

Target effect on the kinematics of Taekwondo Roundhouse Kick – is the presence of a physical target a stimulus, influencing muscle-power generation?

JACEK WAŚNIK¹, GONGBING SHAN^{2*}

¹ Institute of Physical Education and Tourism, Jan Długosz University of Częstochowa, Poland.

² Department of Kinesiology, University of Lethbridge, Canada.

Taekwondo is famous for its powerful kicking techniques and the roundhouse kick is the most frequently used one. In earlier literature, the influence of a physical target (existing or not) on kicking power generation has not been given much attention. Therefore, the aim of this study was to investigate the kinematics of roundhouse kick execution and its factors related to power generation. 6 ITF taekwondo practitioners voluntarily participated in this study. They were asked to perform kicks with and without a physical target. The first kick aimed at breaking a board while the second one was a kick into the air. A Smart-D motion capture system (BTS S.p.A., Italy) was used to quantitatively determine their kinematic characteristics during each kick. The main findings showed that kicks aiming at a breaking board were significantly slower than kicks without a physical target (maximal kick-foot velocities were 10.61 ± 0.86 m/s and 14.61 ± 0.67 m/s, respectively, $p < 0.01$), but the kicking time of the former was shorter (0.58 ± 0.01 s and 0.67 ± 0.01 , respectively, $p < 0.01$). The results suggest that a physical target will negatively influence the kick-foot velocity, which is not necessarily a disadvantage for creating a high quality kick. Possible motor control mechanisms are discussed for the phenomenon. The study made it clear: trainings with and without physical targets would develop different motor control patterns. More studies are needed for identifying the effectiveness of different controls and efficiencies of their training.

Key words: motor control pattern, power generation, kicking velocity, precision, dynamic balancing, trade-off

1. Introduction

Power, speed, and timing are some of the most important factors for martial arts striking performance [3]. Power can be thought of as explosive force (i.e., the product of force and speed) or an athlete exerting his/her strength quickly. Speed and timing include both muscular speed and reaction time. Aspects of the fundamental parameters of power, speed, and timing have been investigated through a wide variety of indirect and direct methods in the past decades [2], [13], [22], [24], [25]. This body of literature has been summarized in previous studies, including the existing limitations [3]. These past studies reveal the relevance of power, speed, and timing in martial arts striking.

Taekwondo is famous for its powerful kicking techniques [8] and taekwondo practitioners have a wide range of kicks to choose from. However, scientific literature has divulged that the roundhouse kick is the most frequently used one [5], [10]. Previous studies show that the roundhouse kick generates foot kicking velocity from 9.94 m/s to 16.26 m/s [14], [15] and kicking force from 1304 N to 2089 N [5]. Further, a previous investigation unveils that the average duration time of the roundhouse kick is 0.35 s and 0.30 s for Singapore professional males and females, respectively [1]. More studies identify also parameters, such as foot take-off velocity, acceleration, momentum, joint angle control, as well as muscle strength, influencing the duration of the kick [11], [21]. In this earlier literature, one important factor which could po-

* Corresponding author: Gongbing Shan, Biomechanics Lab, Department of Kinesiology, University of Lethbridge, 4401 University Drive, Lethbridge, Alberta, Canada, T1K 3M4. Tel: (403) 329-2683, fax: (403) 329-2709, e-mail: g.shan@uleth.ca

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tentially affect the training effect on power generation of taekwondo kicks, but has not been given much attention, is the influence of a physical target (existing or not) on power generation during a training.

Tactics of taekwondo kicking is to aim at hitting a chosen place on the opponent's body in the shortest time possible. Thus, the ability of power generation is extremely important for an effective offense. Therefore, how to set a training environment/program is vital for maximizing the training effective, as empirical evidence/coach experience has shown different training set-ups would result in various outcomes. As literature review above shows that none of previous studies explore the influence of a target on how to efficiently increase kicking power and speed, at the same time, decrease the action time. To bridge the gap in current literature, the aim of this study is to investigate target effect on kicking kinematics of the roundhouse kick and its possible influences on kick power generation. Two training environments were chosen: a roundhouse kick to break a board and a roundhouse kick without having a physical target. The study was designed to answer the following questions:

1. How does a target setting affect the speed and duration time of the roundhouse kick?
2. What could be the possible effects of a physical target on motor control patterns related to kick power generation?

2. Materials and methods

The study was based on biomechanical/kinematic analysis of 6 taekwondo ITF (International Taekwondo Federation) athletes – 1 female and 5 males (age 16.5 ± 5 years, weight 64.14 ± 7.0 kg, height 176.5 ± 4.6 cm). The subjects' group consisted of European Junior Champions, Polish Junior Champions and skilled performers with a minimum of 4-year training experience (3 to 5 regular training sessions per week).

The kinematic quantification focused on the analysis of foot and knee velocities as well as the kicking time. The method was adopted from well-established one applied in previous studies [20], [23]. Basically, the method employed partial-body biomechanical modeling/analysis for kinematic quantification [17]–[19]. All subjects were informed of the testing procedures, provided written informed consent and voluntarily participated in the study. Subjects were given enough time to warm up in order to reach optimal physical condition for performing the test skills. Each subject

decided on his or her own pacing, so that the individual's optimal motor control patterns could be measured. For a standardization of the test among subjects, the athletes were asked to adopt the same initial stance (Fig. 1) Niunja So Palmok Degi Maki and to perform the roundhouse kick in two versions: version 1: kick aimed at breaking a target board – a plastic re-breakable board with dimensions of $30 \text{ cm} \times 30 \text{ cm} \times 2 \text{ cm}$, and version 2: throwing a kick into the air, i.e., without having a physical target. Each version was performed by each athlete once, which gave a total of 12 executed kicks.



Fig. 1. The initial stance for standardization of tests

A Smart-D motion capture system (BTS S.p.A., Italy) was used to quantitatively determine the selected kinematic characteristics during each kick. The system consisted of six infrared cameras to triangulate the positions of multiple reflective markers that were placed on selected anatomical landmarks of the subjects. The use of such a motion-capture system permitted considerable freedom of movement without influencing the accuracy of data, so no restrictions were placed on the movement of the subject within the capture volume and subjects could perform without having to alter their trained motor control pattern. Using the manufacturer's specified guidelines, calibration resolution yielded results accurate to 0.3–0.45 mm. Data was gathered at 120 frames/second, which allows the finest details of movement to be accurately examined.

The following selected anatomical landmarks related to the power and speed characteristics of roundhouse kicks were analyzed: (1) three components of foot velocity in x direction – v_x [m/s], y direction – v_y [m/s] and z direction – v_z [m/s] (Fig. 1);

(2) three components of knee velocity in x direction – v_{knee-x} [m/s], y direction – v_{knee-y} [m/s] and z direction – v_{knee-z} [m/s] (Fig. 2); and (3) kicking time t [s]. These parameters allowed researchers/practitioners to abstract the uniqueness of the selected performance.

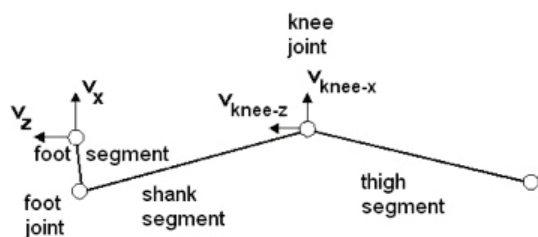


Fig. 2. General view presenting relevant joints and segments of the kicking leg

Descriptive statistics such as means and standard deviations were supplied for characterization of the skills tested, and paired T-tests were performed on kicks with and without a target for the purpose of determining if there was a significance ($p < 0.05$). All statistical analysis was performed using MS Excel 2000.

3. Results

Two major parameters were presented in this investigation: velocities of kicking foot and knee, and kicking time. The results were reported in the form of descriptive statistics, T-test analysis and the directionality of the target effect. The results of descriptive statistics are shown in Table 1. As shown in Table 1, kick foot speeds aiming at a breaking board were overall slower than kicks without a physical target, but the kicking time of the former was shorter. T-tests reveal that almost all variables selected (except v_y and v_{knee-y}) hold significance when looking at the effect of target. Unexpectedly, the differ-

ences identified were highly significant ($p \leq 0.01$). It is of interest that there was a negative effect on the velocity but a positive effect on kicking time. For further elaborating some details related to the dynamic characteristics of the two-version kicks, two representative samples of kick-foot velocity excursions over time were selected and displayed in Fig. 3: the dotted line – the kicking aimed at a breaking board in version 1, and solid line – the kicking thrown into the air in version 2. The velocity excursions over time unveil that the kicking in version 1 had a maximum velocity of 11.38 m/s and kick time of 0.38 s, while the kicking in version 2 ensured a maximum velocity of 14.05 m/s, i.e., 23.5% higher than that in version 1; and kick time of 0.40 s, i.e., 5.3% slower than that in version 1. Further, it is remarkable to see that, around 0.25 s, the kicking velocity in version 1 witnesses a local maximum-and-minimum oscillation: 6.15 m/s and 4.94 m/s, respectively. The oscillation may be linked to different motor control strategies applied in both versions.

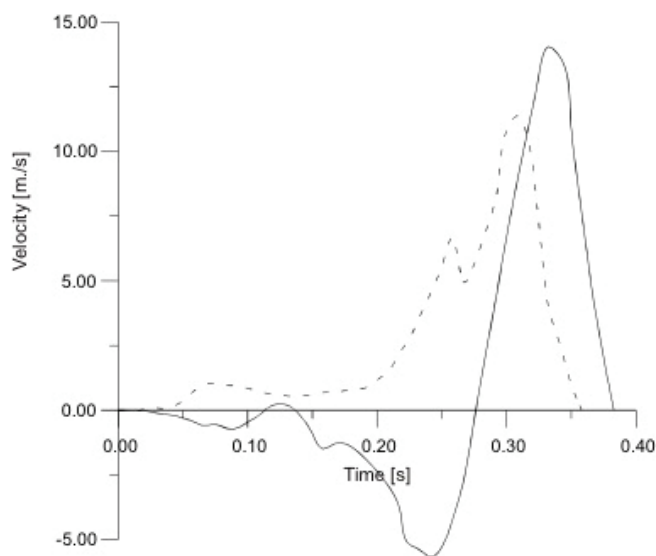


Fig. 3. Example course of foot velocity changes for the kick aimed at a breaking board (dotted line) and for the kick thrown into the air (solid line) with regard to X axis

Table 1. Biomechanical variables which affect kick's effectiveness

Variables	Kicks without a physical target	Kicks aiming at a breaking board	t -test
	Average \pm SD	Average \pm SD	
v_x [m/s] speed of the foot with regard to X axis	14.61 \pm 0.67	10.61 \pm 0.86	0.00388
v_y [m/s] speed of the foot with regard to Y axis	7.09 \pm 0.56	5.86 \pm 0.07	0.06027
v_z [m/s] speed of the foot with regard to Z axis	14.53 \pm 0.05	8.00 \pm 0.47	0.00153
v_{knee-x} [m/s] speed of the knee with regard to X axis	5.28 \pm 0.13	5.79 \pm 0.14	0.01059
v_{knee-y} [m/s] speed of the knee with regard to Y axis	4.74 \pm 0.29	4.73 \pm 0.18	0.97513
v_{knee-z} [m/s] speed of the knee with regard to Z axis	7.35 \pm 0.51	4.82 \pm 0.14	0.00906
t [s] kicking time	0.57 \pm 0.01	0.48 \pm 0.01	0.00258

4. Discussion

One aim of this study was to quantitatively describe effect of a physical target on the kick-foot velocity in the roundhouse kick. Results reveal a physical target to downgrade notably the kick-foot velocity. A cross comparison to previous studies shows that the kick-foot velocities without a physical target are considerably equivalent. The free-kick velocities of elite taekwondo practitioners are reported to be between 13.4 m/s and 15.9 m/s [4], [16]. Collectively, the results of this and previous studies suggest that a physical target will negatively influence the kick-foot velocity. The reasons could be multi-sides.

Firstly, a physical target will change the condition of the performance, i.e., it induces a stimulus to an athlete, influencing his or her motor control strategy-selection. Basically, there are three primary factors influencing muscle power generation: (1) expected limb/segment velocity production. It will affect the shortening velocity of muscles involved [7]. (2) Muscle initial length. This parameter depends on postures applied and will influence the tension generation of muscles involved [7]. And (3) the types of stimulation and the time course of muscle activation following stimulation [7], [12]. The first two should be about the same for kicks with and without a physical target, because the intension of both kicks was the same (kicking as fast as possible) and the standardization of beginning posture set the muscles' initial lengths at an equivalent level. As such, the difference measured should be caused by the third one, because, when breaking a board (i.e., an additional stimulus), logically, the subjects have to adjust his/her motor control pattern to increase/maximize their kick force at the impact to the hard object, which is missing in a kicking into the air.

Secondly, in addition to these primary factors, there are secondary determinants, which arise from interactions between the primary determinants. In the case of Taekwondo Roundhouse Kick, the secondary determinant would be the maximization of muscle-power output at the moment of foot hitting the target. It is known that power – the product of force and speed – represents the ability of how quick an athlete exerts his/her strength, i.e., the explosive force. Aiming at maximizing kick-foot velocity could not guarantee a maximized power (Fig. 4). Figure 4 shows us that maximization of kick power is a control ability to balance the segmental velocity and the muscle force applied. Such an ability could only be increased through targeted training. Therefore, our results would

suggest that, for increasing kick power, regularly applying a physical target in trainings would be essential. From this, we recommend that a quantification of kick power is needed in order to determine whether trainings with a physical target leads to the generation of a maximal power at the foot impact with the target. This will require further studies.

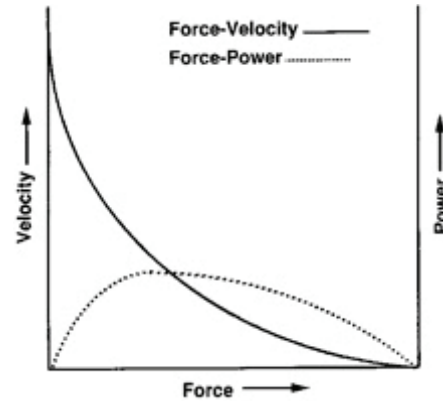


Fig. 4. Relationship among muscle tension, muscle shortening velocity and muscle power (Hall [7])

Thirdly, the control accuracy could be the next influence factor affecting the velocity. It is interesting to see that knee velocity of both kicks are very close, 5.28 ± 0.13 m/s and 5.79 ± 0.14 m/s, respectively (no significant difference). It might be that the subjects feel a need to generate great power by accelerating the flexed leg as much as they could, but then, just before the impact (i.e., before the onset of the foot on the target) they slow down the motion. One explanation for such a motor control is that they try to aim at the exact place where the plastic board is to be broken. The athletes realize that re-breakable boards are rather difficult to tackle, as a failure to hit the board correctly (exactly within the striking area) might result in an injury. As such, the speed-accuracy trade off mechanism [6] occurs. This suggests that the athletes who find it extremely important to hit the target correctly will trade the speed for accuracy.

Lastly, our data further imply some training effect of skilled athletes, such as the capability of dynamic balancing and the ability for a quick adjustment of motor control strategies. The subjects of this study are well trained, therefore their motor control should be very stable. However, the results show that the foot velocity of 10.61 ± 0.86 m/s and kicking time of 0.58 ± 0.01 s achieved in delivering the roundhouse kick aimed at a breaking board are considerably smaller than the foot velocity of 14.61 ± 0.67 m/s and kicking time of 0.67 ± 0.01 s of the kick thrown into the air ($p < 0.01$). Further, the negative velocity ex-

hibited in free kicking (Fig. 3, solid line) could only indicate a larger range of motion, or a less balancing dynamic posture comparing to the kicks at a physical target. Such a phenomenon could indicate that some changes in control pattern happened during the kicks. One possible factor involved might be the fear of the loss of balancing. Experience obtained from years' training would tell athletes that a contact between fast-moving foot and a hard target would cause a possible off-balance. On the other hand, a high explosive force (e.g., power) would break or drive any target away from the trajectory of kick-foot, so that the dynamic balancing of his/her body would be kept. The slow down of kick-foot velocity as well as reducing the range of motion of kick-foot could be understood as a preparation of maintaining dynamic balancing, and the velocity oscillation before impacting the target (oscillation in Fig. 3) most likely related to the adjustment of motor control in order to increase muscle force. Collectively, the results propose that, when seeing a physical target, elite taekwondo athletes automatically adjust their motor control, i.e., slowing down the kicking velocity, reducing the range of motion, at the same time, increasing muscle force to maximize the kicking power, a control state suggested by Fig. 4. Such an ability of "selection" between muscle shortening speed and muscle tension/activation of elite taekwondo athletes could be considered as a training effect.

An alternative explanation for the speed trade-off could be a trade-for-accuracy, not a trade-for-power. Two priorities – precision and speed – may play a role in the decision making. Usually, the precision priority takes over when there is no time limit whereas the speed priority comes first when there is a strictly defined time limit. In some situations, the trade-for-accuracy may be neglected. For example, in light-contact sparring, a competitor scores points for hitting a given part of the opponent's body. It does not matter whether an athlete hits the opponent's temple or jaw as far as the hit is on the head, the points will be valid. However, in many situations, the two priorities work against each other (Fig. 5). In such situations a typical dilemma that an athlete is usually facing is whether to hit once but with great precision (according to the theory of one possibility [9]) or whether to hit as fast as possible taking a risk of being imprecise. Such dilemma in a self-defense situation might simply mean life or death.



Fig. 5. Counter-productive priorities normally considered by Taekwondo practitioners

Since there is no report on the trade-off mechanism in previous literature, further quantitative studies on the relationship among power generation, segmental velocity and strike accuracy are needed conforming one or the other assertion. Presumably, both trades would happen for well-trained athletes. Therefore, studies on training with and without a physical target and their efficiency on strike accuracy and power generation are also essential for demystifying the possible motor control strategies.

5. Conclusions

Summarizing the above, the setting of a target determines how a kick is executed. A physical target will function as a stimulus, affecting the motor control of athletes. The results of current study have shown that a physical target negatively influences the kick velocity, which is not necessarily a disadvantage for creating a high quality kick. In practice, kick quality is mainly associated to power, speed/timing, accuracy and balancing. Multiple motor control possibilities exist for increasing the kick quality. Currently, it is not clear what the best control looks like. The results of this study suggest only that trainings with and without physical targets will develop different motor control patterns. More studies are needed for demystifying the know-how of an effective roundhouse kick and an efficient way of its training.

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