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The kicking process in tae kwon do: a biomechanical analysis; running title: biomechanical analysis of taekwondo

Abstract

Objectives: There is a dearth of studies examining the kicks used in Tae Kwon Do (TKD). This study sought to compare the biomechanics of various TKD kicking techniques.

Methods: A motion analysis video-camera based system was used to study the biomechanics of three different types of kicks performed by five Black Belt level athletes. The velocity of the kicking foot, the velocity of the pelvis, and the lower body linear momentum were estimated to compare the kicking techniques.

Results: Similar patterns of ankle, knee, and hip movement were found for different kicks. The greatest peak foot velocity was observed for the front kick. The peak linear momentum of the lower body was highest for the side kick. Subjects who were able to simultaneously reach peak pelvis velocity and peak lower body linear momentum displayed the best performance. Techniques performed with a step forward after the kicks delivered a more powerful blow than techniques performed by returning to the initial position.

Conclusion: This study shows that the fastest kick is the front kick and the most powerful kick is the side kick. The effectiveness of the technique is associated with the coordination of movement of the pelvis and lower body.

Keywords: martial arts, biomechanics, tae kwon do, sports injuries

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Introduction

There are various forms of martial arts practiced throughout the world, each with its own philosophy and style.[1–3] Tae Kwon Do (TKD) is a popular Korean martial art and the most commonly practiced one in the United States. About 2 million people participate in martial arts throughout the United States.[4] When practiced as a light contact sport, TKD is considered relatively safe.[5–7] The increasing interest in TKD is reflected in its recent incorporation into the Olympic Games.[8,9] There are a variety of kicks taught within the sport, which are thought to have different applications and powers. The differences in the biomechanics of the individual kick styles may be accompanied by different injury risks.[10,11] Few studies have rigorously addressed these differences.

While some studies have described the types of injuries that take place in TKD,[12,13] the question of how these injuries occur has not been addressed. Most TKD kicking techniques embody high speed and power, and thus present an increased potential for injury.[14] The forces that are generated depend on the kick and how the kick is executed. Some kicks involve stepping towards the target, following a kick. Other kicks involve leaving the ground. Some involve rotation of the pelvis, others involve spinning motions. The kinetics of these separate motions remains unclear.

In a study done by Serina et al.[15] the potential incidence of thoracic injury as a result of various TKD kicks was analyzed. A series of four basic kicks were studied including the roundhouse, turning roundhouse, back and sidekicks. The velocity and energy produced by each kick was calculated. They found that the roundhouse and turning-round house kicks are the fastest and they argued that therefore these kicks have the greatest potential for causing soft tissue injury. They also suggested that the back and side kick may predispose a TKD opponent to the highest likelihood of injury given the level of chest compression caused by these kicks.

Robertson et al.[16] used a biomechanical model to describe the occurrence of peak power during a front kick. They found that the peak power during a front kick was greater for the open stance than for the closed stance position. They also found that the hip extensors and flexors were the prime movers of both the hip and knee.

These studies have however lacked a thorough analysis of the motor strategies employed to deliver a powerful blow. This is important information for TKD proponents who teach this martial art as a means of self defense. In addition, as TKD is becoming an increasingly popular sport, understanding the biomechanics of the various kicks may be used to improve competitiveness and safety within the sport. This may have clinical relevance for the sports medicine physician in that patients may be educated on both how they can improve their strategy and safety during the kicking process.

In this study, TKD black belts were recruited to investigate the effectiveness of three types of kicks: the front kick, side kick and round kick completed using two different techniques to deliver the blow. In the first technique, the kicking leg started as the back leg and returned to its original position after the kick was completed. In the second technique, the same back leg was used to kick and then, after completion of the kick, stepped down in the direction of the target. Data was derived using a motion analysis camera-based system and used to study the motor strategies utilized to deliver the most effective blow and contrast the investigated types of kicks and techniques to deliver the blow.

Methods

Five adult men and women were recruited with the assistance of the American Tae Kwon Do Association. Their main characteristics are described in Table 1. All participants were active and held the rank of third degree black belt or higher. All participants gave informed consent. The kicks were all performed from the normal "fighting" stance with one limb remaining in contact with the ground throughout the duration of the kick. Subjects were asked to forcefully kick at an imaginary target.

Table 1 Characteristics of the subjects recruited in the study

Subject	Height(m)	Mass(kg)	Sex
1	1.61	52	F
2	1.75	74	M
3	1.77	88	M
4	1.75	101	M
5	1.74	55	F

Subjects were asked to perform three types of kicks: front kick, side kick, and round kick. Each kick was performed using two techniques to deliver the blow, i.e. either returning the kicking leg to its original position or stepping forward into a front stance after completing the kick. Therefore, a total of six kicks were studied. In the following, they are referred to as: front-back, front-forward, side-back, side-forward, round-back, and round-forward. The terms back and forward refer to the technique of returning the kicking leg to its original position (back) and the technique of moving into a front stance after completing the kick (forward). Subjects were allowed to repeat the kick if the kick had been improperly performed. Eight repetitions of each kick were recorded and analyzed. For all subjects, the kicking leg was the right leg and the stance limb was the left leg.

The kicks were recorded using an 8-camera motion analysis system (Vicon). Subjects wore 15 lightweight reflective markers to track the kinematics of the lower body according to a standard model.[17,18] Kinematic data were recorded at 120frames/s. The motion data were analyzed using a biomechanical model consisting of seven rigid body segments, including the stance and kicking limb feet, legs and thighs, linked by a pelvic segment.[17,18]

The beginning of the kick was defined by the instant when the kicking foot velocity reached 2.5 % of its maximum velocity. The end of the kick was taken to be the instant when the kicking foot reached its highest vertical position. The data showed that this occurred about 20% of the kick period after the peak foot velocity. As TKD students are taught to kick to a point beyond their imaginary target, the time of maximum foot velocity approximates target impact time.

Three variables descriptive of kick biomechanics were calculated: the velocity of the kicking foot, the velocity of the pelvis, and the normalized lower body linear momentum. The normalized lower body linear momentum was calculated by estimating the velocity of each of the seven body segment centers of mass and multiplying it by the segment's fractional contribution to body mass. The lower body linear momentum indicates how powerful the blow delivered to a potential target would be if it were to reach the target. Body segment mass distribution and center of mass positions were estimated from data tabulated by Winter.[19] The three above-described variables were normalized by dividing each subject data by the maximum value achieved for that variable by each individual across all types of kicks and techniques to deliver the blow. Such normalization was intended to account for differences in individual ability.

Joint kinematics in the sagittal plane of movement was quantitatively compared via inspection of group average trajectories. Group means and standard deviations were estimated for the peak velocity of the kicking foot, the peak velocity of the pelvis, the peak normalized lower body linear momentum, and the value of the normalized lower body linear momentum corresponding to 80% of the duration of the kicking movement (i.e. the expected time of impact, were a target actually present). Although adequate to perform a preliminary descriptive assessment of different types of kicks and techniques to deliver the blow, the sample size utilized in this study did not allow us to perform further statistical analysis.

Results

Qualitative description of kick kinematics and kinetics

The kicking limb joint angles were similar across the different kicks (Figure 1). All the kicks ended with the hip flexed and the knee nearly fully extended. The sidekicks ended with the ankle in a neutral position while the other kicks ended with the ankle maximally plantar flexed.

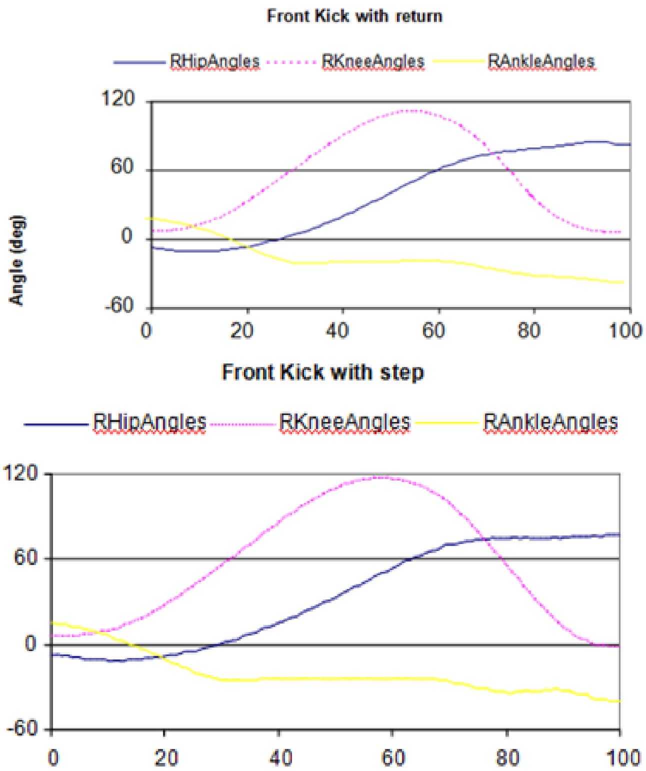

Figure 1 Group mean hip, knee, and ankle joint angles of the kicking leg. Data are shown for the six kicks investigated in this study

The velocity profiles of the various kicking styles showed similar overall profiles, but differences in magnitude and timing among the kick styles were observed (Figure 2). Foot velocity showed a peak at about 75% of the kick duration. Pelvis velocity reached a peak early during the kick. For the side kick there was a pronounced second peak occurring at mid-kick. The normalized lower body linear momentum also showed a peak about mid-kick.

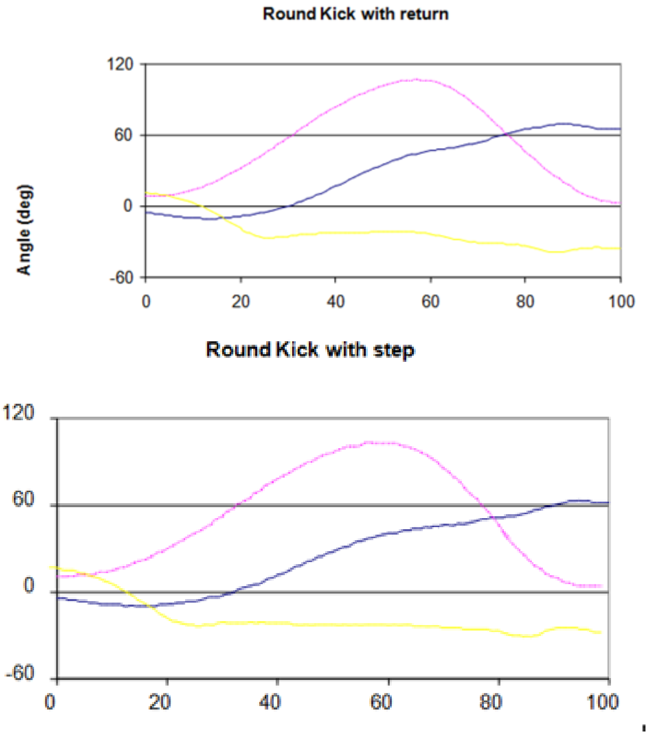

Figure 2 Peak foot velocity, peak pelvis velocity, peak normalized lower body linear momentum, and value of the lower body linear momentum corresponding to 80% of the duration of the kick. Mean plus standard deviation values are shown

The foot velocity was lowest for the side kick and highest for the front kick. For each kick type, the kick with a step towards the target achieved greater normalized lower body linear momentum than kicks followed by a return to the original position. The ranking of peak normalized lower body linear momentum was the opposite of peak foot velocities, i.e., the peak normalized lower body linear momentum was the highest for the side kick and the lowest for the front kick.

Magnitude of peak foot velocity, pelvis velocity and lower body linear momentum

Analysis of mean and standard deviation values of the peak foot velocity data supported the observation that foot velocity was greatest for front kicks, followed by round kicks and slowest in sidekicks (Figure 3). For the peak pelvis velocity and the peak normalized lower body linear momentum the opposite trend was observed, i.e., the side kick produced the greatest peak values and the front kick, the smallest ones. For pelvis velocity and normalized lower body linear momentum, a trend was observed towards increased values for the kicks followed by a forward step compared to the kicks followed by a return to the starting position.

Ouch factor

Peak foot velocity and peak normalized lower body linear momentum provided divergent information as to which kick would deliver the most powerful blow. The maximum peak foot velocity was achieved in the front kicks while the maximum peak normalized lower body linear momentum was observed for the side kick, the kick that produced the lowest peak foot velocity. Also, disparities were observed in the timing of these events. The peak foot velocity occurred at about 75% of the kick duration, which approximates the time of impact, were a target actually present. Peak normalized lower body linear momentum occurred at about mid-kick, significantly before the presumed target impact. To resolve this issue we determined the maximum value of normalized lower body linear momentum in the interval from 80 to 100% of kick duration. Since lower body velocity monotonically decreased in the last 20% of the kick, finding the maximum value in the interval between 80 and 100% was equivalent to determining the lower body velocity at 80% of the kick, i.e., "the contact time." The normalized 80% lower body linear momentum (Figure 3), which is our best estimate of the presumed effect of the kick (termed the "ouch factor"), indicated that the side kick is the most powerful kick and the front kick is the least powerful. This parameter also indicated that kicks performed by stepping forward after the kick were consistently more powerful than the corresponding kicks performed by returning to the starting position. The peak pelvis velocity, peak normalized lower body linear momentum, and 80% lower body linear momentum parameters were consistent in this regard.

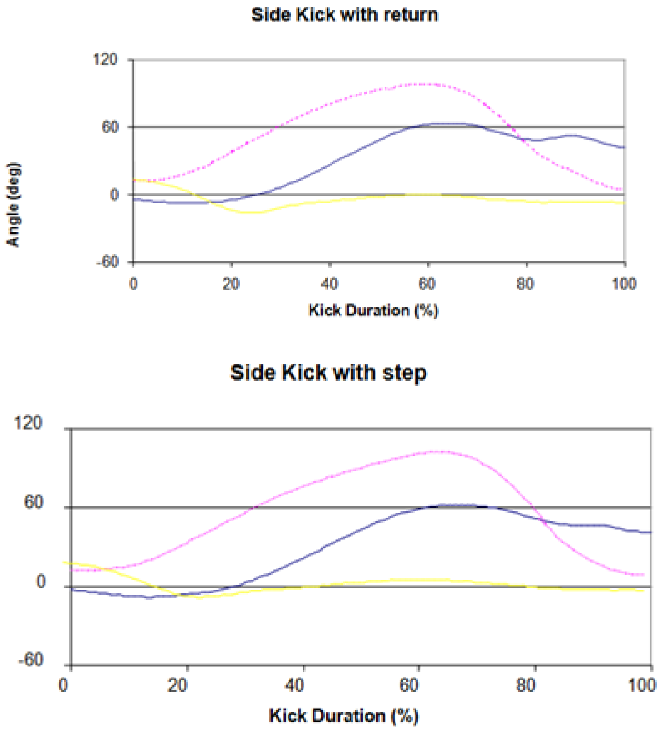

Figure 3 Upper plot, relationship between peak pelvis velocity and peak normalized lower body linear momentum for the sidekicks. Lower plot: timing of peak pelvis velocity and peak normalized lower body linear momentum. Data are shown for all five subjects recruited in the study; numbers represent each subject

Coordination of the pelvis and lower body

Some insight as to how individuals achieve optimal performance could be gleaned from reviewing the relationship between pelvis velocity and normalized lower body linear momentum. The magnitude and timing of the peak pelvis velocity and the peak normalized lower body linear momentum in the most powerful kick, the side kick, were compared as shown in Figure 4. The upper plot shows peak pelvis velocity and peak normalized lower body linear momentum. Values are shown in mm/s for each individual. Except for subject 3, a close relationship between the magnitudes of the peak pelvis velocity and the peak normalized lower body linear momentum is demonstrated. Subject 3's side kick performance appeared to be limited by an inability to generate a powerful kicking leg action coupled with pelvic movement. The lower plot of Figure 4 shows the occurrence of the peak pelvis velocity and the occurrence of the peak normalized lower body linear momentum. For subjects 1 and 4, the peak pelvis velocity occurred at a different time during the kick than the peak normalized lower body linear momentum. For these subjects, the maximum pelvis velocity occurred early during the kick and the mid-kick pelvis velocity peak normally seen in sidekicks was weaker or absent. Thus, generating a forceful side kick appears to require both performing appropriately fast kicking leg and lower body movements, as well as synchronizing such movements. Only subjects 2 and 5 achieved this optimal combination. The values of the peak normalized lower body linear momentum for these two subjects were in fact higher than the values observed in the other individuals.

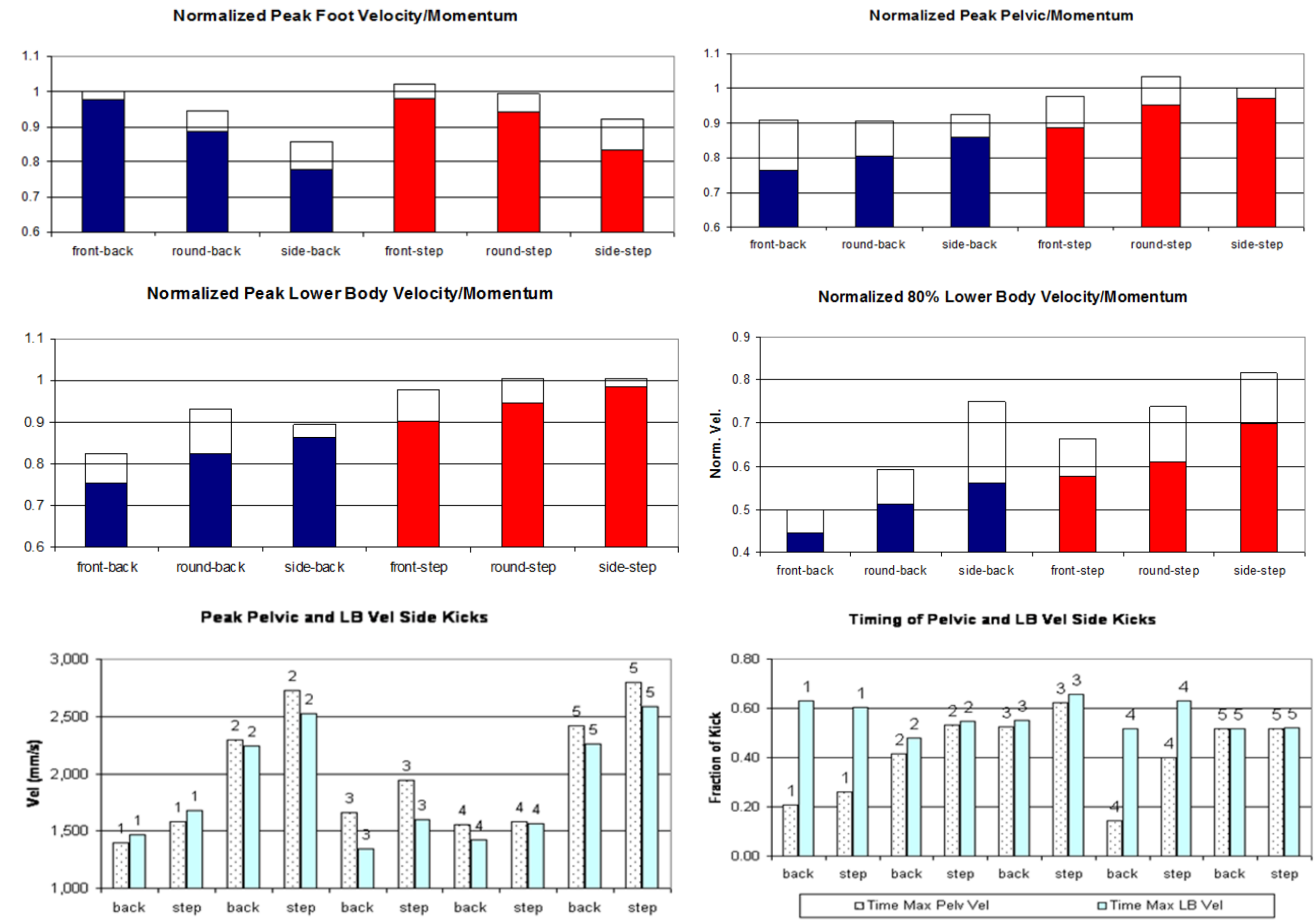

Figure 4 Occurrence of the peak pelvis velocity and the occurrence of the peak normalized lower body linear momentum.

Discussion

There are only few studies that thoroughly examined TKD kicks and compared them from a biomechanical standpoint, none of which demonstrated that the coordination of pelvis and lower body movements affects the effectiveness of the kicking technique. These results are important in determining which of the basic TKD kicks delivers the most powerful blow (i.e., "ouch factor"). These results can be useful to a martial arts practitioner who is in training, as well as to instructors who teach martial arts. The choice among the available kicking techniques is the focus of many martial arts discussions.[20] The data herein presented indicate that the side kick is the most powerful technique. The side kick is followed by the round kick and then the front kick.

In addition to the type of kick being used, the way in which the kick is delivered is often a source of discussion.[21,22] Since TKD is often taught as a style of weaponless defense which can be used against several opponents at once, traditional TKD training often teaches an individual to kick an opponent and then move the foot back to its place of origin rather than stepping with the striking leg toward the target. This sequence allows a second strike to be launched in any direction. Stepping towards the target at the end of a kicking sequence is not taught unless one is pursuing an opponent, or is seeking to maximize power. While this has a great deal of face validity, the results presented in this paper are the first to show quantitatively how effective this is. Stepping towards the target does increase the magnitude of the lower body momentum, and therefore, this technique is the most effective to deliver a powerful kick.

In TKD, it has been thought that the faster a kick, the more powerful the kick. The present analysis demonstrates that there was no direct correlation between the velocity of the foot and the linear momentum associated with the lower body. The magnitude of the foot velocity was found the greatest with the front kick, which produced the least low body momentum. Thus, one must consider the desired effect of the kick. If the goal is to reach the target quickly, the choice of kick would differ from that which would be appropriate to reach the target with the most powerful blow. According to Serina et al.[15] an analysis of the roundhouse, spin roundhouse, side and back kick, revealed that the average foot velocity for the round house kicks was 80 percent greater than the side and back kicks. In this study, the emphasis was placed on how TKD kicking techniques embody high speed and power and how this can cause a greater potential for thoracic soft tissue injuries. During competition, it is not necessary to deliver a blow with a great deal of force. In fact, as the rules of many organizations now prohibit excessive contact.[5] the development of a great amount of force is contraindicated. As the scoring of points in most cases involves light contact or "near contact", one might view it as more desirable to launch an attack with the most velocity.

The data obtained in this study add some validity to the ancient discussion about the movement of the chi/pelvic region when delivering a kick.[23] As taught, the power of a kick is generated through the TKD practitioner moving the area of the chi towards the target as one coordinates a kick. As this level is described as residing within the pelvic region, in an area close to or just below the umbilicus, our correlate was taken as that of pelvic movement. It is quite instructive, therefore, to demonstrate that the pelvic velocity correlates better with the lower body linear momentum than the velocity of the striking surface. Although the results of this study have to be considered as preliminary, they do provide some scientific insight into the validity of the ancient teachings of martial arts. In addition, our data do suggest why the performance of the martial art takes years to perfect. Only those who coordinated pelvic and leg movement were able to maximize the effect of their kicks. Such coordination is emphasized in training.

Subjects recruited in this study kicked at an imaginary target and therefore the magnitude of the linear momentum of the lower body was taken as an estimate of the effectiveness of the kick. In future studies, we intend to measure forces while the practitioners hit an actual target to account for modifications in the motor strategy in preparation for the impact with the target. Indeed, studies of kicking of targets reveal that kick velocity decreases before target impact.[2] Also, we intend to take into account that injury potential is a function of where the opponent is struck, which may be affected by kick style. The opponents' defensive/avoidance technique is also a factor, which, in turn, may be related to kick duration as well as the velocities achieved.

Conclusion

This study shows a difference in momentum generated by martial arts kicks and indicates that coordinated movement of the pelvis and lower limbs is a critical component in development of linear momentum by the martial arts practitioner. Our data indicate that kicks completed by stepping forward into a front stance produce more momentum than those in which the kicking leg is returned to its original position.

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Conflict of interest

The author declares no conflict of interest.

References

1. Brudnak MA, Dundero D, Van Hecke FM. Are the 'hard' martial arts, such as the Korean martial art, TaeKwon-Do, of benefit to senior citizens? *Med Hypotheses*. 2002;59(4):485–491.
2. Chan K, Pieter W, Moloney K. Kinathropomietric profile of recreational taekwondo athletes. *Biology of Sport*. 2003;20(3):175–179.
3. Heller J, Peric T, Dlouhá R, et al. Physiological profiles of male and female taekwon-do (ITF) black belts. *J Sports Sci*. 1998;16(3):243–249.
4. Toskovic NN, Blessing D, Williford HN. The effect of experience and gender on cardiovascular and metabolic responses with dynamic Tae Kwon Do exercise. *J Strength Cond Res*. 2002;16(2):278–285.
5. D Burke, K Barfoot, S Bryant, et al. The effect of implementation of safety measures in Tae Kwon Do competition. *Br J Sports Med*. 2003;37(5):401–404.
6. Pary LF, Rodnitzky RL. Traumatic internal carotid artery dissection associated with taekwondo. *Neurology*. 2003;60(8):1392–1393.
7. Pieter W, Zemper ED. Incidence of reported cerebral concussion in adult taekwondo athletes. *J R Soc Health*. 1998;118(5):272–279.
8. Koh JO, Watkinson EJ. Video analysis of blows to the head and face at the 1999 World Taekwondo Championships. *J Sport Med Phys Fit*. 2002;42(3):348–353.
9. Patel DR, Stier B, Luckstead EF. Major international sport profiles. *Pediatr Clin N Am*. 2002;49(4):769–792.
10. Pucsok JM, Nelson ED. A Kinetic and Kinematic Analysis of the Harai-goshi Judo Technique. *Acta Physiol Hung*. 2001;88(3–4):271–280.
11. Sung NJ, Lee SG, Park HJ. An Analysis of the Dynamics of the Basic Taekwondo Kicks. *US Taekwondo J*. 1997;6:10–15.
12. Birrer RB. Trauma Epidemiology in the Martial Arts:The Results of an Eighteen Year International Survey. *Am J Sports Med*. 1996;24(6):S72–79.
13. Siana JE, Borum P, Kryger H. Injuries in tae kwon do. *Br J Sports Med*. 1986;20(4):165–166.
14. Layton C. How fast are the punches and kicks of traditional Shotokan karateka? *Tradition Karate*. 1991;4:29–31.
15. Serinae ER, Lieu DK. Thoracic injury potential of basic competition taekwondo kicks. *J Biomech*. 1991;24(10):951–960.
16. Robertson DGE, Beaulieu F, Fernando C. Biomechanics of the Karate Front Kick. Proceedings of the Fourth World Congress of Biomechanics; Canada. 2002. p. 592–594.
17. http://archive.org/search.php?query=publish-er%3A%22New+York%3A+Courant+Institute+of+Mathematical+-Sciences%2C+New+York+University%22php?query=publisher%3A%22New+York%3A+a-+Institute+of+Mathematical+Sciences%2C+New+York+University%22
18. Kadaba MP, Ramakrishnan HK, Wootten ME. Measurement of lower extremity kinematics during level walking. J Orthop Res. 1990;8(3):383–392.
19. Winter DA. Biomechanics and Motor Control of Human Movement. 2nd ed. New York: John Wiley and Sons; 1990. p. 1–88.
20. Sørensen H, Zacho M, Simonsen EB. Dynamics of the martial arts high front kick. J Sports Sci. 1996;14(6):483–495.

21. Putnam CA. segment interaction analysis of proximal-to-distal sequential segment motion patterns. Med Sci Sports Exerc. 1991; 23(1):130−144.
22. Sforza C, Turci M, Grassi GP, et al. Repeatability of Mae Geri-Keage in Traditional Karate: A Three- Dimensional Analysis with Black Belt Karateka. Percept Mot Skills. 2002;95(2):433−444.
23. Saltzberg JR, Hondzinski JM, Flanders M. Humans adapt the initial posture in learning a whole-body kicking movement. Neurosci Lett. 2001;306(1-2):73−76.