

The Attenuation of Strike Acceleration with the Use of Safety Equipment in Tae Kwon Do

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Abstract

Purpose: The objectives of this study include: (1) Determination of the attenuation of strike acceleration that Tae Kwon Do sparring safety pads provide from kicks from Olympic style TKD fighters, (2) The sex and weight differentiation in acceleration achieved within the thorax model with the roundhouse kicks.

Methods: This prospective, observational study utilized 15 Olympic style fighters from an "elite" team kicking a water core heavy bag thorax model with roundhouse kicks. The model was fitted with a tri-axial accelerometer (GCDC, model X250-2) to measure g acceleration from strikes to the bag. The bag was kicked in three, 10 kick phases by all subjects: kicks without padding; kicks with hogu on heavy bag, and kicks with hogu and instep guards on feet. The g acceleration readings were recorded in all phases.

Results: Kolmogorov-Smirnov failed for all variables. There were 8 female subjects: median age 14 years, median weight 53.4 kg and 7 male subjects: median age 17 years, median weight 70.45 kg. The ANOVA on ranks of the acceleration from kicks against the bag achieved significance, $P \leq 0.001$. Spearman rank order correlation between the weights of players and acceleration of strike against the hogu without and with insteps pads was significant, $P=0.035/r=0.54$ and $P=0.018/r=0.59$, respectively.

Conclusion: Heavier and male subjects tend to produce more force in strikes. Protective chest guard reduces acceleration to the thorax model, but the utility of instep guards is questionable.

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INTRODUCTION

Martial arts are practiced by 2-8 million people in the U.S.A annually [1,2]. The most popular martial art practiced is Tae Kwon Do (TKD), a recognized Olympic sport since 2000. There are multiple different styles of TKD with sparring styles ranging from no contact to full contact. Olympic style TKD sparring is full contact, allowing kicks to head and torso, and punches to the torso. The different TKD styles also have different protective equipment

requirements. Protective sparring gear in Olympic TKD consists of soft foam head gear, forearm and shin pads, instep pads, lightly padded gloves, a mouth guard, dense foam thorax/abdomen guard (hogu), and a groin protector.

Despite this padding, injuries from full contact competition are frequent. Prior studies have reported injury rates ranging from 0.4/1000 athlete exposures to 25/1000 athlete exposures to 12.7/100 athlete exposures, depending on the definition of injury and experience level of fighters [3]. A recent meta-analysis

of prospective cohort studies discussing the incidence of injuries in TKD reports a mean injury rate of 79.3/1000 athlete exposures [4]. Injuries from TKD training are reported to be as high as 59.2%, higher than many other martial arts [2]. Although the overall frequency and basis of injury is likely underreported, 74% of injuries in karate and TKD are estimated to be due to sparring [5]. During the 2008 summer Olympic games, 27% of TKD athletes were injured, 64% of those during competition. Tae kwon do was one of the top 6 sports with injury occurrences during the entire summer Olympics [6].

It is suggested that sparring equipment protects the wearer rather than the opponent, and that receiving blows to a TKD chest protector hurt just as much as receiving a blow without it [7]. Injuries to the abdomen, chest, and back comprise about 5% of reported injuries [8]. In review of the prior literature, few studies have demonstrated the efficacy of martial arts safety equipment in reducing force from a blow [9,10]. Schwartz et al studied 14 karate experts striking a dummy's head +/- hand and foot padding. The results revealed boxing gloves minimally reduced peak acceleration, but martial arts foot padding and hand padding increased peak acceleration to the test dummy. The study authors concluded that participation in boxing or full contact karate, despite use of safety pads, may lead to the same pattern of injury [9]. Moffitt and Lieu tested 14 commercial martial arts head gear for their impact attenuation properties to protect from head injury from a simulated blow or simulated fall onto the sparring surface. They reported that the protective properties of the different headgear are variable [10]. Thicker headgear is generally more protective, but all protection can be overcome with increased velocity of the simulated strikes.

Testing of TKD hogu and soft foam instep pads, to determine if their use decreases acceleration and force of a strike to the body, has not been reported. The force of a strike is the root of blunt injury. Eighty percent of competitive techniques used in TKD have been reported as kicks and these kicks have a high risk for injury potential [11]. The roundhouse kick is reported to be the most frequently used kick in full contact TKD competition [12].

The primary objective of this study is to determine the attenuation of strike acceleration that TKD sparring safety pads provide from an Olympic style TKD fighter. Roundhouse kicks were thrown against a thorax model comprised water core heavy bag +/- presence of the hogu and instep guards. Additional objectives include sex and weight differentiation in the acceleration achieved within the thorax model with roundhouse kicks. Lastly, a general review of martial arts injuries as it pertains to injury rates and utilization of safety equipment is provided.

METHODS AND SUBJECTS

This study is prospective and observational. The subjects are 15 Olympic style TKD fighters who compete at the national and international level from a nationally renowned TKD school in mid-Atlantic region, USA. The subjects were all volunteers for the study. All subjects were self-reportedly healthy and free of injury at the time of the study. All gave informed consent for the study analysis and publication of results of their training. The study received institutional review board (IRB) approval from the IRB committee at New York Hospital Queens. The tae kwon do experience of the participants ranged from intermediate belt (blue) to 3rd degree black belt. Ages ranged from 10 to 29 years [median 15 interquartile range (IQR 13.25-20.25)].

The study was performed during an "elite" team training session, with each subject provided with at least 20 minutes for stretching and warming up. As part of their regular training and during their study participation, subjects were measured for the acceleration of their roundhouse kicks. With utilizing a roundhouse kick and the instep portion of their feet, each subject struck a Century© Wavemaster type freestanding water-filled base and core heavy bag. The bag is a simple approximation of a human abdomen and thorax. The base of the bag was filled with water to ensure stability, and the bag was itself composed of dense foam with a water core. The impact acceleration, measured as multiples of the acceleration due to

gravity (g), through the bag was measured with each strike with a tri-axial accelerometer (GCDC, model X250-2). The sensor was calibrated prior to the study. The accelerometer was positioned within the foam near the center of the bag to most mimic the center of mass for the model. The bag was kicked by each subject in 3 phases, 10 kicks per phase, for 30 kicks total: (1) kicking a bag without any safety pads with bare insteps to establish baseline acceleration through the bag; (2) kicking with bare insteps against a new Adidas (Herzogenaurach, Germany) WTF approved TKD hogu encircling the bag; (3) and kicking with new Adidas foam instep protectors against the hogu encircling the bag. The last scenario most mimics actual padding for TKD sparring purposes. Fighters were able to rest approximately 30 minutes between phases of kicks to minimize fatigue. Data was downloaded from the accelerometer and recorded into Microsoft Excel (Redmond, WA) and transferred to SPSS 18 (IBM Armonk, NY) statistical package for analysis. Normality testing was performed and multiple non-parametric tests were utilized with consideration of an alpha of $P < 0.05$ as significant.

RESULTS

Initial Kolmogorov-Smirnov testing for normality failed for all considered variables and non-parametric testing was performed on the data.

There were 8 female subjects, median age 14 years (IQR 13-18) and median weight 53.4 kg (IQR 50-55). They ranged in belt level from blue belt to 3rd degree black belt. There were 7 male subjects, median age 17

years (IQR 14.5-21) and median weight 70.45 kg (IQR 62.5-76.7). They ranged from purple belt to 2nd degree black belt. Mann Whitney U testing reveals no difference between ages of the male and female subjects, but the weight difference was significant, $P \leq 0.001$. The demographics of the subjects and results of median strike acceleration are described in table 1.

The median strike acceleration (g) from all players to the bag model was: (1) without pads 58.5 (IQR 51.75-62.75) (2) with hogu only 54.5 (IQR 43.13-59) (3) with hogu and instep guards 54 (IQR 42.75-56.75). A Friedman repeated measures ANOVA on ranks was performed to evaluate acceleration from kicks per player against the bag, with the addition of the hogu onto the bag model, and the addition of the instep pad to the player, $P \leq 0.001$. The Tukey test for multiple comparisons revealed significant differences ($P \leq 0.05$) in median kick acceleration between players kicking the bag without safety pads and kicking against the hogu wrapped bag, +/- instep guards, respectively.

The Spearman rank order correlation between the weights of players and acceleration of strikes without safety pads is significant, $p = 0.045$ and $r = 0.52$. The Spearman rank order correlation between the weights of players and acceleration of strike against the hogu without and with insteps pads was significant, $P = 0.03$ / $r = 0.54$ and $P = 0.02$ / $r = 0.59$, respectively. Please see figure 1 for visual representation.

DISCUSSION

In physics, $F_{net} = m \cdot a$; $F = \text{force}$, $m = \text{mass}$, $a = \text{acceleration}$. In this study, acceleration, measured

Table 1: Demographic information and median strike acceleration of the subjects as determined by sex

Sex	Male	Female
Weight (kg)	70.45 (IQR 62.5-76.7)	53.4 (IQR 50-55)
Age (years)	17 (IQR 14.5-21)	14 (IQR 13-18)
Belt level	Purple-2 nd Dan	Blue-3 rd Dan
Strike acceleration: no pads	61.5 (IQR 56-66)	53 (IQR 47-60)
Strike acceleration: hogu	59.5 (IQR 54-61)	43.5 (IQR 36-54)
Strike acceleration: hogu + instep guard	56 (IQR 54-58.62)	44.5 (IQR 33.5-54)

SD: Standard Deviation

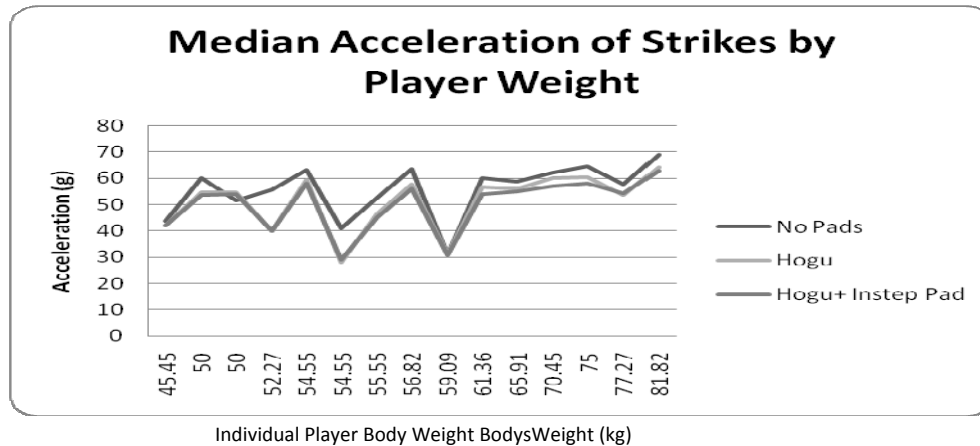


Fig. 1: The strike acceleration of the subjects according to body weight with and without the presence of safety pads on the model

as multiples of the constant acceleration g , was considered a surrogate marker for the force of the kicks performed by the study subjects. The force produced by a fighter generating these kicks is the root of the blunt injury and trauma experienced by the fighter receiving the kicks. Relative to impact, peak force is the acceleration of an object multiplied by its effective mass. Effective mass is defined as all of the mass utilized at impact [13]. The difference in weight between the male and female fighters and the differences in strike acceleration, as delineated in table 1, may be explained by the greater muscle mass and percentage of muscle per body weight that males have in comparison to females. These groups of TKD fighters have been previously reported to sustain more injuries: young males and females, junior females, and adult males [4]. The larger mass, greater strength/acceleration, and subsequent great force generation of adolescent to adult men may explain their inclusion into this injury group. The smaller size and muscle mass may explain why younger females are included in this group, they may be less able to absorb the force of blows and sustain more injuries.

The results from this study are generally mixed. In the male and female kickers, there was a modest reduction in acceleration measured within the bag kicked with the addition of the hogu. This may have been due to a spreading of the impact along the hogu and less direct forces reaching the center of the bag

where measurements were being taken. Also, decreased reproducibility in kick form and placement on the bag due to fatigue might have reduced power with subsequent kicks. Further, the surface material of the bag itself is soft foam and the material of the hogu is denser foam. Fighters may have been “pulling” kicks and not striking with full force due to increased pain with kicks from their bare insteps against the dense foam.

With addition of the instep guards, male fighters continued to have a modest reduction in strike acceleration to the thorax model. Female fighters saw an increase in their strike acceleration. This may be explained by an increase in force of kicks as the foot was padded. Pain may have been reduced and there may have been a decreased fear of injury. Fatigue may have been a factor in the decreased acceleration of the male fighters as this study took place during the course of a physically rigorous, 3 hour elite team practice. More likely, these mixed results are due the small numbers of subjects within the study.

In review of related literature, it has been suggested that 60% of martial art injuries that occur during competition and practice are not reported [14]. Considering that TKD is practiced in 197 countries with millions of participants, the number of unreported injuries is immeasurable [15,16]. Utilization of sparring equipment is intended to reduce these injuries, but evaluation of the efficacy of martial arts sparring

equipment in reducing injury has been inconsistently and infrequently reported. It has been reported in a prior survey of 12 month pre-competition TKD injuries that 6% of injuries related to TKD are to the chest or abdomen, and 11% to the upper and lower back, both areas that are covered by the hogu [17]. Also, foot padding has not been shown to reduce peak accelerations to the head from roundhouse kicks [9]. Further, the most common TKD injuries are contusion and sprains of the lower extremities, areas that are protected by padding [18,4,17]. In studies of padded gloves in impact, higher momentum levels were recorded for gloved punches on a heavy bag as compared with bare fist punches. One explanation is that padding spreads impact forces over a longer period of time at higher velocities and causes greater accelerations within the impacted object. Through this cushioning effect, it appears that protective equipment is more beneficial to the striking athlete than it is to the receiver of the strike [19].

The data on the effects of other protective equipment tends to be sparse and mixed. By some evidence, protective head gear equipment may reduce incidence of severe head and facial injury. As reported from the 6th world taekwondo championship, during a time where head gear, instep, shin, and gloves were not listed as mandatory equipment, 4% of competitors and 9 of 13 injuries admitted to the hospital casualty ward were located on the head and neck [20]. Many of these injuries were facial and dental fractures, tracheal injury, contusions, epistaxis, and lacerations. With implementation of safety equipment and limited contact, physician evaluated injuries at large scale United States Tae Kwon Do Alliance national and regional tournaments, 16 of 33 injuries were to the head and neck, but 13/16 were due to kicks to the face, where the head gear does not cover [3]. Despite this promising report, recent longitudinal TKD injury data from Canada reports that the most common locations of injury treated during competition is the head and lower extremity, as has been confirmed by prior studies [21]. The roundhouse kick has been determined to be involved in the majority of injuries sustained in competition [22]. The most common mechanism for injury in TKD during competition has been from defensive kicks or offensive kicks [21]. The head and

lower extremity are largely covered by protective equipment.

This study is limited by a number of factors. The number of subjects is small with a narrow age range. This may have impacted the statistical significance of the results. Although all members of an “elite” tournament team, there was variability in belt level and experience of the subjects, which may have impacted the force and acceleration of the kicks. There was no sample size calculation performed prior to study enrollment, which may have impacted the results and statistical significance. The approximated thorax model is of limited fidelity to a true human thorax. The measure of acceleration has a theoretical relationship to the force of impact, but it is uncertain at what acceleration injury would actually occur if the data were extrapolated to humans. The study only evaluated a small sampling of equipment from one manufacturer. Differences in materials and manufacturing of the equipment from different companies may produce different results. Lastly, at the time of the study, available literature was limited in order to assist study design.

CONCLUSION

As has been revealed by this study, the introduction of a TKD hogu confers a modest reduction in acceleration by a roundhouse kick strike to a thorax model. The efficacy of foot padding with the same strike is inconclusive. Considering the results of this study and by the review of the literature, the direct efficacy of TKD sparring equipment to reduce the force of a blow and to reduce incidence of injury is unknown. Injuries to TKD practitioners, especially to the head and extremities, are still common despite the introduction of gear and advancement of materials. The popularity of TKD and martial arts is expanding internationally, and across both genders and all age groups. It is imperative that further scientific studies are undertaken to evaluate the protective quality of the gear that is utilized by practitioners to shield themselves and others from harm.

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Conflict of interests: None

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