

Kinematics of the turning kick – measurements obtained in testing well-trained taekwon-do athletes

Authors' Contribution:

- A Study Design
- B Data Collection
- C Statistical Analysis
- D Manuscript Preparation
- E Funds Collection

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Abstracts

Background & Study Aim: The aim of the paper is the influence of selected kinematic factors on the turning kick technique. This issue is practically relevant in the traditional version of taekwon-do, where an effectively performed strike may divulge the winner.

Material & Method: Using 3D motion capture technology, six International Taekwon-do Federation athletes were tested. Biomechanical parameters related to range of motion, kick power and kick time were applied in the analyses. The athletes executed the turning kick three times in a way typically applied in a board breaking kick. The quantification focused on the speed changes related to kicking leg extension, the maximum knee and foot velocities in the Cartesian coordinate system and the total time of kick execution. The descriptive statistics (i.e. average values and the standard deviations) and correlation analysis were applied in data analysis.

Results: The results have shown that the effect of the kick is mainly represented by component of kick foot velocity in frontal – and lateral-directions. The correlation analyses unveil that the maximal knee speeds reached in frontal – and lateral-directions as well as foot take-off velocity in frontal – and vertical-directions are highly correlated to kick foot effectiveness ($r = 0.60$ to 0.87). The analysis of velocity development in relation to kick leg extension divulges that the maximal velocity occurs around 80% of a full leg extension.

Conclusion: For increasing kick effectiveness, athletes should work on the foot take-off velocity, the dynamics of the knee motion and consider the optimum kick length for kicking power maximization.

Key words: 3D motion analysis, biomechanics analysis, combat sports

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INTRODUCTION

Taekwon-do boasts a range of kicking techniques. It has been proved that the turning kick (in taekwon-do terminology referred to as *dollyo chagi*) is the technique used most frequently in combat [1-3].

The effectiveness of a kick is affected by a number of factors. However, biomechanical identification of factors related to the kick effectiveness has potential to enable athletes to increase their learning capability

as well as to perform the fastest and most powerful strikes [4,5]. That is the reason why an increasing number of researchers attempt to work out how to optimize striking techniques [6-10].

Kinetics of the turning kick has also been one of research topics for decades. Previous studies have shown that the kicks can reach the velocity of 9.94 to 16.26 m/s [11] and the force of 1304 to 2089 N [12]. Wąsik [13] has confirmed that the total time of

Taekwon-do – a Korean martial art based mainly on punches and kicks.

3D motion capture – the process of recording the movement of objects or people.

Biomechanical analysis – the use of technical sciences for the analysis of biological systems.

Turning kick – kick in which the attacker swings his or her leg around in a semi-circular motion, striking with the front of the foot.

the turning kick is influenced by the velocity of foot take-off, acceleration of the foot at take-off, strength of the muscles engaged in a given movement as well as the kicking technique. There are also investigations focusing on acceleration of centre of mass, changes in the angles of the body segments as well as the changes of the momentum during the execution of the turning kick [14].

Further biomechanical characteristics of taekwon-do kicks have been revealed by studying other kicking techniques, such as front kick and axe kick. One study has been shown that in the high front kick thigh deceleration results from the movement dependent on the initial movement of the lower extremity and not on the activeness of braking [15]. Wąsik investigation [16] has unveiled that during the performance of the side kick the knee velocity increases the foot velocity and an optimum distance is needed in order to obtain the maximum dynamics of that kick. Yu et. al. [5] have found that the key factor determining the best quality of the heel kick is the flexibility and the strength of the lower extremity muscles.

The results of above studies suggest that there could be an optimum existed for maximization of turning kick effectiveness. Yet, there is no reference available to confirm the hypothesis. Therefore, the aim of the paper is the influence of selected kinematic factors on the turning kick technique. Specifically, the investigation tried to answer the following questions related to the skill optimization/kicking effectiveness:

- What biomechanical factors influence the maximum of the turning kick speed?
- At which moment is the foot speed the highest?
- Do the techniques of the foot and knee performance affect the kinematics of the kick?

The answers to these questions might help practitioners to select more efficient way of performing this type of strikes and maximize the kick effectiveness when they aim to break hard objects, perform sports combat or self-defence (that is, application purpose).

MATERIAL AND METHODS

Subjects

The study was based on six ITF (International Taekwon-do Federation) taekwon-do athletes (age: 16.5±0.7; weight: 64.1±7.0; height: 176.5±4.6). The subjects group included European Junior Champions, Polish Junior Champions and other athletes who had practised taekwon-do for a minimum of 4 years with regular training of 3 to 5 times per week. All subjects

voluntarily participated in the study and the study was conducted under the ethical guidelines of the University Human Subject Research Committee. All subjects were informed the test procedure and signed a consent form before the data collection.

Protocol

Adopted from biomechanical analysis of combat sports [17], and the measuring criteria of taekwon-do techniques [18], four movement phases have been distinguished in the present study: the initial stance (starting posture), foot take-off, foot upswing and the final stage – braking. In phase 1 (starting posture), an athlete adopts the L-stance forearm guarding block (in taekwon-do terminology referred to as *niunja sogi palmok debi maki*) with the left foot at the front. According to the taekwon-do rules [19] in this stance 70% of the body weight should rest on the back foot and 30% should rest on the front leg. Both feet should be slightly pointed inwards and the heel of the front leg should be lined up with the toes of the back leg. Both knees are slightly bent.

The term “initial stance” i.e. “starting posture” comprises information on the stance of and the place where an attempted kick starts. In phase 2 (foot take-off), the athlete transfers his/her weight to the front (left) foot and rotates his/her trunk and the arms in the direction opposite to the direction of the intended movement. Then, the athlete takes off the right foot (which is at the back) while transferring his/her weight to the left foot. The arms help gain more rotation to the body and the swing of the right arm pulls the right part of the trunk and the kick foot from take-off. In phase 3 (foot upswing), the force coming from the foot take-off facilitates the upward motion of the foot (i.e. the upswing). There is a maximum flexion in the knee joint and further movement occurs as a result of the leg muscles taking control of the movement. In phase 4 (braking), the kicking leg is extended in the knee joint. The arms moved in the opposite direction to the direction of the lower extremity flexion so as to prevent the body from doing a full turn. The athlete needs to balance the whole body in such a way so as to keep balance whilst standing on the supporting leg.

For standardization of the test condition, the initial stance (in taekwon-do terminology called *niunja so palmok degi maki*) was applied to each subject. Due to the standardization, all subjects performed the right kick while standing on the left. For the data collection, every subject performed the turning kick three times, which resulted in 18 kicks data in total.

The study employed a 3D motion capture system (Smart-D system, BTS S.p.A., Italy). The system consisted of six infrared cameras, tracing reflective markers fixed on the athletes' body. The system made it possible to record the picture of the athlete's moving body and evaluate the kinetic parameters obtained. The movement was recorded with the accuracy of 0.3 to 0.45 mm at frequency of 120 Hz. Data collected concerning the movement and speed of markers' characteristic on the athlete's body were analysed. The analyses allowed specifying the indicators which define the structure of space and time of the athlete's movement. In the analysis of particular segments of the technique, the following factors were taken into consideration:

- v_x – speed of the kick foot (i.e. the big toe marker) with regard to X axis,
- v_y – speed of the kick foot (i.e. the big toe marker) with regard to Y axis,
- v_z – speed of the kick foot (i.e. the big toe marker) with regard to Z axis,
- v_{kx} – speed of the knee (i.e. the knee marker of the kick leg) with regard to X axis,
- v_{ky} – speed of the knee (i.e. the knee marker of the kick leg) with regard to Y axis,
- v_{kz} – speed of the knee (i.e. the knee marker of the kick leg) with regard to Z axis,
- v_{xt} – take-off speed of the kick foot (i.e. the big toe marker) with regard to X axis,
- v_{yt} – take-off speed of the kick foot (i.e. the big toe marker) with regard to Y axis,
- v_{zt} – take-off speed of the kick foot (i.e. the big toe marker) with regard to Z axis,
- t – time from the moment of the movement of the athlete's whole body to the moment of the full extension of the kicking leg.

Statistics

For data analysis, the average values and standard deviations (SD) were calculated. Correlation coefficients were determined between the foot velocities and other kinematic data obtained. The correlation analysis was performed to determine the parameters highly influencing kick effectiveness. All the statistical calculations were carried out with the use of Microsoft Excel 2000.

RESULTS

The kinematic characteristics of turning kick are shown in Table 1. The results show that the effect of the kick is mainly represented by component of kick foot velocity in Z-direction (frontal) and X-direction (lateral) (Fig. 2). The contribution of Y-component (vertical) is the least. Further, the results reveal that the knee movement and foot take-off are dominated by Z – and Y-component; X-component is consistently ranked the last. Finally, the duration of the kick is about half seconds for well-trained taekwon-do athletes.

As elaborated in previous session, the same initial stance was applied for a standardization of the investigation. Therefore, the influencing factors on the kick effectiveness, i.e. kick foot velocity in phase 4, are mainly from phase 2 and phase 3. The correlation analyses unveil that the maximal knee speeds reached in frontal (X-axis) and lateral (Z-axis) directions are highly correlated to kick foot effectiveness ($r = 0.60$ to 0.75) (Table 2). The maximal knee speeds in vertical (Y-axis) direction has good correlation with kick foot effectiveness ($r = 0.52$ to 0.63).

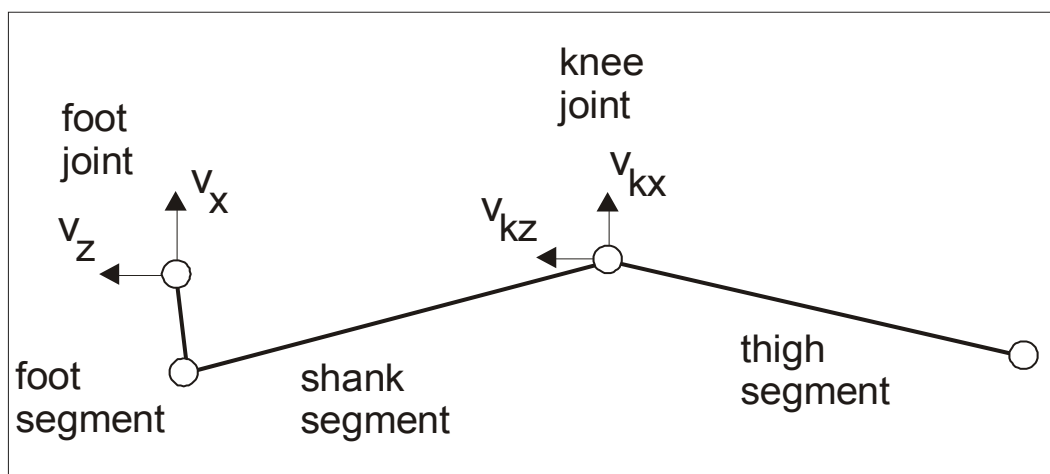


Figure 1. General view presenting relevant joints and segments of the kicking leg.

Table 1. Biomechanical factors affecting efficiency of the kick

Variables	Average	SD	Range
maximum v_z [m/s]	9.75	2.54	7.10 – 14.6
maximum v_y [m/s]	5.91	0.90	4.14 – 7.65
maximum v_x [m/s]	8.62	2.72	5.36 – 15.35
maximum v_{kz} [m/s]	4.96	1.36	3.18 – 7.5
maximum v_{ky} [m/s]	4.13	0.52	3.26 – 5.03
maximum v_{kx} [m/s]	3.77	1.07	2.38 – 6.17
v_{zt} [m/s]	3.68	0.14	1.01 – 6.15
v_{yt} [m/s]	4.25	1.04	1.88 – 5.66
v_{xt} [m/s]	3.52	2.25	1.30 – 7.85
t [s] time from the moment of the movement of the athlete's whole body to the moment of the full extension of the kicking leg[s]	0.57	0.11	0.36 – 0.80

v_x – speed of the kick foot with regard to X axis; v_y – speed of the kick foot with regard to Y axis; v_z – speed of the kick foot with regard to Z axis; v_{kx} – speed of the knee with regard to X axis; v_{ky} – speed of the knee with regard to Y axis; v_{kz} – speed of the knee with regard to Z axis; v_{xt} – take-off speed of the kick foot with regard to X axis; v_{yt} – take-off speed of the kick foot with regard to Y axis; v_{zt} – take-off speed of the kick foot with regard to Z axis; t – time from the moment of the movement of the athlete's whole body to the moment of the full extension of the kicking leg

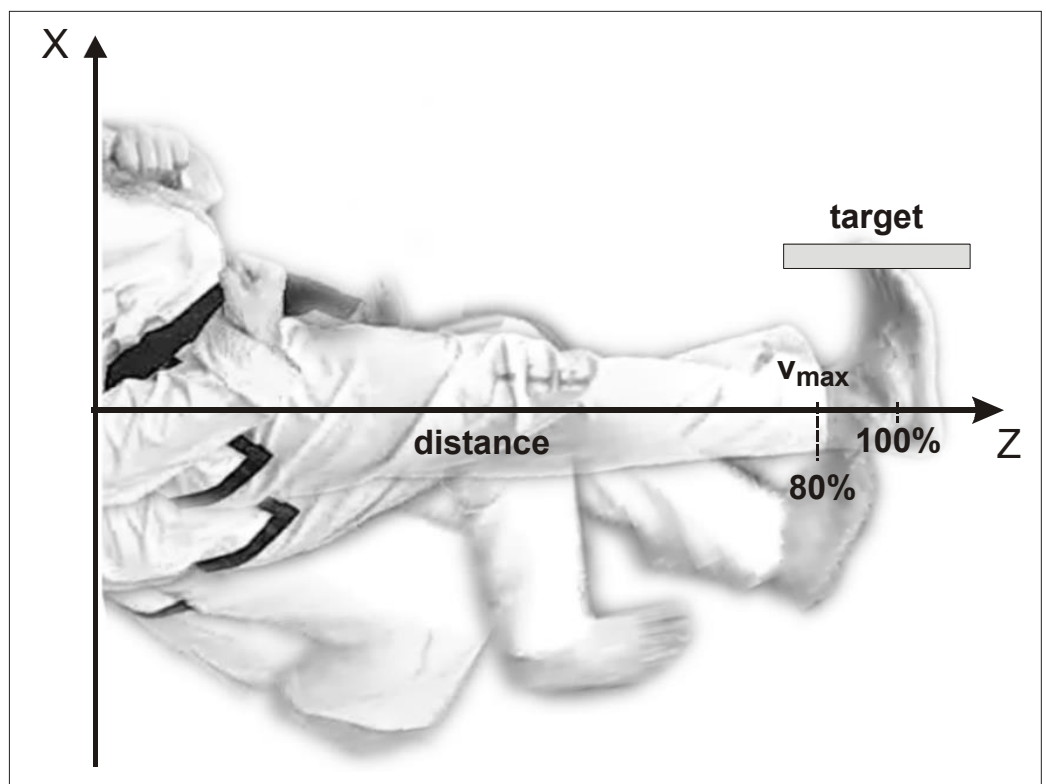


Figure 2. Structure of the turning kick – overview

Table 2. Correlation coefficients (*r*) between parameters influencing the effectiveness of the kick

Variables	v_x	v_y	v_z
v_{kx}	0.69	0.00	0.75
v_{ky}	0.52	0.06	0.63
v_{kz}	0.60	0.10	0.67
v_{xt}	0.63	-0.17	0.87
v_{yt}	0.74	0.037	0.77
v_{zt}	-0.13	0.15	-0.07
<i>t</i>	-0.44	0.18	-0.59

v_x – speed of the kick foot with regard to X axis; v_y – speed of the kick foot with regard to Y axis; v_z – speed of the kick foot with regard to Z axis; v_{kx} – speed of the knee with regard to X axis; v_{ky} – speed of the knee with regard to Y axis; v_{kz} – speed of the knee with regard to Z axis; v_{xt} – take-off speed of the kick foot with regard to X axis; v_{yt} – take-off speed of the kick foot with regard to Y axis; v_{zt} – take-off speed of the kick foot with regard to Z axis; *t* – time from the moment of the movement of the athlete’s whole body to the moment of the full extension of the kicking leg

Further, the results of correlation analyses show that the components of foot take-off velocity in frontal (X-axis) and vertical (Y-axis) directions have remarkably influences on the effectiveness of the kick. The correlation coefficients are 0.63 to 0.74 for X-direction and 0.77 to 0.87 for Y-direction respectively (Table 2). Notably, the

negative correlation between the duration of the kick (*t*) and the component of kick foot speed in lateral direction ($r = -0.59$) suggests that the larger the kick duration, the larger the influence of *t* on kick foot effectiveness.

Lastly, a detailed analysis of velocity development in relation to kick leg extension (Fig. 3) reveals that the maximal velocity occurs around 80% of a full leg extension.

DISCUSSION

One fundamental principles of kicking in taekwon-do is the power. Power, in the context of striking, can be thought of as the ability to deliver enough force to off balance, damage or knock out an opponent [4]. Based on physics, power can be determined by the product of the force applied and the velocity/speed as a result of that force. Therefore, in taekwon-do practice, speed is a key attribute for success in competition or self-defence. 3D motion analysis is capable of quantifying speed details of any joints/points on an athlete doing taekwon-do kicks and strikes. The current study using 3D technology has clearly identified the effectiveness of turning kick is mainly determined by kick foot speed in frontal and lateral directions. The result is clearly fit the practical experience. For answering the 1st research question: the current study has successfully revealed that the biomechanical factors influencing the maximum speed of the turning

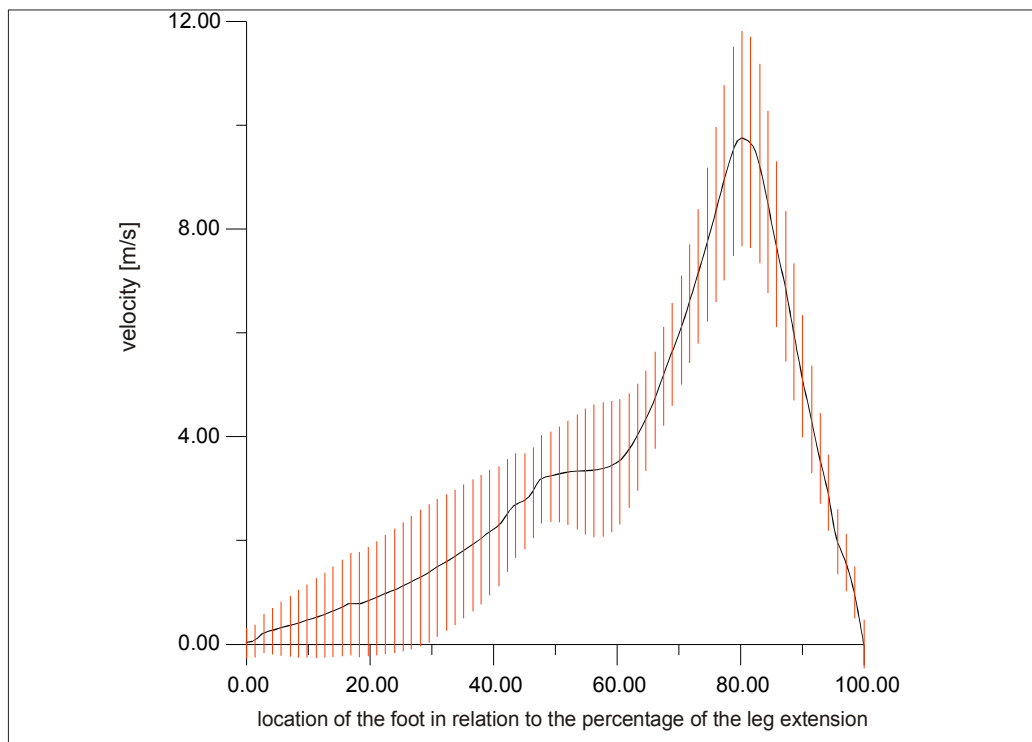


Figure 3. Changes in the foot velocity during execution of the turning kick in relation to axis Z.

kick are the foot take-off speed in frontal ($r=0.87$), and vertical ($r = 0.77$) directions and the knee speed in frontal directions ($r=0.75$). Interestingly, the kick effectiveness does not depend on the maximum speed of the leg upswing and the foot take-off speed in lateral direction. The results could be due to the shorter acceleration distance in lateral direction for foot and practically no acceleration of knee in the final phase of the kick (phase 4 is dominant by knee extension).

To answer the 2nd research question, the current study has unexpectedly found that the maximum speed of kick foot occurs around 80% of a full leg extension, not close to the end of the kick. The unexpected results could be linked to the tests condition. Comparing with the previous studies, the maximal kick speed is relatively low.

The dependence between the duration of the kick and the maximum speed is rather weak. Such weak dependence results from the athlete's priority, which aims at achieving maximum force of impact at the breaker board. In this particular situation the duration i.e. the length of the execution time of the kick is not as important as in a situation of combat. The priority of force exists when there are no time limits and an action is aimed at producing maximum kinetic energy [20]. The speed of the turning kick performed by the elite taekwon-do athletes which was given by Conkel is 14.60 m/s [21]. Serina & Lieu [22] obtained the value of 15.9 m/s. In those studies the athletes aimed their kicks at a punching bag. In the current research in which the subjects performed their kicks without a physical target, the speed of the kick is lower because athletes need to decelerate the speed of the kicking foot. Using the above mentioned method, kicks performed by karate practitioners (no particular karate style mentioned) were measured and the speed obtained was between 9.5-11.0 m/s [23]. Again the same method was used in the research where determined average maximum speed of turning kicks was 9.75 m/s. The later studies' results are relative identical with the present research. Hence, for confirming/rewriting the answer to the 2nd research question, further studies are needed in the future.

Also, the results jointly answer the 3rd research question: the techniques of the kick foot and knee affect the kinematics of the kick. The findings imply that the most effective kick should perform a whip-like movement towards a target; kicking is initiated at the trunk and hip, and the movement followed a proximal to distal segmental sequence, a sequential flow of energy and momentum transfer to the kicking foot [24].

Additionally, the results of this study would suggest that the distance to target would affect the effectiveness of the turning kick. The previous measurements of the absolute force of the turning kick showed that the tested taekwon-do practitioners obtained values ranging from 404 to 518 N [11]. However, it remains unknown how the distance from the target was chosen for kick execution. The athletes who performed the turning kick at a specifically chosen distance obtained force of 1304-2089 N [12]. Thus, the kinetics of a particular strike can only be used fully to its advantage if the attacked target is located at an optimum distance for this particular strike. In the present study the average maximum speed was obtained when the length of the leg was 80% of the maximum leg extension. This length could be considered as an optimum length in this particular kicking technique in order to achieve the maximum dynamics of the turning kick. One should note that an improper variation in distance may result in negative effect, as a previous study has shown that a variation of 5-10% in relation to the distance to the attacked target results in a clear decrease of the force of the kick [25,26]. Hence, a precise evaluation of the distance as well as the moment of impact is of significant importance for athletes especially when it comes to power test events at taekwon-do competitions, where a breaker board is the athletes' target.

CONCLUSION

For increasing kick effectiveness, athletes should work on the foot take-off velocity, the dynamics of the knee motion and also when the foot is travelling in the air, they must use their muscles to accelerate the motion of the kicking foot. In addition, when performing the turning kick special attention should be paid to assessing the distance so that the impact of the foot at the target takes place at the moment of the peak speed of the kicking foot.

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COMPETING INTERESTS

Authors declare that we do not have any financial or personal relationships with other people or organizations that could inappropriately influence the paper.

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