in taekwon-do techniques [19].

The turning kick and side kick are among the most commonly used in the taekwon-do ITF (International Taekwon-do Federation, since we will be focusing on this martial art) [20]. The fundamental difference between these two techniques is the direction of the strike. In a turning kick, the foot moves in an arc along the body's axis, while in a side kick, the foot is moved sideways towards the opponent [21,22].

Determining the effective mass in these strikes is important for training practice and preparation for combat. Effective mass, a term often used interchangeably with "inertial mass," refers to the portion of an athlete's body mass that effectively contributes to the force of a strike. This mass is not a static measure, but is dynamically influenced by several biomechanical factors, including muscle stiffness, co-contraction, and the kinetic chain involved in the movement. A critical aspect of effective mass is its dependence on the biomechanical alignment and muscular activation at the moment of impact. When a fighter executes a strike, not all body mass contributes equally to the impact. The effective mass is predominantly determined by the mass of the body segments in motion and their velocity, but, significantly, it is also influenced by the stiffness of the muscles and joints involved [23]. Muscles that are actively contracted at the moment of impact can increase the effective mass of the striking limb, thereby enhancing the force delivered [8]. Furthermore, the concept of joint stiffness is integral to understanding effective mass. Increased joint stiffness through muscle co-contraction can lead to a higher transfer of force. This biomechanical strategy is often observed in skilled fighters, who can adeptly modulate their joint stiffness to maximize the impact force. It is not only about the mass, but about how effectively this mass is used in the context of a combat sport movement. The kinetic chain, which refers to the sequence of movements in different body parts leading up to a strike, also plays a critical role in the effective mass. Efficient kinetic chain sequencing can augment the effective mass involved in a strike. For instance, a punch that properly harnesses the sequential movement from the legs through the torso to the arm and fist can deliver a more potent force than a punch that relies solely on the arm's movement.

The dynamics equations used to determine effective mass in combat sports [9,23,24] are based on simple models of the principle of conservation of momentum. Measurements of effective mass and estimates calculated from regression equations [25] confirm that the studied athletes presented higher effective masses than their estimated hand masses, confirming what has been suggested by other researchers [16]. Moreover, with such a measurement, effective mass can vary depending on the mass of the object being struck. Investigating momentum transfer in combat sports uncovers critical biomechanical dynamics crucial for athletes' performance and safety. Lenetsky et al. [26] tackled the less studied concept of effective mass in punch dynamics, showing that existing theoretical models do not fully account for the complexities of real-world impacts. This gap highlights the need for more nuanced research to improve training and reduce injuries. Therefore, we decided to determine the effective mass differently than before, relying on the classical relationship of Newton's second principle of dynamics:

$$\text{Effective mass} = \frac{\text{Force pressure}}{\text{Foot acceleration}}$$

The appropriately chosen effective mass in taekwon-do is an extremely important element of training, affecting the effectiveness of kicks. However, it requires an understanding of the biomechanics of movement and the recognition of the impact of various variables. Therefore, the aim of these studies was to gain knowledge about the influence of the obtained effective mass on the strength of the turning and side kick in the context of lateralization. In this regard, the following research questions were posed: What is the effective mass in the side and turning kicks, and which of these kicks achieve higher values of this variable? Can we observe the phenomenon of lateralization, and how does the correlation between effective mass, kick force, and foot acceleration shape up?

Answers to these questions can help coaches and competitors in optimizing training and their potential to increase the effectiveness of kicks in practice. This could contribute to the application of the unused technical potential of competitors.

2. Materials and Methods

2.1. Participants

Four male taekwon-do ITF (International Taekwon-do Federation) trainees (age: 28.5 ± 6.5 years; body mass: 77.5 ± 6.1 kg; height: 180.0 ±1.4 cm) participated in this study. The conditions for inclusion in the study group were being male, 18 years old or older, holding a 1st Dan (black belt) or higher, and active participation in sports competition at the national level for at least 4 years.

2.2. Equipment

To assess the impact force, a force plate was used as the target. It was padded with a training shield to protect the participants from hitting the force plate directly and mounted onto a stable structure (AMTI, model MC12-2K, 2000 series, Watertown, MA, USA). The force plate dimensions were 305 mm × 406 mm × 79 mm. The force plate was synchronized in time and space to Noraxon (MR 3.18, Scotssdale, AZ, United States). Acceleration data were obtained by mounting a wireless IMU sensor, Ultium, manufactured by Noraxon, which was synchronized with the force plate. The sampling rate of the IMU sensors was 2000 Hz. The sensors were equipped with acceleration-only attachments, allowing for measurements up to 4000 g. The sensor was attached to a side of the foot, near the lateral malleolus.

2.3. Protocol

Data were collected at the Center for Human Movement Analysis, Jan Dlugosz University of Humanities and Sciences, Częstochowa [27]. Participants performed a self-selected

10 min warm-up. After the warm-up, participants performed side kicks (yop chagi) to the target five times with their right leg, starting in sport stance. In taekwon-do, the turning kick is described as focusing on the kinetic and kinematic aspects. Kinematically, it involves a rapid rotation of the body around the vertical axis, initiated by hip rotation and followed by a sequential movement of the body segments, leading to the extension of the leg towards the target. The kicking leg's motion includes flexion at the knee followed by a rapid extension. Kinetically, this kick generates significant angular momentum and force. The force is transferred from the ground through the supporting leg, while the hip, knee, and ankle joints of the kicking leg contribute to the speed and power of the kick [28].

After a one-minute rest, the participants performed a turning kick (dollyo chagi) five times from sport stance to the target with their right leg. In biomechanics, the "yop chagi" or side kick in taekwon-do is a complex movement involving several key biomechanical principles. It starts with the practitioner rotating their body and lifting the knee of the kicking leg towards the target, aligning the hip. The kick is executed by rapidly extending the leg, with the foot ideally making contact using the heel or the blade of the foot. This motion primarily involves the muscles of the hip, thigh, and lower leg. Kinematically, it is about the coordination and alignment of body segments to maximize force and reach. Kinetically, it involves generating force through the leg muscles, transferring it through the body to the target [29].

Then, the same procedure was repeated for the left leg for all participants. Participants were asked to kick with maximum effort to achieve the highest impact force they could, with no time constraints to execute the kicks (Figure 1).

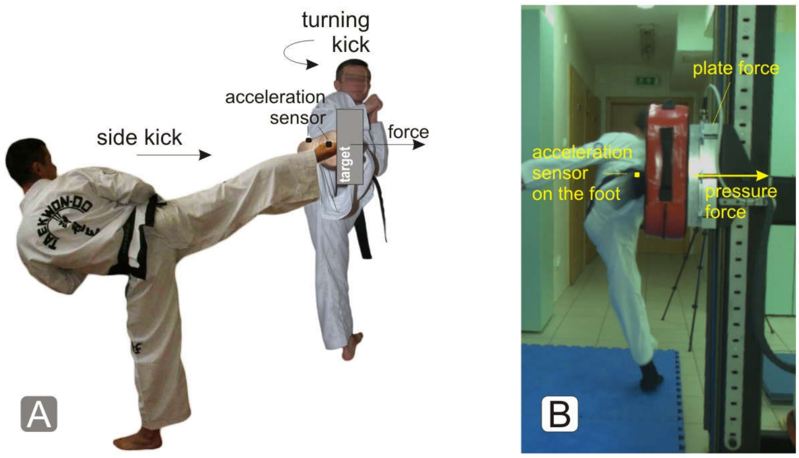

Figure 1. Visualization of kick and overall setup environment, including force plate covered with training shield and acceleration sensor attached to the foot: (**A**) positioning of the athlete according to the type of kick to the target of the strike; and (**B**) the setup of the force plate, padded with a training shield and mounted to a stable vertical structure, with the participant performing a turning kick.

Data acquisition entailed recording five strikes for each technique per participant. Initially, the data were exported from the measurement software (Noraxon MR 3.18 with Myomotion module) into the Excel (Microsoft 365 version, WA, United States) *.slk format and subsequently converted to the *.xlsx format for enhanced processing. The maximum force was ascertained using a Python (version 3.12) script, utilizing the scipy library and the findpeaks function to identify the peak force values. The script was launched through Jupyter Lab (version 4.0.11) and executed for each Excel file separately. After collecting the data, i.e., the values of maximum force pressure on the platform and changes in foot acceleration, they were exported to Excel (Microsoft Office Professional Plus 2010) for organization according to the type of kick and the left or right leg. In this way, data for 80 measurement positions (4 people $\times$ 5 trials $\times$ 2 types of kicks $\times$ 2 legs) were collected.

The code was composed of uploading data with pandas, converting raw data from milligs to m/s^2, and peak detection. As data were collected for five strikes per file, the code detected events (strikes) around the maximum value of force for a specific strike, then detected the values of acceleration of each marker at the time value of maximum force. Code is provided in the github repository (https://github.com/Dareczin/tkd_force_acceleration_detection).

2.4. Statistical Analysis

After analyzing the data, they were exported to Statistica 13 software (TIBCO software, Santa Clara, CA, United States). Due to the lack of normal distribution of the data, as verified by the Shapiro–Wilk test, further analyses of differences between groups were conducted using the Mann–Whitney U test. Descriptive statistics were based on the median and the upper and lower quartiles, and additionally, the mean and standard deviation were given. Statistical significance was set at a level of $p < 0.05$. The sample size, estimated using G*Power software (version 3.1.9.2; Kiel University, Kiel, Germany) [30], returned a minimum of 70 measurement positions for $\alpha = 0.05$, effect size f = 0.9, and $\beta = 0.95$.

3. Results

In Table 1, the registered force pressure and foot acceleration, as well as the calculated values of effective mass in kg and % of total mass, are compiled according to the type of kick and whether the right or left leg was used. The median force pressure values amounted to 2661.53 N for the turning kick and 4596.15 N for the side kick, with foot acceleration of 150.56 m/s^2 and 74.34 m/s^2, respectively. The calculated median effective mass for the turning kick was 20.12%, and for the side kick, it was 73.09% of the total body mass. The conducted analysis indicated a lack of statistically significant differences between the right and left leg in the obtained kinetic variable values ($p > 0.05$). Figure 2 presents the medians of force pressure (side kick: F = 4596.15 N and turning kick: F= 2661.53 N; Z = −5.25; $p < 0.001$) and the calculated values of the competitors' effective mass for the turning kick at 14.69 kg (20.12%) and for the side kick at 54.56 kg (73%) (Z = −7.43; $p < 0.001$). Table 2 includes a summary of the Spearman correlation coefficients of the analyzed variables. It shows that the side kick positively correlated with effective mass (r = 0.84; $p < 0.05$) and force pressure (r = 0.59; $p < 0.05$), while the turning kick negatively correlated with foot acceleration (r = −0.84; $p < 0.05$). Furthermore, the greater the effective mass, the greater the force pressure (r = −0.74; $p < 0.05$) and the smaller the foot acceleration (r = −0.87; $p < 0.05$).

Table 1. Average values of selected kinetic indicators during the execution of turning kicks and side kicks with the left and right leg.

Kick Type	Indicator	Leg	Mean	SD	Median	Lower Quartile	Upper Quartile	Z	p
Turning kick	Force pressure [N]	Right	2820.28	596.21	2793.905	2432.915	3078.750	1.296	0.194
		Left	2475.59	623.09	2602.770	2353.070	2733.020		
		Total	2636.93	628.54	2661.535	2413.320	2913.720	-	
	Foot acceleration [m/s^2]	Right	170.38	45.23	150.064	137.946	201.576	0.214	0.830
		Left	180.96	62.40	152.966	120.845	225.101		
		Total	176.01	54.72	150.566	127.860	217.252	-	
	Effective mass [kg]	Right	17.59	6.14	16.324	13.459	18.923	1.120	0.262
		Left	15.46	6.79	13.237	11.816	20.911		
		Total	16.46	6.51	14.696	12.404	19.054	-	
	Effective mass [%]	Right	22.80	8.76	20.832	16.560	25.390	0.843	0.398
		Left	20.17	10.01	16.518	14.020	29.044		
		Total	21.40	9.43	20.126	14.562	25.749	-	

Table 1. *Cont.*

Kick Type	Indicator	Leg	Mean	SD	Median	Lower Quartile	Upper Quartile	Z	*p*
Side kick	Force pressure [N]	Right	4551.55	1363.99	4321.310	3449.290	5820.810	0.131	0.895
		Left	4319.84	1390.00	4828.220	3213.875	5525.125		
		Total	4438.52	1364.45	4596.155	3449.290	5562.930	-	
	Foot acceleration [$m/s^{2.5}$]	Right	68.93	24.69	79.489	54.156	89.214	0.307	0.758
		Left	72.58	20.54	71.934	50.911	89.311		
		Total	70.71	22.55	74.337	53.163	89.214	-	
	Effective mass [kg]	Right	77.72	46.75	52.473	45.851	80.360	−0.014	0.988
		Left	60.66	18.43	54.561	45.762	75.318		
		Total	69.40	36.45	54.561	45.851	76.906	-	
	Effective mass [%]	Right	101.96	67.22	66.538	52.736	103.292	−0.540	0.588
		Left	78.89	22.52	74.752	61.841	93.164		
		Total	90.71	51.34	73.097	56.088	94.765	-	

Statistical significance: $p < 0.05$.

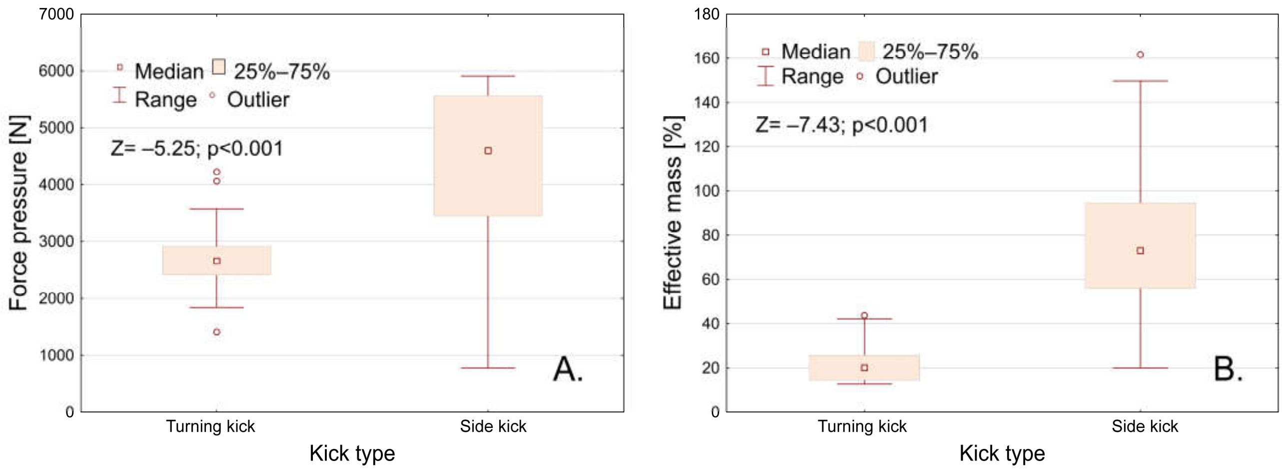

Figure 2. Force pressure (**A**) and effective mass (**B**) for turning kick and side kick.

Table 2. Spearman correlation matrix.

Indicator	Leg	Force Pressure	Foot Acceleration	Effective Mass	Body Mass
Kick type	0.00	0.59 *	−0.84 *	0.84 *	0.01
Leg		−0.11	−0.03	−0.04	−0.12
Force pressure			−0.37 *	0.74 *	0.15
Foot acceleration				−0.87 *	0.22 *
Effective mass					−0.13

* Statistical significance: $p < 0.05$.

4. Discussion

From the conducted analyses, it emerged that the average force of the side kick was 4596 N, significantly greater than the turning kick's force of 2661 N. Other studies have suggested that the turning kick achieves a force ranging from 1800 N [31] to 6400 N [32]. Unfortunately, there are not many studies recording the force of kicks in taekwon-do. In the review of Vagner et al. [33], the reported values of roundhouse kicks were much lower, ranging from 1200–1800 N. A study by Thibordeeand and Prasartwuth [34] had even lower values of up to 200 N. A study of side kicks by Lee et al. [35] also obtained lower values of around 1300 N. Differences in the study designs can be attributed to various factors, such as the chosen targets, their size, the distance of participants from these targets, and the height of the targets. These elements must be considered when comparing force values across different studies. The challenges in reproducing these studies arise from the variability in technique execution; the non-standardization of distances; and the heterogeneous nature of the equipment, like shields or dummies, in some of the mentioned studies. As the study of this subject is more or less 15 years old with the current setup capabilities, our study used a fixed column that did not move. This might be a reason why we obtained higher values of force compared to other studies, considering the lack of force loss upon impact.

These factors contribute to the difficulty of establishing a single, objective indicator of total force values as a reliable predictor of performance across different assessment facilities. However, these very settings, which complicate direct force measurement, might also be seen as variables influencing the acceleration and velocity of a kick, with the target acting as a dependent variable. In this context, the concept of "effective mass" could provide a viable approach to determining a benchmark for assessing the effectiveness of a kick. By focusing on the kinetic aspects of the movement, such as the speed and momentum of the kick in relation to the target, a more consistent and objective measure of performance could be established, potentially offering a more accurate representation of an athlete's skill and effectiveness.

The estimated effective mass of the competitors for the side kick was 73%, and for the turning kick, 20% of the total body mass of the competitors. However, this requires confirmation. Our measurements indicate that the analyzed kicks positively correlate with effective mass and force pressure. This is consistent with current knowledge and the available scientific literature on sports and taekwon-do, where a relationship has been found in the ability of athletes to increase striking force as a result of increasing body mass [36–38]. However, it has been noted that beginner competitors mainly use their body mass to generate large striking forces, overestimating its significance [15]. This suggests that the level of athlete advancement may influence the ability to balance the center of gravity and the specific movement technique to achieve greater striking force. Consequently, perhaps the technical skills of competitors could be recognized based on the relationship between kick force and effective mass. Additionally, it has been noted that the starting position and body alignment relative to the target also influence the force of the kick [39], which was not considered in our measurements. In considering the differences between linear and circular motion in martial arts, the distinction between the turning kick and the side kick is crucial. The turning kick involves a whip-like motion with body rotation around the supporting leg, generating force through the rotational action of the core muscles and the kicking leg. For effective force transfer in the sagittal plane of the opponent, a martial artist typically approaches at an angle ranging from 45 to 90 degrees, which affects the possibility of transferring body mass effectively. Conversely, the side kick is characterized by its linear motion and direct approach toward the target, allowing for a more straightforward transfer of body mass towards the opponent or target. However, the choice of technique is not solely determined by force. Technical and tactical considerations, such as the duration of the kick, its executability under specific combat conditions, and the duration of contact with the target, also play significant roles in deciding which technique to employ next. From a utilitarian perspective, this study suggests that the side kick tends to be stronger, utilizing a higher percentage of body mass, and thus requires a lower level of skill for effective execution. This makes it a recommended technique in emergency situations, like breaking through doors or barriers for escape, due to its straightforward application and potent force transfer.

Generally, our studies show a correlation between three variables, informing us that a greater effective mass results in greater force pressure and lower foot acceleration. No significant differences were noted between the right and left leg in the average values of force, acceleration, or effective mass while performing both turning kicks and side kicks. Perhaps the effect of lateralization will reveal itself with a larger research group. However, this is consistent with studies showing that, among ITF taekwon-do competitors, no significant differences can be observed between maximum speed and movement time during the execution of selected kicks with the right or left leg [40].

It was registered that the foot acceleration was greater for the turning kick. This correlation was also demonstrated by the calculated correlation coefficients. Therefore, it can be assumed that the studied kicks have different kinetic specifics. The side kick is slower to execute, but achieves greater striking force as opposed to the turning kick [41,42]. Studies show that in combat sports, competitors most often use the turning kick in fights [20,43]. This indicates that high striking force alone is not the only determinant of effectiveness in combat. However, in a situation where one does not need to worry about the opponent's reaction and the value of generated force is the main priority, utilizing the side kick may be a better solution.

Certainly, a limitation of the results is the small size of the study group. Despite these limitations, it is undeniable that this study expands the knowledge about the biomechanical dependencies of executing kicks in martial arts, and fills the gaps concerning research on effective mass in taekwon-do. Of course, in the pursuit of perfection, further research is necessary to determine the value of the effective mass of different strikes and, more precisely, its impact on taekwon-do competitors in real combat, which will help us to understand how variables influence moments of high performance. It represents a certain segment of the issue; the results and considerations presented here can serve as a reference point for other researchers and may pave the way for further exploration.

5. Conclusions

This study has uncovered significant insights into the biomechanics of taekwon-do kicks, particularly focusing on the side (dollyo chagi) and turning (yop chagi) kicks. Our key findings include that the median force pressure values for the turning kick and side kick are 2661.53 N and 4596.15 N, respectively, with foot acceleration at 150.56 m/s^2 for the turning kick and 74.34 m/s^2 for the side kick. The calculated median effective mass was 20.12% of the total body mass for the turning kick and 73.09% for the side kick. These results demonstrate a substantial difference in the force generated between the two kicks, highlighting the impact of effective mass and acceleration on kicking force.

The practical implications of these results for taekwon-do athletes and coaches are substantial. They suggest that training regimes could be optimized by focusing on techniques that enhance effective mass and acceleration to maximize the force of kicks. This could lead to more effective strategies in both training and competition.

In conclusion, this research significantly contributes to the understanding of physical dynamics in martial arts, offering valuable insights for both theoretical knowledge and practical application in sports science and martial arts training.

Author Contributions: Conceptualization, T.G., D.M. and J.W.; methodology, T.G., D.M. and J.W.; validation, T.G., D.M. and J.W.; formal analysis, T.G., D.M. and J.W.; investigation, T.G., D.M. and J.W.; data curation, T.G. and D.M.; writing—original draft preparation, T.G., D.M. and J.W.; writing—review and editing, T.G., D.M., R.P. and J.W.; supervision, J.W.; project administration, J.W.; funding acquisition, J.W. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: The Human Subjects Research Committee of the Jan Dlugosz University scrutinized and approved the test protocol as meeting the criteria of Ethical Conduct for Research Involving Humans (KE-O/4/2022). All participants in the study were injury-free, informed of the testing procedures, and voluntarily participated in the data collection. Study complied with the requirements of the Declaration of Helsinki.

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 upon request and after appropriate IRB approvals. The data are not publicly available due to privacy.

Acknowledgments: We would like to thank all the subjects of the study who donated their time and expertise.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Serrano-Huete, V.; Latorre-Román, P.A.; García-Pinillos, F.; Morcillo-Losa, J.A.; Jiménez-Reyes, P.; Párraga-Montilla, J.A. The variability of strength production capacities during a judo contest. *Phys. Act. Rev.* **2023**, *11*, 1–10. [CrossRef]
2. Matusiński, A.; Gołaś, A.; Zając, A.; Nitychoruk, M.; Maszczyk, A. Optimizing the load for peak power and peak velocity development during resisted sprinting. *Phys. Act. Rev.* **2021**, *9*, 128–134. [CrossRef]
3. Zemkova, E. Reliability of a novel method assessing muscle power and velocity during seated trunk rotations. *Phys. Act. Rev.* **2019**, *7*, 1–8. [CrossRef]
4. Wąsik, J.; Ferreira da Silva Santos, J.; Franchini, E. Movement structure and kinetics of the traditional straight punch: Measurements in taekwon-do athletes. *Ido Mov. Cult.* **2013**, *13*, 42–47. [CrossRef]
5. Párraga Montilla, J.A.; Latorre Román, P.Á.; Serrano Huete, V.; Cabrera Linares, J.C.; Lozano Aguilera, E.D.; Jiménez Reyes, P. Differences in the Force-Velocity profile between Judoist and freestyle wrestlers. *Phys. Act. Rev.* **2022**, *10*, 141–149. [CrossRef]
6. Wąsik, J.; Mosler, D.; Góra, T.; Scurek, R. Conception of effective mass and effect of force—Measurement of taekwon-do master. *Phys. Act. Rev.* **2023**, *11*, 11–16. [CrossRef]
7. Gu, Y.; Popik, S.; Dobrovolskiy, S. Hand punch movement kinematics of boxers with different qualification levels. *Int. J. Biomed. Eng. Technol.* **2018**, *28*, 366–376. [CrossRef]
8. McGill, S.M.; Chaimberg, J.D.; Frost, D.M.; Fenwick, C.M.J. Evidence of a Double Peak in Muscle Activation to Enhance Strike Speed and Force: An Example with Elite Mixed Martial Arts Fighters. *J. Strength Cond. Res.* **2010**, *24*, 348–357. [CrossRef]
9. Walilko, T.J.; Viano, D.C.; Bir, C.A. Biomechanics of the head for Olympic boxer punches to the face. *Br. J. Sports Med.* **2005**, *39*, 710–719. [CrossRef]
10. Blum, H. Physics and the art of kicking and punching. *Am. J. Phys.* **1977**, *45*, 61–64. [CrossRef]
11. Bartlett, R. *Introduction to Sports Biomechanics. Analysing Human Movement Patterns*, 2nd ed.; Routledge: New York, NY, USA, 2007; ISBN 9780415632423.
12. Kalestyński, A.; Widomski, L.; Herman, A. *Podstawy Fizyki dla Kandydatów na Wyższe Uczelnie i Studentów*; PWN: Warszawa, Poland, 2017.
13. Hay, J. *The Biomechanics of Sports Techniques*, 4th ed.; Benjamin Cummings: Spencer, WV, USA, 1993; ISBN 0130845345.
14. Walker, J.D. Karate Strikes. *Am. J. Phys.* **1975**, *43*, 845–849. [CrossRef]
15. Falco, C.; Alvarez, O.; Castillo, I.; Estevan, I.; Martos, J.; Mugarra, F.; Iradi, A. Influence of the distance in a roundhouse kick's execution time and impact force in Taekwondo. *J. Biomech.* **2009**, *42*, 242–248. [CrossRef]
16. Smith, P.K.; Hamill, J. The effect of punching glove type and skill level on momentum transfer. *J. Hum. Mov. Stud.* **1986**, *12*, 153–161.
17. Edriss, S.; Romagnoli, C.; Caprioli, L.; Zanela, A.; Panichi, E.; Campoli, F.; Padua, E.; Annino, G.; Bonaiuto, V. The Role of Emergent Technologies in the Dynamic and Kinematic Assessment of Human Movement in Sport and Clinical Applications. *Appl. Sci.* **2024**, *14*, 1012. [CrossRef]
18. Worsey, M.; Espinosa, H.; Shepherd, J.; Thiel, D. Inertial Sensors for Performance Analysis in Combat Sports: A Systematic Review. *Sports* **2019**, *7*, 28. [CrossRef] [PubMed]
19. Rana, M.; Mittal, V. Wearable Sensors for Real-Time Kinematics Analysis in Sports: A Review. *IEEE Sens. J.* **2021**, *21*, 1187–1207. [CrossRef]
20. Bujak, Z. *Wybrane Aspekty Treningu Taekwon-do*; AWF: Warszawa, Poland; ZWWF Biała Podlaska, Poland, 2004; ISBN 83-909395-9-2.
21. Moreira, P.V.S.; Falco, C.; Menegaldo, L.L.; Goethel, M.F.; de Paula, L.V.; Gonçalves, M. Are isokinetic leg torques and kick velocity reliable predictors of competitive level in taekwondo athletes? *PLoS ONE* **2021**, *16*, e0235582. [CrossRef] [PubMed]
22. Choi, H.H. *Taekwon-Do: The Korean Art of Self-Defence*; International Taekwon-do Federation: Auckland, New Zealand, 1995; Volume 15.
23. Neto, O.P.; Silva, J.H.; Marzullo, A.C.d.M.; Bolander, R.P.; Bir, C.A. The effect of hand dominance on martial arts strikes. *Hum. Mov. Sci.* **2012**, *31*, 824–833. [CrossRef] [PubMed]
24. Neto, O.P.; Magini, M.; Saba, M.M.F. The Role of Effective Mass and Hand Speed in the Performance of Kung Fu Athletes Compared with Nonpractitioners. *J. Appl. Biomech.* **2007**, *23*, 139–148. [CrossRef] [PubMed]
25. Zatsiorsky, V.; Seluyanov, V. The mass and inertia characteristics of the main segments of the human body. In *Champaign*; Matsui, H., Kobayshi, K., Eds.; Human Kinetics Publishers: Champaign, IL, USA, 1983.
26. Lenetsky, S.; Nates, R.J.; Brughelli, M.; Harris, N.K. Is effective mass in combat sports punching above its weight? *Hum. Mov. Sci.* **2015**, *40*, 89–97. [CrossRef]
27. Wąsik, J.; Ortenburger, D.; Góra, T.; Mosler, D. The influence of effective distance on the impact of a punch—Preliminary Analysis. *Phys. Act. Rev.* **2018**, *6*, 81–86. [CrossRef]

28. Kim, Y.K.; Kim, Y.H.; Im, S.J. Inter-joint coordination in producing kicking velocity of Taekwondo kicks. *J. Sport. Sci. Med.* **2011**, *10*, 31–38.
29. Glevesanu, A. Taekwondo Foot Techniques Found in Tae Bo Programs. In *Bulletin of the Transilvania University of Brasov, Series IX: Sciences of Human Kinetics*; Transilvania University Press: Lexington, KY, USA, 2023; pp. 35–40. [CrossRef]
30. Faul, F.; Erdfelder, E.; Lang, A.-G.; Buchner, A. G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behav. Res. Methods* **2007**, *39*, 175–191. [CrossRef]
31. Estevan, I.; Álvarez, O.; Falco, C.; Molina-García, J.; Castillo, I. Impact force and time analysis influenced by execution distance in a roundhouse kick to the head in Taekwondo. *J. Strength Cond. Res.* **2011**, *25*, 2851–2856. [CrossRef] [PubMed]
32. O'Sullivan, D.; Chung, C.; Lee, K.; Kim, E.; Kang, S.; Kim, T.; Shin, I. Measurement and comparison of taekwondo and yongmudo turning kick impact force for two target heights. *J. Sports Sci. Med.* **2009**, *8*, 13–16. [PubMed]
33. Vagner, M.; Cleather, D.J.; Olah, V.; Vacek, J.; Stastny, P. A Systematic Review of Dynamic Forces and Kinematic Indicators of Front and Roundhouse Kicks across Varied Conditions and Participant Experience. *Sports* **2023**, *11*, 141. [CrossRef] [PubMed]
34. Thibordeeand, S.; Prasartwuth, O. Factors Influencing the Impact Force of the Taekwondo Roundhouse Kick. *Chiang Mai Univ. J. Nat. Sci.* **2014**, *13*, 51–56. [CrossRef]
35. Lee, J.-H.; Lee, Y.-S.; Han, K.-H. A study on impact analysis of side kick in taekwondo. *Int. J. Mod. Phys. B* **2008**, *22*, 1760–1765. [CrossRef]
36. Bober, T.; Zawadzki, J. *Biomechanika Układu Ruchu Człowieka*; BK: Wrocław, Poland, 2001.
37. Pieter, F.; Pieter, W. Speed and force in selected taekwondo techniques. *Biol. Sport* **1995**, *12*, 257–266.
38. Pędzich, W.; Mastalerz, A.; Urbanik, C. The comparision of the dynamics of selected leg strokes in taekwondo WTF. *Acta Bioeng. Biomech.* **2006**, *8*, 83–90.
39. Estevan, I.; Jandacka, D.; Falco, C. Effect of stance position on kick performance in taekwondo. *J. Sports Sci.* **2013**, *31*, 1815–1822. [CrossRef]
40. Wąsik, J.; Mosler, D.; Góra, T.; Ortenburger, D.; Chalimoniuk, M.; Langfort, J. Kinematic Differences between Traditional and Sport Version of Roundhouse Kick Executed by Male Taekwon-do Masters. *J. Mens. Health* **2022**, *18*, 138. [CrossRef]
41. Jakubiak, N.; Saunders, D.H. The Feasibility and Efficacy of Elastic Resistance Training for Improving the Velocity of the Olympic Taekwondo Turning Kick. *J. Strength Cond. Res.* **2008**, *22*, 1194–1197. [CrossRef] [PubMed]
42. Wąsik, J. Kinematics and Kinetics of Taekwon-do Side Kick. *J. Hum. Kinet.* **2011**, *30*, 13–20. [CrossRef] [PubMed]
43. Pyciarz, T. Analysis of sport fight structure in taekwondo during the Olympics in Beijing in 2008 and Senior World Championships in 2009 in terms of technical skills after regulation amendments and implementation of the electronic system of score recording. *J. Combat Sports Martial Arts* **2011**, *2*, 109–115. [CrossRef]