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Original paper

Kinematic analysis of the side kick in Taekwon-do

JACEK WĄSIK*

Jan Długosz University, Częstochowa, Poland.

The aim of the paper is to present the analysis of the influence of chosen kinetic factors on the side-kick technique. This issue is of a significant importance in the traditional version of Taekwon-do, where a single strike may reveal the winner. A male athlete, a black-belt holder, has participated in this case study. Generally accepted criteria of sports technique biomechanical analysis were adhered to. The athlete executed a side kick four times (in Taekwon-do terminology referred to as *yop chagi*) in a way most typical of his usual kick execution in board breaking. The parameter values obtained were used to determine the individual curves of the changes in velocities in the function of relative extension length of the kicking leg. The maximum knee and foot velocities in the Cartesian coordinate system were determined. The leg lifting time and the total time of kick execution as well as the maximum force which the foot exerted on the ground were also determined. On the basis of the values obtained the average values and the standard deviation were calculated. The correlation dependence (r = 0.97) shows that a higher knee velocity significantly affects the velocity which the foot develops and that the total time of kick execution depends on the velocity which the knee develops in the leg lifting phase (r = 0.75). The average maximum speed was obtained at the length of the leg equal to 82% of the maximum length of the fully extended leg. In the kicking technique used by the athlete, this length can be considered for this athlete the optimum value for achieving the maximum strike dynamics.

Key words: *Taekwon-do, movement analysis, kinetics of strikes, effectiveness of kick, biomechanical determinants*

1. Introduction

The ability to break bricks with bare hands used to be associated with supernatural abilities and predispositions that can be developed in Eastern martial arts. The first attempts made at delivering a biomechanical description of the techniques performed in the martial arts can be found in the studies conducted by researchers in the 1970s and 1980s [1], [2].

The studies described kinematic aspect of punches and kicks and analysed the process of breaking hard objects with bare hands. The stroboscopic method was used to register movements whose analyses facilitated determining velocities, accelerations and strike execution times. The studies [3]–[5] attempted to describe the dynamic theory of strikes and a more detailed registration of kinematics of strikes. Among others, the maximum velocities of a side kick executed by a high-class karate athlete were determined, that ranged from 9.9 to 14.14 m/s [3].

At present sports competition has been introduced in most of the Far East martial arts. Some of these sports competitions have been included in the programme of the Olympic Games, for example, judo and Taekwon-do. This resulted in the modification of the aims which that martial arts had set, i.e., changes in practice methods, and necessitated the adjustment of the training process and its different syllabi to sport competition requirements [6].

The analysis of sports technique in accordance with the principles of biomechanics is a basis for technique-oriented training process, which is supposed to result in raising athletes' level of sports advancement. This problem is of a great importance in Taekwon-do, where a single strike might reveal the winner. In the Olympic Games, Taekwon-do has been limited to combat sports in four weight classes,

* Corresponding author: Jacek Wąsik, Institute of Physical Education, Jan Długosz University, Armii Krajowej 13/15, 42-200 Częstochowa, Poland. Tel.: +48 34 365 59 83, fax: +48 34 365 59 83, e-mail: jwasik@konto.pl

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whereas the traditional version of Taekwon-do (International Taekwon-do Federation) comprises four competitive events' tasks, i.e., sparring, patterns, power tests and special techniques [7], [8].

In a power test, the athlete's goal is to break a declared number of boards using five different techniques, i.e., three kicking techniques (side kick, turning kick and roundhouse kick) and two hand-strike techniques (punch and knife hand strike – impact made with the underside of an open hand). The winner of this event task is the athlete who has scored most points. It needs to be emphasized that each athlete is allowed only one attempt at breaking a declared number of boards in each of the techniques. The side kick is the technique in which athletes tend to declare the highest number of boards. Thus, it inevitably affects the final score in a competition.

In sport practice in an aspect of execution, a range of nuances is observed in a performance technique of particular kicks. They are, however, most visible in the execution of the side kick (in Taekwon-do terminology referred to as *yop chagi*). These slight differences are likely to significantly affect the final score.

The aim of this study was to evaluate the effectiveness of the attempted side kicks on the basis of the maximum foot velocities developed. Pursuant to the criteria of sports technique biomechanical analyses [9], and especially the measuring methods applied in Taekwon-do studies [10], [11], four movement phases of the side kick have been specified in the present paper: starting position, shifting the back leg forward, lifting the leg and braking (final phase).

This study was aimed at recognition of biomechanical factors affecting an efficient execution of the kick. The author also wanted to show at which moment exactly the velocity of the foot is the highest and what elements affect the increasing or decreasing of the speed of the travelling foot. The answers to these questions may lead to choosing a more effective way of executing this particular kind of kick in Taekwon-do ITF sport competition power test as well as in self-defence.

2. Material and methods

In the case study presented, a 17-year-old male athlete participated (weight – 75 kg and height – 179 cm), who was awarded 1st Dan. For the purpose of the present case study he was asked to execute a side kick four times starting from the L-stance guarding block (in Taekwon-do terminology referred to as *niunja sogi palmok debi maki*). In practice, this kick is used in the power test. A general diagram presenting the movement structure of the kick performed by the athlete is shown in figures 1 and 3.

Fig. 1. Diagram of the side kick movement structure (in Taekwon-do terminology referred to as *yop chagi*) – front view

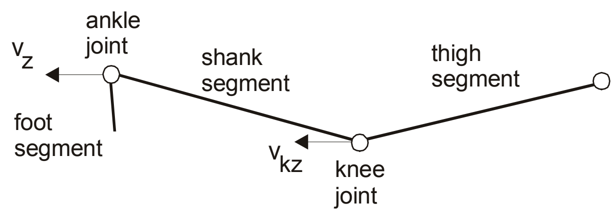

Fig. 2. Scheme presenting relevant joints and segments of the kicking leg

The case study relied on an Italian system called Smart-D, manufactured by BTS S.p.A., used for complex movement analysis. In the method applied, six cameras reflecting infrared rays were used. They recorded in real time the location of the markers fixed to the athlete's body. The system made it possible to record the picture of the athlete's moving body and to evaluate the kinetic parameters of the movement. The movement was recorded with the accuracy of 0.3–0.45 mm and the frequency of 120 Hz.

The parameters determining the temporal and spatial structure of the movement of the markers located on the athlete's knee and foot were registered. The parameters determined the changes in the speed of knee and foot with time. This enabled the author to determine the maximum foot velocities (v_y, v_z) and the maximum knee velocities (v_{ky}, v_{kz}) in respect to the *Y*- and *Z*-axes, the leg lifting time (t_w) and the total time of kick execution (t). The data obtained was used to calculate the average mean values and the standard deviation.

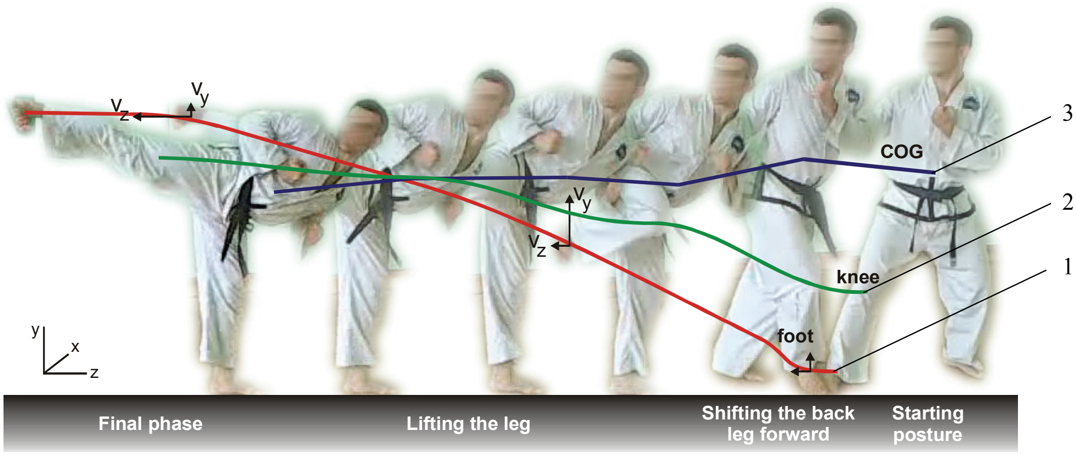

Fig. 3. *Yop chagi* movement structure diagram – side view.
Line 1 – the way of foot movement; line 2 – the way of knee movement; line 3 – transition of the centre of gravity (COG)

3. Results

Starting posture: The athlete adopts the L-stance forearm guarding block (in Taekwon-do terminology referred to as *niunja sogi palmok debi maki*) with the right foot moved forward. According to Taekwon-do rules [4] in this stance 70% of the body weight should rest on the back foot and 30% on the front one. Both feet should be slightly pointed inwards and the toes of the foot at the front should be lined up with the heel of the back foot. Both knees are slightly bent. The term "starting posture" comprises information on the stance and the place where the attempted attack starts.

Shifting the back leg forward: The athlete moves the back foot forward in the direction of the intended impact. This results in a slight rise of the centre of gravity (COG). The hands are held up in a guard. When the feet have touched the ground, the ankle

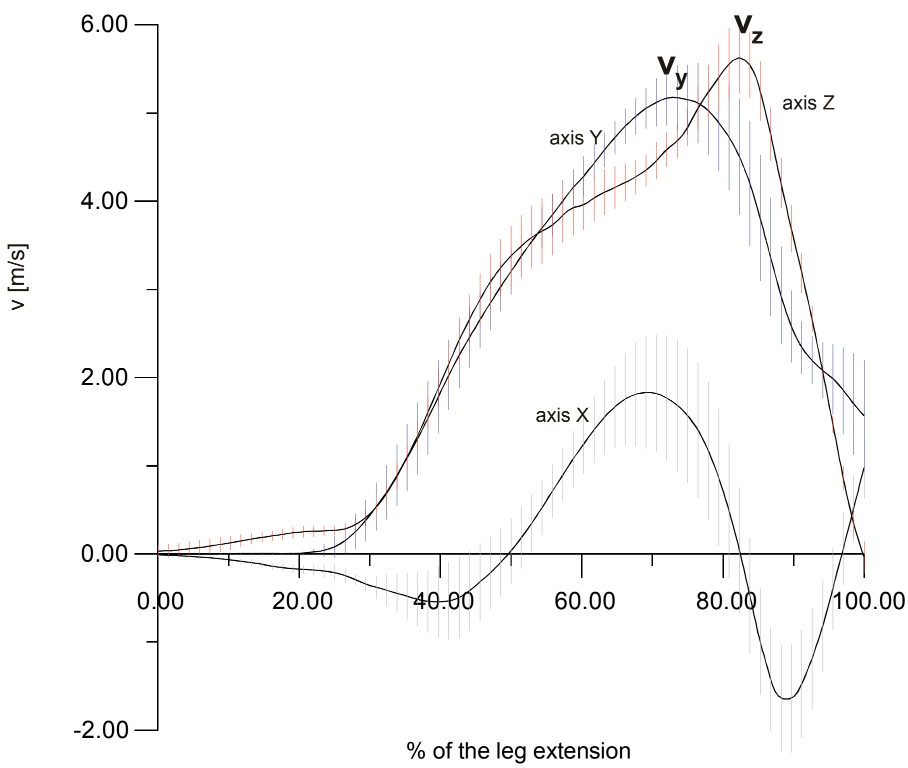

Fig. 4. Average changes in linear velocities of the foot with regard to leg extension

joint tenses and the athlete energetically pushes the right foot off the ground.

Lifting the leg: As a result of the right foot take-off the force pushes the foot upwards. Further movement is facilitated by the fact that it is the muscles of the lower limb that take control over the movement. Thus, the knee and hip joints are extended. In this phase, we deal with the highest velocity of the foot moving with the average velocity being v_y = 5.05 m/s. On average, it is in the 82% of the full leg extension when the foot reaches its peak velocity, whose average is v_z = 5.63 m/s (figure 4). The average time of lifting the leg until the moment of its full extension is 0.62 s.

Final phase: The kicking foot is extended in the ankle joint. The athlete has had to balance his body in such a way as to make sure that the foot planted on the ground has remained the only point of his body touching the ground. The total time of kick execution (from the starting position to the final phase) produced the average time t = 1.02 s.

The average values of the kinetic parameters are presented in the table.

Table. Biomechanical parameters influencing the effectiveness of the kick

Variables	Average ± SD	Range
v_z (m/s)	5.63 ± 0.40	5.80 ÷ 6.05
v_y (m/s)	5.05± 0.64	4.09 ÷ 5.47
v_{kz} (m/s)	4.14 ± 0.78	3.14 ÷ 5.05
v_{ky} (m/s)	2.82 ± 0.31	2.53 ÷ 3.10
t (s)	1.02 ± 0.09	0.95 ÷ 1.15
t_w (s)	0.62 ± 0.11	0.53 ÷ 0.78

4. Discussion

The average maximum velocity values v_z obtained in the this analysis of the side kick execution were lower than those reported by WILK et al. [3]. It is possible that the differences result from different sport experience of the athletes tested and different ways of executing the side kick measuring method used.

Figure 5 presents the correlation between the foot maximum velocity and the knee maximum velocity during the execution of the side kick (r = 0.97). This dependence shows that a higher knee velocity significantly affects the velocity which the foot develops. This means that when working on the improvement of the foot velocity while practising the technique of the side kick, attention needs to be paid to the velocity of the knee moving in the same direction as the foot. Figure 6 presents the correlation between the total time of the side kick and the maximum velocities of the knee in relation to the *Y*- and *Z*-axes (r = 0.75). Hence, a short time of the side kick execution will depend on the velocity which the knee develops in the leg lifting phase. A similar dependence can be observed in the case of the foot velocity and the kick execution time. The total time of the kick comprises the time between the starting position, shifting and lifting the leg. The deatiled factors that may influence the total time of side kick are shown in figure 7.

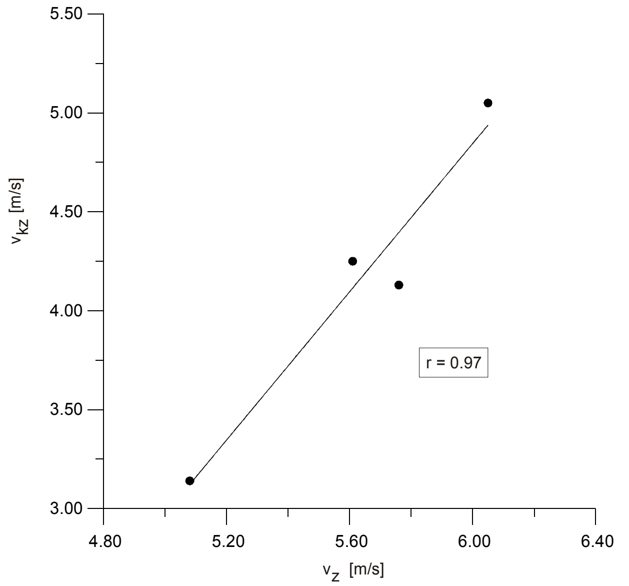

Fig. 5. Correlation between the maximum velocities of the foot and the knee in relation to *Z*-axis

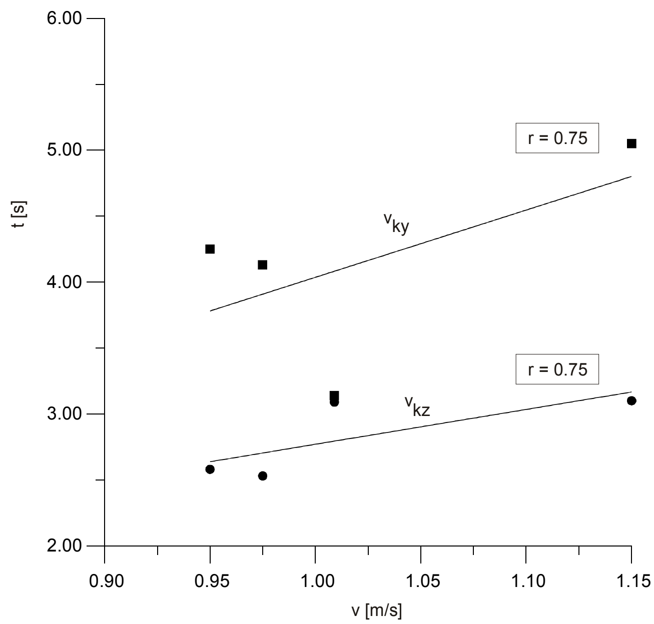

Fig. 6. Correlation between the total time of the side kick and the maximum velocity of the knee in relation to *Y*- and *Z*-axes

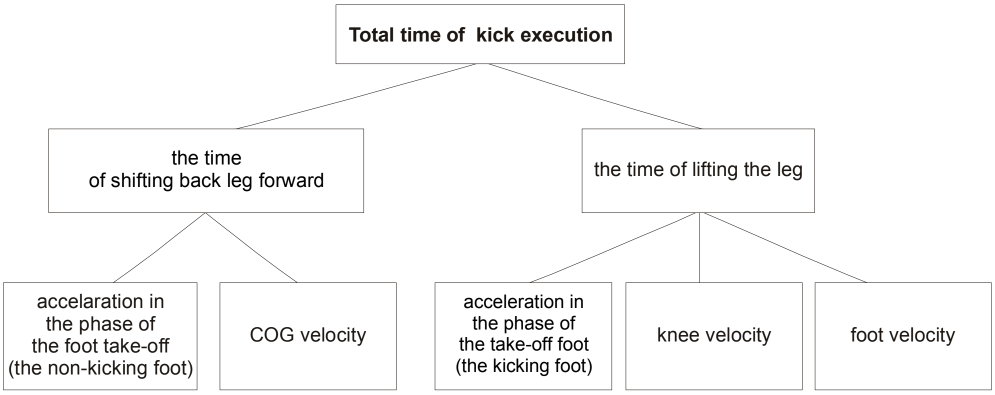

Fig. 7. Diagram presenting times and detailed factors affecting the side kick total execution time

The average maximum speed was obtained at the leg length equal to 82% of the maximum length of the fully extended leg. This length can be treated as an optimum value in this particular technique allowing the maximum dynamics of the kick to be achieved. The law of dynamics states that the greater speed an object develops, the greater acceleration it receives. As the following formula shows:

$$F = \frac{m \cdot v^2}{2s},$$

it is possible to assume that the moment the foot velocity reaches its maximum, the force at impact is also the greatest [9], [12]. If the force at impact is calculated on the basis of the formula presented above with using average maximum velocity and the average weight of the athlete (provided that it is assumed that the total weight of the athlete is involved in the movement) the force obtained will amount to $F \approx 1120$ N. The value of the force at the impact calculated in this way could be affected by an error of 10% in calculating the distance between the subject and object being attacked and it could be reduced to the value of 900 N. Hence, both factors, i.e., the precision in assessing the distance and the moment of impact, are of a great importance for athletes, especially in the power test, where a board fixed to a frame is the object of the intended strike. This data confirms the importance of advanced kinematic research in the optimisation of the strikes performed in power tests.

Obtaining exceptional and outstanding motor and technical skills and abilities is the clue in practising martial arts. A proper methodology of sports practice as well as optimisation of the training allow athletes practicing combat sports to achieve maximum results and become champions. The ever increasing level of preparation for sport competition in martial arts necessitates searching for and developing increasingly detailed and advanced aspects in combat sports as well as a more detailed insight into the research conducted so far.

This paper should be considered as an introduction to a more detailed research of this particular problem. Only through comparison of individual characteristics of movement mechanics of high-class athletes will it be possible to verify the conclusions reached in this paper. The results and considerations presented herein can only be used as an introductory material for comparisons made by other researchers and as a starting point for further research for the author himself.

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