



Kinematic Effects of the Target on the Velocity of Taekwon-Do Roundhouse Kicks

by

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The phenomena of target kinematic effects under different striking conditions and applying different techniques constitute one of the fields of research for sports biomechanics. However, the influence of some kinematic variables which change under different strike conditions for specific parts of the lower limb remains unknown. The aim of this study was to extend the knowledge on how targets of different shapes or the lack of a physical target would affect maximal velocity registered by a marker placed on the foot, knee and hip during the execution of a roundhouse kick. In total, 15 adult males were included in this study. All participants were taekwon-do elite athletes. The displacement of markers placed on the lateral side of the foot, knee and hip during movement execution was registered by a stereophotogrammetry apparatus. Participants performed taekwon-do roundhouse kicks for three target types (into the air, a table tennis ball and a training shield) applying either a sport or a traditional style. The highest maximal velocity was obtained for kicking into the training shield. When applying the sport style, the highest maximal velocity of foot markers for the executed kicks was registered. Kicking into air resulted in higher velocities for proximal body parts than kicking into a tennis ball, but the effect was reversed for the foot marker. In conclusion, a large resistance target is suitable for athletes' motor preparation as it allows the highest maximum velocity to be reached. Small non-resistant targets are recommended for technical training.

Key words: biomechanics, martial arts, photogrammetry, sport analysis, lower extremity.

Introduction

The phenomenon of aiming at an object is often the focus of research for neurophysiology and biomechanics. The process of aiming can be studied under both standard and movement execution conditions or in a state of pathology. This phenomenon is complex as visual-motor coordination together with selecting the optimal trajectory of movement towards the target are required. During movement execution, proper motor control over the body is necessary. Both hemispheres of the brain are involved in this process, thus there is no "aiming area" in the brain which is responsible for this function in

contrast to speech or listening areas (Winsten, 1997).

The execution of rapid and precise movements exceeds the ability to consciously process information (Plamondon, 1998). Movement is typically intended and planned; therefore, the effect is dependent on the experience of the individual and the ability to perform coordinated movement. The development of aiming skills is related to experience and age (Olivier and Bard, 2000). Adults are better at handling complex coordination tasks given the mature nervous system. Successful aiming depends on several

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variables. Peterson (2015) indicates that while aiming, attention should be paid to proper economy of the movement. In addition to external indices, individuals should depend on their inner perception of movement execution.

The term *target kinematic effect* was formulated in previous studies (Wąsik et al., 2015, 2016). It is defined as the influence of objects of different types and shapes, which are targets (or lack of a physical target) on the spatial-temporal variables of the executed movement and its technique. This phenomenon is more complex than models based on Fitts's law (Bullock and Grossberg, 1988; Meyer, 1988; Schmidt, 1979). In contrast to the Fitts's model, the target kinematic effect takes into account differences in movement when there is no physical target (it could be imagined by an athlete), whereas the performed technique is the same as when hitting a physical object such as a training shield. The lack of a physical target when executing the kick does not cause the movement to be randomly performed (Landeo and McIntosh, 2008). Most martial arts techniques are performed at fixed heights (striking zones), and the movement stops at specific moments chosen by an athlete, such as imaginary contact with the opponent's head. However, this imaginary target (or kicking into the air) does not require adjusting and aiming the same way as striking toward a physical object. It is assumed that our nervous system does not take into account that we could possibly miss our own imaginary target.

Most studies in this field of research are focused on revealing differences between testing conditions based on chosen kinematic variables. Variables most frequently studied are maximal linear and angular velocity as they can be used as a simple performance assessment method.

During taekwon-do competitions, fast and precise execution of movement highly contributes to the victory. In this study, we focused on the taekwon-do roundhouse kick (*dollyo chagi*) because it is most commonly used during competition due to high scores awarded for successive contact with the opponent's head (Estevan et al., 2011; Jae-Woong et al., 2010; Matsushigue et al., 2009).

The aim of this study was to evaluate how targets of different shapes or the lack of a physical target would affect maximal velocity of the

movement registered by a marker placed on the foot, knee and hip during execution of the roundhouse kick. The practical objective was to expand the knowledge about kinematics of the effective execution of this kick, enhance future training methods for taekwon-do and provide new recommendations for athletes and coaches.

Methods

Participants

Fifteen adult males (age 22.5 ± 6.2 years; body mass: 71.9 ± 11.5 kg; body height: 175.7 ± 8.4 cm) were included in the study. All of them were taekwon-do ITF (International Taekwon-do Federation) athletes at the elite level (1 cup to 2 dan belt) with mean training experience of 10.67 years (minimum 5 and maximum 26 years of training and competition).

All participants were informed of the testing procedures and signed informed consent for voluntary participation in this study. The study was approved by the Ethics Committee of the University in Rzeszow (number 2/6/2017, date 08.06.2017).

Measures

The experiment took place in the Human Motion Lab (HML). An stereophotogrammetry apparatus with 10 NIR Vicon MX-T40 infrared cameras with resolution of 4 MP (2352×1728 pixels) and a 10-bit grayscale was used, which allowed to capture 370 frames per second with full resolution. Displacement of markers placed on the lateral side of the foot, knee and hip (anterior superior iliac spine) during movement execution was registered. Velocity values were computed for the X, Y and Z planes separately. The results were stored in a c3d file format, and the resultant velocity and peak values were obtained using the python library *pyomeca* (<https://github.com/pyomeca>) (Martinez et al., 2020).

Design and Procedures

The study design was the same as in previous studies (Wąsik et al., 2016, 2018). Participants performed roundhouse kicks three times for every testing condition which varied considering different types of a target, a kicking side of the body and the style of the kick execution. The targets applied were: a nonphysical target (imaginary) in the air, a table tennis ball hanging on a string from the ceiling,

and a training shield held by an assistant. The tasks were performed from both a traditional and a sport stance. The sport stance is characterized by an evenly distributed load on both limbs with feet directed towards the target, while in the traditional stance, the kicking limb is more loaded, and the foot is 90° from the target with the inner side towards it. Under all conditions, participants were instructed to kick at the same height (a high striking zone). Before every trial, participants were allowed to perform few attempts of the kicks to adjust the distance from the target due to differences in limb length. A fixed area of striking could result in more advantageous distance for some athletes, which could affect the reliability of results. Participants were told to perform kicks with maximal effort. There was no command to start, and participants performed the kick when they were ready. After each trial, they returned to the initial stance and performed a kick once again. Each testing condition was finished after the participant hit a target three times. The data include only kicks that hit the target. In total, 540 kicks were registered and further analyzed.

Statistical analysis

The obtained kinematic variables were computed by means of standard descriptive statistics, such as the mean and standard deviation. ANOVA (analysis of variance) was performed to verify that there were no significant differences between trials under each tested condition. For the purpose of identifying the joint effect of categorical variables meant by specific conditions, MANOVA (multivariate analysis of variance) was performed due to its power and sensitivity. The level of statistical significance was set at $p < 0.05$. All computations were performed using Statistica 12 (Hamburg, Germany) software.

Results

For a marker placed on the foot, the highest mean value for the sport style was registered for a right kick (15.39 m/s) into a shield. The lowest mean value for the sport style was registered for kicking into the air with the left foot (12.4 m/s). Under only one condition for the sport style, i.e., kicking into a table tennis ball, higher mean values were obtained for the left kick (13.06 vs. 12.25 m/s for the right kick). A similar trend was observed for the traditional style. Specifically,

the highest mean velocity was obtained for kicking into a training shield with a right kick (12.15 m/s), and the lowest mean value was obtained for kicking into the air (11.15 m/s). Although the order of targets at which the kick was executed was the same for all athletes, i.e., the shield, the ball, and the air, the knee marker registered higher values for kicking into the air than into a table tennis ball for the left kick performed applying the sport style (6.23 m/s for the air and 6.15 m/s for the ball). The same was observed for the traditional style for both kicking sides (5.78 m/s for the right kick and 5.43 m/s for the left kick in comparison to 5.4 m/s for the right kick and 5.33 m/s for the left kick). The same phenomena were observed for the hip marker when kicks were executed applying the traditional style (Figure 1).

For the joint effect of three markers analyzed at once in multivariate analysis (MANOVA), no significant effects were noted between categorical variables (type of target, side, and style). For all categories separately, statistically significant differences were found in maximal velocities reached. For single marker analysis, statistically significant differences between maximal velocities were noted for the foot marker for each category separately. Moreover, the joint effect of the type of the target and the initial stance (style) was also proven to be statistically significant (Table 2). No joint effects were observed for a marker placed on the knee. For the marker placed on the hip, in addition to statistically significant differences between maximal velocities for each category separately, a statistically significant joint effect was noted between the kicking side and the style used (Table 3).

Correlation analysis between pairs of markers revealed statistically significant correlations with low to high power in almost all cases ($r = 0.347$ to $r = 0.810$). In only two cases, the foot-hip correlations were non-significant ($r = 0.084$ for the left kick in the sport style into the air and $r = 0.191$ for the left kick into a shield in the traditional style). The highest mean correlation was obtained for the foot and knee markers ($\bar{r} = 0.741$), whereas the lowest was obtained for the foot and hip markers ($\bar{r} = 0.423$) (Table 4).

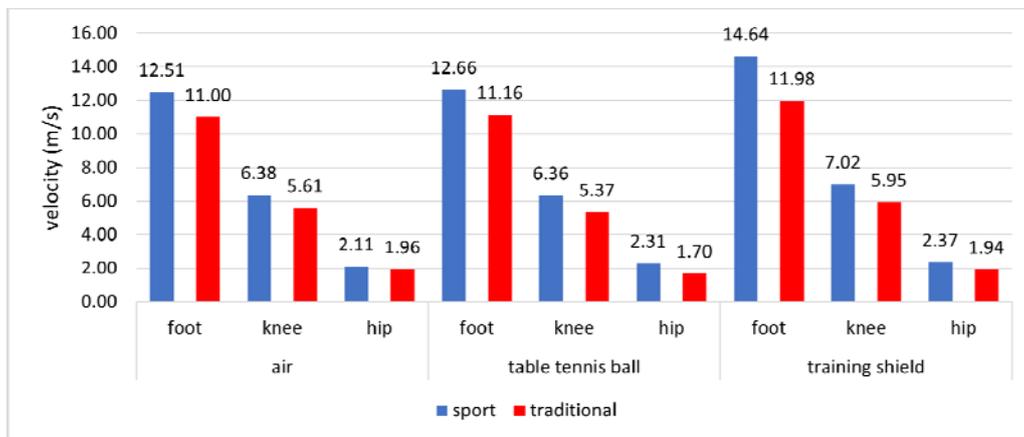


Figure 1

Mean values of maximal velocity for both kicking sides for all markers under experimental conditions

Table 1

The interaction between categorial variables for a marker placed on the foot (MANOVA)

Effect	SS	df	MS	F	p
Side	33.52	1	33.52	6.32	0.012**
Target type	225.19	2	112.59	21.23	0.000**
Style	539.82	1	539.82	101.79	0.000**
Side*Target type	13.25	2	6.63	1.25	0.288
Side*Style	1.41	1	1.41	0.27	0.607
Target type*Style	35.88	2	17.94	3.38	0.035**
Side*Target type*Style	15.44	2	7.72	1.46	0.234

**statistically significant ($p < 0.05$); SS – sum of squares; df – degree of freedom;
MS – mean square; F – Fisher statistic value; p – significance level value.

Table 2

Interaction between categorial variables for a marker placed on the hip (MANOVA).

Effect	SS	df	MS	F	p
Side	2.433	1	2.433	21.55	0.000**
Target type	9.394	2	4.697	41.59	0.000**
Style	14.621	1	14.621	129.47	0.000**
Side*Target type	0.405	2	0.203	1.79	0.167
Side*Style	0.795	1	0.795	7.04	0.008**
Target type*Style	0.582	2	0.291	2.58	0.077
Side*Target type*Style	0.056	2	0.028	0.25	0.781

**statistically significant ($p < 0.05$); SS – sum of squares; df – degree of freedom;
MS – mean square; F – Fisher statistic value; p – significance level value.

Table 3
Correlation coefficients between maximal velocity values of markers placed on separate body parts during execution of the roundhouse kick.

Side	Target type/Style	Foot/Knee	Foot/Hip	Knee/Hip
right	air/sport	0.810*	0.617*	0.762*
	ball/sport	0.666*	0.364*	0.695*
	shield/sport	0.634*	0.467*	0.710*
	air/traditional	0.764*	0.651*	0.631*
	ball/traditional	0.783*	0.520*	0.698*
	shield/traditional	0.714*	0.561*	0.593*
left	air/sport	0.731*	0.084	0.439*
	ball/sport	0.754*	0.358*	0.597*
	shield/sport	0.699*	0.408*	0.646*
	air/traditional	0.783*	0.499*	0.527*
	ball/traditional	0.806*	0.347*	0.569*
	shield/traditional	0.755*	0.191	0.462*

* statistically significant ($p < 0.05$)

Discussion

Maximal velocity values are a characteristic benchmark of striking technique performance that has been used by sport biomechanics for years. The experiment conducted in this study is unique due to the applied testing conditions, especially the use of non-resistant, small targets, such as table tennis balls hung from the ceiling on a string. Therefore, our results are only partly comparable with findings of other researchers. In the study of Landeo and McIntosh (2008), participants performed kicks into the air and maximal velocity values obtained for the foot ranged from 12.21 to 12.94 m/s, while for knee markers they were between 6.13 and 6.63 m/s. In the study of Estevan et al. (2015), the mean values were 11.90 m/s for the foot, 7.02 m/s for the shank and 4 m/s for the thigh. These values are comparable with our results, where maximal velocity ranged from 12.4 to 12.61 m/s for the foot, 6.23 to 6.53 m/s for the knee and 2.01 to 2.2 m/s for the hip marker. Differences could be explained by marker placement, as in the study by Estevan et al. (2015) the thigh marker was placed on the lower limb and not on the pelvic girdle as in our experiment.

In another study, Estevan et al. (2013) used a training pad as a physical but non-resistant target, which is larger than a table tennis ball. However, as the kick does not stop at the contact, the results are comparable. In the study by Estevan et al. (2013), participants reached maximal velocities of 12.89 m/s for the foot marker. Those researchers also studied different foot placement, which was similar to the traditional stance applied in our research. Those participants obtained maximal velocity values of 14.3 m/s, whereas our study participants reached maximal velocities of only 10.99 to 11.32 m/s.

Definitely more studies were performed with a training shield as a target of the kick. In the study by Hsieh et al. (2012), participants reached maximal velocity of the foot from 13.2 to 14.4 m/s. The values were 14.66 m/s in the study conducted by Gavagan et al. (2017), 14.7 m/s in the study conducted by Kim et al. (2001), and up to 17.35 m/s in the study by Aandahl et al. (2018). Those findings could be compared to our results, where mean values were from 13.88 to 15.39 m/s. In addition, the highest obtained value of a single kick was 19.25 m/s for this condition.

There are also studies with similar to ours

target conditions, however, the difference is that the resistant target was not an assistant with a training shield, but a training mannequin. Moreira et al. (2016) obtained maximal velocity of approximately 2.5 m/s for hip markers, 7-7.5 m/s for knee markers and approximately 16 m/s for foot markers. These values are comparable to our findings.

The studies presented above and following comparisons with our results show that different measurement conditions including the existence of a physical object and its resistance to a strike, significantly affect the maximal velocity of the kicks performed by athletes. This hypothesis was also confirmed in the study of Quinzi et al. (2014), where significant differences between kicks into a physical target and into the air were found as well as their relationship with the performance level of participants. Elite athletes showed different movement patterns than novice athletes in the execution of roundhouse kicks. The higher the performance level, the more optimal the movement patterns, especially considering overextension of the knee under the non-physical target condition which could be harmful to the joint without slowing down before the end of the knee extension. We may also conclude that the target kinematic effect could have a different impact depending on the level of expertise of the tested groups (Falco et al., 2009; Quinzi et al., 2013). Thus, only elite athletes participated in our study. Additionally, in all studies mentioned above, participants were also at the highest performance level.

These findings extend the knowledge about the phenomena of target kinematic effects by taking into account more markers in comparison to previous studies focused on this topic. Initially, in previous studies, only markers on the most distant part of the limb were analyzed. Those studies either focused on the foot in the execution of the frontal kick (Wąsik and Góra, 2016; Wąsik et al., 2018) or a straight punch (Wąsik et al., 2016). On the other hand, the use of three markers allows to demonstrate the relationship for the entire sequence of the lower limb movement, which reveals distinguishable patterns not only for separate markers, but also as a kinematic chain for different measurement conditions. Kicking into the air does not require aiming and movement control toward the target,

which explains the higher velocities of proximal body parts, although the inability to plan the end of the movement at the moment of contact with a physical object should be highlighted. It is necessary to consciously stop the movement to avoid overextension. Despite the lack of resistance, the existence only of a physical target seems to result in different movement patterns given that a non-abstract point in space improves the movement pattern, where deceleration of lower parts does not seem to be as crucial as when kicking into the air. However, small objects require more precise movement; therefore, there is a higher demand for proximal body part control, which results in lower mean velocity values registered by hip and knee markers. When the target is large and resistant, but soft enough not to harm the striking limb, precision and the active phase of deceleration of the distant part of the limb are not required. Therefore, full torque and force can be transmitted into the target, which also shows potential of an athlete and could serve as a benchmark for motor preparation of athletes. This conclusion is supported by a previously validated method of the use of roundhouse kicks to test the athletes' performance level; that method also focuses on the most powerful strikes toward resistant-type targets (Tayeh et al., 2020).

The second important factor determining the velocity of the roundhouse kick is the initial stance which refers to the style applied. In the sport style, the load on the lower limbs is evenly distributed, while in the traditional style, the rear (striking) leg takes more body load with different foot placement (toes are placed more to the side than being pointed toward the opponent). Bodyweight distribution on both legs affects the preload and push-off phases of the executed movement. Different foot placement results in different hip joint rotation angles. Therefore, the initial phase of movement when the traditional style is applied induces different pelvic girdle rotation patterns, which results in lower maximal velocity values. In the study by Estevan et al. (2013), participants performed kicks with foot placement similar to that applied in the traditional style, but they reached much higher mean values of maximal velocity. However, there was no information about body weight distribution, which was probably different from that used in our study. Additionally, the results indicate

significant differences in the interaction effect between the style and the kicking side for the hip marker.

A significant result of MANOVA for the foot marker, revealing a significant interaction between the type of the target and the style, indicates a crucial role of the initial stance and body weight distribution in the effective execution of roundhouse kicks. Coaches and athletes should pay attention to the load distribution on the lower limbs and shift the pelvic girdle to identify the optimal distribution for individuals to perform the fastest and most powerful kicks. Proximal and core stability muscles seem to play an important role in shaping proper movement patterns for effective kicks. Moreover, coaches should be aware that different types of a target can significantly change training outcomes. A small, non-resistant target could be used for precision training, while a large shield would be a more appropriate tool for enhancing maximal power and speed, although introducing it before perfecting proper motor patterns could lead to future injuries or an inability to overcome

the opponent's defense. An acute approach angle of the lower limb, as a result of insufficient hip joint rotation, could lead to a hit of the opponent guarding the upper limbs instead of the head. Such mistakes could determine final combat results. Despite greater kicking power, athletes with improper movement patterns may lose. This conclusion could be supported by the role of execution distance when scoring a head strike point during competition (Estevan et al., 2012).

In summary, an optimal training program for the effective execution of the roundhouse kick should take into account different striking conditions. Coaches could consider spending less time while kicking into the air, which is a core of the traditional form of far-east martial art training, as it does not contribute to precision and striking power. Although to preserve the specific character of taekwon-do, balance should be found between traditional forms of practice which highlight the value of the mental component, and novel training programs aimed at optimal performance of athletes.

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