

# BIOMECHANICAL PERFORMANCE FACTORS FOR DEVELOPMENT OF MINIMUM DISABILITY REQUIREMENTS IN PARA-TAEKWONDO — PART 1

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**Abstract. Objective:** To assess taekwondo sparring performance variables, such as joint ranges of motion, reaction times, and kicking foot speeds, to serve as a framework for developing sport-specific classification in Para-taekwondo competition. **Methods:** After a standard taekwondo warm up, athletes executed five popular scoring techniques, back kick, cut kick, fast kick, turning kick, and tornado kick five times each (25 total). Kinematic and kinetic variables were recorded by a motion capture system of seven infrared cameras and two force plates. Maximum joint range of motion, foot velocities, and reaction time were calculated. **Results:** Collapsed over kick, maximum hip abduction motion, maximum hip flexion, maximum knee flexion, peak foot velocity, reaction time for male athletes were  $47.8 \pm 10.4^\circ$ ,  $46.3 \pm 7.6^\circ$ ,  $105.3 \pm 14.0^\circ$ ,  $11.5 \pm 2.4$  m/s, and  $0.46 \pm 0.06$  s respectively. maximum hip abduction motion, maximum hip flexion, maximum knee flexion, peak foot velocity, reaction time for female athletes were  $49.1 \pm 6.8^\circ$ ,  $43.9 \pm 11.0^\circ$ ,  $94.2 \pm 13.7^\circ$ ,  $10.9 \pm 2.2$  m/s, and  $0.48 \pm 0.11$  s respectively. **Conclusions:** The results of this study provide a foundational framework for future studies designed to compare and assess Para-taekwondo athletes with various physical and neurological impairments. From this, future studies may move towards developing practical on-site sport specific testing methods which may ultimately assist in making taekwondo-specific classification for Para-taekwondo competitions.

**Key words:** para-taekwondo, classification, kinematics

## Introduction

The World Taekwondo Federation (WTF) is one of the largest international sport federations with 205 member nations including approximately 80 million practitioners worldwide ([www.wtf.org/wtf\\_eng/site/about\\_wtf/intro.html](http://www.wtf.org/wtf_eng/site/about_wtf/intro.html)). In this sport's relative young history, several significant milestones have been passed such as inclusion as an official Olympic medal sport for the 2000 Sydney Games by 1994, just six years after holding demonstration sport

status at the 1988 Seoul Games. At the 2012 Games in London 63 nations were represented by 128 athletes. Along with the success of taekwondo as an Olympic sport, participants representing numerous physical and intellectual impairments have represented the Paralympic movement via different taekwondo competition formats (full contact sparring (i.e. kyorugi) and pattern presentation (i.e., poomsae). In 2015, taekwondo was officially included to the 2020 Paralympic Games program. Along with this addition, the taekwondo community has been fostering other partnerships with groups, such as the International Federation for Persons with Intellectual Disability, International Blind Sports Federation, and the Cerebral Palsy International Sports and Recreation Association.

In 2009, the 1st World Para-taekwondo Championships were held in Baku, Azerbaijan where 38 competitors (representing four disability classes; athletes with upper-limb amputations) from 19 countries participated. In 2013 the 4th World Para-taekwondo Championships were held with 86 competitors representing 25 WTF member nations. Current full-contact sparring championships include four classes of athletes with upper-arm amputations and peripheral neurological impairments.

As athletes present with a number of physical impairments (acquired limb deficiency, congenital limb deficiency, and paralyses), the current classification has been divided into single and double amputations, where levels of impairment are defined by the location of amputation (e.g., K41: bilateral arm amputation or dysmelia, through the shoulder joint with a total loss of humerus, K42: unilateral, through the shoulder amputation or dysmelia, or bilateral above the elbow amputation, K43: bilateral amputation through or below the elbow, K44: unilateral through the wrist amputation or a monoplegia, or a significant loss in muscle strength (loss of 2 grades) in elbow flexion or extension or cannot complete one heel raise to 25 degrees. Athletes participating with various congenital limb deficiencies are also included within these classes and compete within the four aforementioned classes depending on the location of the limb deficiency. Although the WTF has seen increasing participation at the World Para-taekwondo Championships, a young history with 32 total divisions (male and female categories, four weight categories each with four impairment classifications) has at times led to joint classifications (K43 joined with K44 participants into K44/K43 class). This dilemma for ensuring fairness, presented by joint classifications in competition, warrants evidence-based classification.

As the popularity of Para-taekwondo movement demands a more comprehensive sport specific classification, the WTF has recently launched an aggressive effort to institute research aimed at providing groundwork for understanding biomechanical parameters that effect performance among non-Paralympic participants (i.e., those with no physical impairments) and athletes with physical impairments (e.g., upper limb amputations and other limb impairments). The IPC calls for evidenced-based study to develop minimum disability criteria to aid in an understanding of fundamental movements and other performance characteristics among able-bodied competitors (Beckman and Tweedy 2009); therefore, an investigation of these components in Para-taekwondo is warranted. In line with recommendations by Tweedy and Vanlandewijck (2011) the objective of this study was to work towards correctly classifying eligible impairments according to the extent of activity limitation they cause. Thus, we set out to measure biomechanical performance characteristics (i.e., joint range of motion during kicking, functional reaction time, and peak kicking velocity) which are vital factors for success in elite taekwondo sparring competition. This study is the first step of a multi-part series of investigations aimed at developing minimum disability requirements and ensuring an evidence based classification system is adopted WTF sanctioned Para-taekwondo competitions.

## Methods

Athletes participating in this study executed five kicks (offensive turning kick, fast kick, cut kick, jump back kick, and tornado kick) used during Para-taekwondo competition. Each athlete performed five repetitions of the five kicks in blocked randomization. All kicks were performed at torso height as the WTF Para-taekwondo competition rules prohibit head kicks.

Although it is understood that sparring performance is a multitude of various physical attributes (speed, agility, reaction time, execution time, strategy, timing, power, distance management, etc.) we aimed to observe the most common techniques used during sparring in the most realistic, however controlled, environment as possible. In an effort to ensure this environment existed, participants were asked to execute each technique as quickly as possible in response to an LED light situated near the kicking target. Participants executed each technique a total of five times yielding 25 total trials.

Motion capture data were collected using seven MX-13 Vicon infrared cameras (Vicon Motion Capture Systems Ltd., Oxford, England) and two BP400600 AMTI force plates (Advanced Mechanical Technology, Inc., Watertown, MA USA). Kinematic data were collected at 150 Hz. Ground reaction force data and the LED analog signal were used to obtain reaction time were collected at 1500 Hz. Kicking speeds, joint angles, and body positions were obtained by using a 40 retro-reflective marker set with markers placed on bony anatomical landmarks.

## Participants

Six elite sparring (3 female [22 ±5 years, 170 ±5 cm, 67 ±3 kg] 3 male [22 ±5 years, 170 ±5 cm, 67 ±3 kg]) competitors volunteered for this study. All participants reported more than 10 years of taekwondo experience and were members of a first division university sparring team.

## Testing procedures

This study was approved by an internal ethics board of the WTF adhering to the Helsinki Accord. Participants were orally briefed on the study objectives, testing procedures, and were provided an informed consent to sign prior to participation. All participants were asked to warm-up prior to testing and given a period of time to become familiar with the testing protocol. Participants were asked to execute all techniques with both feet on two force plates, and were instructed to engage in natural footwork movements prior to kicking. A teammate was asked to hold the kicking target (hand-held pad for all kicks and a kicking shield for the jump back kick) at an individually determined distance from the kicking stance. All athletes were prompted to kick by the LED light flashing, by which time the athlete was to execute the selected kick as quickly as possible.

## Data acquisition

All data were acquired using the Vicon Nexus platform. The raw kinematic data were labeled, then exported as C3D files and imported into Visual 3D (C-Motion, Germantown, MD, USA). All motion capture data were processed using the interpolation function for a maximum of 10 frames and a low pass filter with a cut off frequency at 15 Hz. Reaction time was calculated as the time period from the point of stimulus, an LED signal, until the raising of the kicking foot off the force platform. The maximum kicking foot speed was calculated as the maximum of the kicking foot segment speed before the point of impact. For the three components, flexion/extension, adduction/

abduction and internal/external rotation hip angle was calculated as the relative angle between the pelvis and the thigh segment. Similarly the knee angle was calculated as the relative angle between the thigh and shank segment.

## Statistical Analysis

This was an observational study in which the objective was to quantify the biomechanical measures that have the greatest affect on performance in taekwondo. As this project was the first step in a series of observational studies aimed at ultimately developing a highly standardized Para-taekwondo-specific activity limitation test protocol, data in this study were assessed in descriptive terms. As males and females do not compete in combined divisions, statistical comparisons were not performed between genders.

## Results

The means and measures of central tendency for peak foot velocity (FVEL), maximum hip abduction motion, maximum hip flexion, maximum knee flexion, foot velocity and reaction time for each individual kick for males and females are presented in Tables 1 and 2 respectively. Additionally, the mean and standard deviation collapsed over all kicks for each measure are presented for males and females.

**Table 1** Descriptive statistics (mean  $\pm$ SD) of biomechanical measures of kicking performance by type of kick among female participants

Kicking Technique	Maximum Hip Abduction	Maximum Hip Flexion	Maximum Knee Flexion	Foot Velocity (m/s)	Reaction Time (s)
Back	52.1 $\pm$ 3.7°	33.0 $\pm$ 6.6°	84.6 $\pm$ 3.9°	10.1 $\pm$ 0.7 m/s	0.52 $\pm$ 0.09 s
Cut	53.3 $\pm$ 4.6°	43.2 $\pm$ 11.0°	99.0 $\pm$ 25.1°	7.7 $\pm$ 1.1 m/s	0.53 $\pm$ 0.09 s
Fast	44.3 $\pm$ 8.1°	45.9 $\pm$ 8.9°	90.3 $\pm$ 3.8°	10.9 $\pm$ 0.5 m/s	0.41 $\pm$ 0.13 s
Turning	44.5 $\pm$ 5.1°	53.5 $\pm$ 7.2°	93.7 $\pm$ 10.1°	13.5 $\pm$ 0.9 m/s	0.45 $\pm$ 0.12 s
Tornado	53.5 $\pm$ 6.0°	43.2 $\pm$ 11.0°	103.1 $\pm$ 3.1°	12.6 $\pm$ 0.7 m/s	0.53 $\pm$ 0.09 s
All Kicks	49.1 $\pm$ 6.8°	43.9 $\pm$ 11.0°	94.2 $\pm$ 13.7°	10.9 $\pm$ 2.2 m/s	0.48 $\pm$ 0.11 s

**Table 2.** Descriptive statistics (mean  $\pm$ SD) of biomechanical measures of kicking performance by type of kick among male participants.

Kicking Technique	Maximum Hip Abduction	Maximum Hip Flexion	Maximum Knee Flexion	Foot Velocity (m/s)	Reaction Time (s)
Back	46.4 $\pm$ 8.7°	38.6 $\pm$ 7.1°	102.2 $\pm$ 14.9°	10.7 $\pm$ 0.5 m/s	0.50 $\pm$ 0.05 s
Cut	55.2 $\pm$ 7.6°	44.2 $\pm$ 4.8°	108.3 $\pm$ 9.8°	8.0 $\pm$ 1.1 m/s	0.46 $\pm$ 0.05 s
Fast	43.4 $\pm$ 7.3°	46.0 $\pm$ 2.8°	107.0 $\pm$ 13.5°	11.3 $\pm$ 0.3 m/s	0.42 $\pm$ 0.06 s
Turning	41.9 $\pm$ 6.6°	53.8 $\pm$ 5.2°	103.0 $\pm$ 14.7°	13.8 $\pm$ 1.5 m/s	0.43 $\pm$ 0.04 s
Tornado	53.0 $\pm$ 13.1°	46.9 $\pm$ 5.6°	103.3 $\pm$ 17.6°	14.1 $\pm$ 0.8 m/s	0.50 $\pm$ 0.06 s
All Kicks	47.8 $\pm$ 10.4°	46.3 $\pm$ 7.6°	105.3 $\pm$ 14.0°	11.5 $\pm$ 2.4 m/s	0.46 $\pm$ 0.06 s

## Discussion

The results from the current study hold value from a few different standpoints. Although there are a number of earlier studies (Capozzo et al. 1997; Curran and Frossard 2012; Fife et al. 2012) that have reported kinematic and

kinetic assessment of taekwondo kicks, our study present three (i.e., cut, fast, tornado kick) techniques that have not been presented in the literature before. Because we included three additional kicks that are most often used for scoring during competition, the results of this study provide a base of comparison for future studies aiming to evaluate the effects of various impairment types on taekwondo performance variables.

As there are no published studies reporting the biomechanical characteristics of the cut, fast and tornado kick, it may be difficult to verify the validity these measurements in comparison to other existing studies. However, the maximum kicking foot speeds reported for both back kick and the turning kick are similar to those reported by Fife et al. (2012) respectively, 9.67 to 11.45 ms<sup>-1</sup>, 10.8 to 13.02 ms<sup>-1</sup>. Furthermore, the reaction times were similar to the reaction times of elite karate practitioners (Curran and Frossard 2012). Results from these previous studies and the current study indicate, even with a low number of recruited participants, results can be confirmed as performance levels to be expected among this level of athletes.

Recent recommendations (Beckman and Tweedy 2009) from the IPC, guide researchers to conduct a process-focused approach encompassing evaluations of the validity and methods used to characterize classes from an empirical basis rather than that of the judgment of a community of experienced classifiers. The measurement of impairments is most appropriate when conducted with a battery of test(s) that are simple, convenient and have objective methodology that can be confirmed through further analyses of validity and reliability (Beckman and Tweedy 2009). As our study has selected the most common kicks used during competition with objective biomechanical measures (reaction time, kicking velocity, etc.) that are important for performance during competition, it may be possible to develop a convenient field test (Mori et al. 2002) to determine minimum disability requirements based on performance characteristics evaluated in the current study.

Beckman and Tweedy (2009) provided a simple battery of tests that are common movements used during athletics training and can be easily administered during a competition as a measure of minimum disability requirements as well as activity limitation test batteries. As the techniques measured in the current study were simply kicks used during competition, it may serve as a framework towards development of standardised sport-specific tests such as reaction time tests incorporating lower body movements. Because taekwondo does combine facets of game strategy, distance management between competitors, and situational game management techniques it will be important to pull from a representative knowledge base of successful coaches (Mori et al. 2002) in an effort to assess other important performance characteristics that may not have been measured in the current study. Performance measures obtained in this study, although from a small subject pool, may serve as a comparative data set for when data are obtained from future developed field tests of related performance variables.

## Limitations

Due to this study being a preliminary step to set the stage for a larger study aimed at comparing performance variables among Para-taekwondo athletes, it should be understood that the number of participants may be insufficient to claim conclusive results from our elite taekwondo athlete pool. Future comparative studies should collect data that holds sufficient power on a representative cohort<sup>1</sup> of those with various physical impairments and those with no impairments. As this sport is not performed in the confines of a laboratory setting and holds a sport-combative environment, the physical and psychological demands that at times may affect performance were non-existent during our data collection effort. As with many biomechanical motion analyses the challenge of employing the most reliable methods for tracking reflective markers exists. It should be understood that the use of cluster set

markers or even bone-embedded pin markers may present more accurate data (O'Sullivan et al. 2009), however the use of these methods was not available during this study.

## Suggestions

Future studies should consider observing performance of the variables presented in this study among a representative (i.e., of all current WTF Para-taekwondo Classes and from an ethnically diverse population (Beckman and Tweedy 2009) group of Para-taekwondo athletes. As the variables measured in this study do not encompass all performance characteristics important in taekwondo competition success, future groups should aim to gain in-depth input from expert coaches to ensure face validity of field tests used to determine minimum disability and classification status. As a field test is developed, the reliability and validity of the testing battery must be confirmed along with subsequent large data collection efforts from a large number of subjects of an ethnically representative cohort that may serve as a standardized testing battery used in parallel with appropriate regression analyses (Beckman and Tweedy 2009). As suggested earlier (Tweedy and Vanlandewijck 2011), an option for ensuring that a large data pool is analysed is to employ the use of a mobile biomechanics laboratory to be used in conjunction with competition classification activities.

An important taekwondo-specific consideration for athletes in the current four classifications (K41-K44) is the role of amputee upper limb length. As taekwondo employs the use of a body protector with the function of real-time electronic scoring, it must be understood that athletes with longer amputated limbs paired with athletes with shorter limbs could be placed at a disadvantage in regards to blocking ability. If an athlete with no neurological function of the entire arm is paired with an athlete of K41 (amputation of both limbs above the elbows) status, an obvious advantage in the case of the athlete with neurological impairment could be evident. Future studies should investigate the role of limb length on ability to block (intended or un-intended) the electronic chest protector.

## Conclusions

The results of this study provide an objective measure of normative performance ranges for performance variables important to taekwondo sparring success. From these results, future studies will have a basis for comparison among Para-taekwondo athletes. Components of techniques used in this study may provide a framework for developing field-tests used for classification at competitions. It is important for future studies to consider the results of this study when comparing results with Para-taekwondo athletes that represent all current WTF classifications to move towards improving the existing classes.

## What this study adds / what are the new findings?

- Normative performance for key components of sparring
- A steppingstone towards development of a battery of tests to be used for evaluating the core components of sparring performance
- Introduction to the discussion of developing evidence based study of taekwondo-specific classification field tests

## How might this study impact clinical practice in the future

The results of this study provide a framework for conducting future studies that are recommended to compare able-bodied taekwondo athletes and athletes with physical limitations. Techniques tested in this study, as they are the most common techniques used during competition, may serve as a possible on-site taekwondo-specific testing protocol.

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