

**RELIABILITY AND VALIDITY OF
A TAEKWONDO ELECTRONIC
BODY PROTECTOR**

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RELIABILITY AND VALIDITY OF
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BODY PROTECTOR

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RELIABILITY AND VALIDITY OF A TAEKWONDO ELECTRONIC BODY PROTECTOR

ABSTRACT

Protector and Scoring System (PSS) was introduced in Taekwondo to encourage transparency in scoring during competition and has been used in the Olympics since London 2012. It consists of two main components which are the electronic body protector and electronic socks. There have been limited number of studies done on the PSS, nearly all of the previous studies were not comprehensive and had questionable testing methods. Therefore the main objective of this study was to methodologically examine the validity and reliability of the PSS. To fulfill these objectives, a custom made mechanical pendulum was built to test the PSS. The reliability of the pendulum was first determined by tracking the pendulum's mean velocity at impact on two separate occasions. The kinetic energy of the pendulum was then calculated on average to be 55.52 Joules. For the experimental trial, the electronic body protector was divided into 12 sections and each section was tested with 50 trials on two separate days. It was found that only three sections had no significant differences ($p > 0.01$) between the two days while the rest of the sections had significantly different reading between day one and day two. Based on the homologous descriptive statistic, only two sections were in the same group which translates to the PSS being only 16.7% reliable overall over both days. In terms of validity, t-test was used to measure the differences between the calculated kinetic energy from the pendulum and the displayed kinetic energy on the PSS; values were found to be significantly different ($p < 0.01$). Overall, the PSS was found to be neither reliable nor a valid scoring tool. It is suggested that each unit should also be examined and scrutinized prior to being used in any future tournaments.

Keywords: Martial arts, Scoring system, Sports

BENGKUNG ELEKTRONIK TAEKWONDO

ABSTRAK

Bengkung elektronik Taekwondo (PSS) diperkenalkan untuk menggalakkan ketelusan dan keadilan semasa pertandingan. Ia telah digunakan di Olimpik 2012 dan 2016. Ia terdiri daripada dua komponen utama iaitu pelindung badan elektronik dan stokin kaki. Hanya terdapat beberapa kajian yang terhad mengenai PSS, malangnya kajian lalu tidak lengkap dan mempunyai persoalan mengenai kaedah ujian mereka. Oleh itu, matlamat utama kajian ini adalah untuk meneliti kesahihan dan kebolehpercayaan PSS. Untuk memenuhi objektif ini, pendulum mekanikal yang diubahsuai telah dibina khas untuk menguji PSS. Kebolehpercayaan bandul dikenalpasti dengan mengira halaju purata 50 ujian pada dua hari yang berasingan. Data kedua-dua hari itu dibandingkan dan tidak menunjukkan perbezaan signifikan antara dua hari iaitu $p = 0.08$. Tenaga kinetik pendulum kemudiannya dikira dan didapati di sekitar 55.52 Joule. Bagi ujikaji ke atas pelindung badan elektronik pula, ia dibahagikan kepada 12 bahagian dahulu dan setiap bahagian diuji dengan 50 ujian pada dua hari yang berasingan. Hanya terdapat tiga bahagian yang tidak mempunyai perbezaan signifikan ($p > 0.01$) diantara dua hari itu, manakala bahagian-bahagian lainnya mempunyai bacaan yang berbeza diantara Hari 1 dan Hari 2. Berdasarkan statistik deskriptif homologus, hanya terdapat dua bahagian yang berada dalam kumpulan yang sama. Oleh itu, kebolehpercayaan PSS hanya 16.7% yang boleh dipercayai secara keseluruhan untuk kedua-dua hari. Dari segi kesahihan, ujian statistik “t-test” digunakan untuk mengukur perbezaan antara tenaga kinetik yang dikira dari pendulum dan tenaga kinetik yang dipaparkan pada PSS; nilai didapati sangat berbeza ($p < 0.01$). Keseluruhannya, PSS didapati tidak boleh dipercayai dan bukan merupakan alat penilaian yang sah. Ia perlu diperiksa dan diuji dengan lengkap sebelum digunakan dalam sebarang kejohanan pada masa akan datang.

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CHAPTER 1: INTRODUCTION

Taekwondo is a martial art which originates from Korea. It was first introduced as a demonstration sport in 1988 Seoul Olympic Games. Later it was accepted as an official sport in Sydney Olympic Games in year 2000. In Taekwondo, every match is contested for three rounds of two minutes with one minute rest in between. Matches are held in a square or octagon shaped ring with a size of 8m x 8m. Male and female exponents are divided into eight weight categories. Points will be awarded when an exponent lands their foot on the opponent's chest or head. Exponent receives one point for hitting the chest, three points for the head and an additional one more point for rotating techniques. All points are traditionally given by the judges whom are placed at the four corners of the ring.

Previously, all Taekwondo competitions were judged manually via judge's subjective interpretation during matches. It started with manually written point scoring and later changed to live electronic scoring system (ESS). As the sport grew, Taekwondo competition evolved from time to time in order to give thrilling excitement to the spectators as an entertainment event. Not only limited to readjusting the rules and regulation of the competition, technological innovations have also been introduced to bring fairness to all sparring competitors. The World Taekwondo (WT) had recently introduced the latest technological change, which is the Protector Scoring System (PSS) during 2012 London Olympic Games to avoid biasness and to encourage transparency of scoring during competition. This system is meant to support the judges in scoring due to judge's subjective judgment and inconsistency. Athletes and coaches have been complaining about biasness and fair play since the inception of sparring matches. Now with the current PSS technology, it can theoretically be much more objective and accountable (Leveaux, 2010). Daedo TK-Strike Protector and Scoring System (PSS) is

one of the two WT approved Taekwondo PSS brand. Daedo is also the official brand used for the London Olympic 2012, and it was used as well in Rio Olympic 2016.

As the premise is that PSS is more reliable than judges, therefore reliability and validity testing on the PSS is an important undertaking. Taekwondo exponents will be able to benefit from understanding the system and reconsider the strategies and the athlete's game play. Consequently, proven reliability and validity of the PSS can also help to eliminate athlete's doubt regarding the system whereby they can play without having the fear of biasness. Considering that this technology is still new, athletes would want to have more knowledge about the PSS equipment to hold an upper hand during competition.

In order to have a fair competition especially in an event like the Olympic Games, every official equipment and new technology must be reliable and valid. It is hoped that this study will be able to shed some light regarding the capability of this particular Taekwondo equipment. Although the PSS scoring equipment is now accepted as official scoring equipment in every WT sanctioned Taekwondo competition, there are still not many studies that have been conducted on its reliability and validity.

This study is divided into two parts. First, specific measuring tool is needed to test the PSS therefore a customized mechanical pendulum apparatus was designed and built specifically for this purpose. Furthermore, the specially built apparatus itself was tested for its reliability before it can be utilized in this study.

The second part, is to test the reliability and validity of the PSS using the customized mechanical pendulum apparatus. The electronic body protector was divided into 12 sections and a total of 1200 trials were done on the electronic body protector.

1.1 Problem statement

Taekwondo exponents have encountered anecdotal inconsistent scoring on the electronic body protector, whereby sometimes it was able to register a score without using high impact kicks but at other times it was unable to register a score although there were high impact kicks. A valid score can only be given when the impact of the kick on the electronic body protector has reached the minimal kinetic energy threshold. The minimal threshold is set according to the player's weight division where higher weight division will have higher minimal threshold to score.

1.2 Objective

- 1.2.1 To investigate the reliability of the Daedo Tk-Strike electronic body protector over two repeated days of impact testing
- 1.2.2 To investigate the validity of the Daedo Tk-Strike electronic body protector over two repeated days of impact testing

1.3 Hypothesis

1.3.1 (a) Experimental hypothesis 1

Not every area of the electronic body protector is able to consistently recognize the same impact threshold.

1.3.2 (b) Null hypothesis 1

Every area of the electronic body protector is able to consistently recognize the same impact threshold.

1.3.2 (a) Experimental hypothesis 2

The kinetic energy measurement of the electronic body protector is not valid

1.3.2 (b) Null hypothesis 2

The kinetic energy measurement of the electronic body protector is valid

1.3 Definition of terms

Daedo TK-Strike Protector and Scoring System (PSS)

A wireless protector and scoring system designed to satisfy to the current WT competition rules and regulation which consist of body protector, foot protector and software.

Impact Energy

The amount of energy that is displayed during the collision between the electronic body protector and the electronic socks

Contact threshold

Minimum kinetic energy value registered into the software to be acknowledge as contact

Piezoelectric sensor

Force sensor that measure changes of force by converting them into electrical charge

Validity

Measures what is purported to measure

Reliability

Measurement which produces a degree of consistency of result

1.4 Significance of study

Validity and reliability of this TK-Strike Daedo electronic body protector (PSS) is of the utter most importance, considering it is an official scoring system for Olympic Games. Theoretically the PSS should measure impact force accurately and consistently. The inconsistency of the PSS was questioned by many Taekwondo exponents who had tried it first hand by Leveaux (2012). They experienced that a purportedly strong force from a kick did not register any point while a weak force on the other hand does register point into the system.

The result of this research would also likely gain interest from many Taekwondo exponents. This research will benefit coaches and exponents to take advantage of the system and strategies their game play and training methods to adapt accordingly to gain technological advantages during competition.

The Taekwondo Malaysia (TM) coaching board would want to be ahead of other countries in term of knowledge and also strive for better results in international tournaments. Meanwhile, Taekwondo exponents can also emphasize on specific kicking area or method to gain valuable points during competition. Each section of the electronic body protector may have different sensitivity. Some sections may have higher sensitivity where not only high impact kicks were able to generate high kinetic energy reading but low impact kicks too are able to generate high kinetic energy reading.

Emphasizing on high sensitivity section could give the exponents a better winning chance compared exponents who were randomly kicking on every section on the electronic body protector to score.

1.5 Limitation of study

For this study, only one used unit of the electronic body protector was utilised throughout the experiment. The sole unit was randomly picked from a batch of six units of electronic body protector which were currently in use for Taekwondo competitions in Malaysia. Therefore results from this study must be viewed with caution and should not be automatically generalized for all body protector units

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CHAPTER 2: LITERATURE REVIEW

2.1 Fair play in sports

All sports have their own rules and regulations during competition to help protect athletes from risks as well as fair play, this is epitomized in the Olympics. Sport biasness has been a thorny issue since the inception of competitive sports and the problem still persist today. This is ever more present in subjective sports such as gymnastic and Muay Thai which are judged subjectively by referees or judges. The possible reason why biasness occurs is either visual error or because of the subjective judgment by the referees as there is not a proper standard operation specification in the particular competition (Papadopoulos, Kaimakamis, Kaimakamis & Proios, 2011). It was found that there was not a specified criterion for referee to judge in gymnastics competition which made biasness rampant, scoring was given according to the referee's preferences hence it had affected gymnastics as one of the Olympic sport. Besides Papadopoulos's team findings, another study which had analyzed the 2011 European Gymnastic Championship found that biasness was still rampant and the scores which were given to participants were unreliable (Leskosek, Cuk, Pajek, Forbes & Bucar, 2011). Besides gymnastic, another example of subjective judging which was found unaccountable due to the issue of normative range of agreement among judge is the sport of figure skating (Lockwood & McCreary, 2005).

Meanwhile, in combat sport such as Muay Thai, similar problem of bias judging was also found occurring at the international level (Myers, Balmer, Nevill & Al-Nakeeb, 2006). There were indications of nationalistic biasness at tournaments. They also suggested that Muay Thai should also adopt the electronic scoring system like Taekwondo's PSS to introduce a more objective scoring and judging system.

On top of that unstandardized operation criterion, home advantage also amplifies biasness, for instance a host's baseball team are normally given the last offensive advantage compared to other teams which should not occur in a fair match (Arrese, Urdiales & Izquierdo, 2012). Women's soccer in Europe was also found to give home advantage where it happened due to territorial protection and being pressured by home supporters that had subsequently influenced referees to favor the home team (Pollard & Gomez, 2012). Biasness of sport which happens during matches gives a negative impression towards the sport, such as protest by the officials who try to overturn the decision made by referees which in turn causes major image damage towards the sport especially those which are included in the Olympic Games (Kosiewicz, 2014).

2.2 Impact of sports technology on fair play

In order to reduce biasness in sports, many new equipments have been developed to assist in terms of judging so that officials are able to judge more objectively. Sports technology has a very strong influence and potential in improving the sports environment by providing aids to the referees to promote fair play (Leveaux, 2010). With the help of sports technology, participants are able to show more of their individual skills and abilities without necessitating the use of illegal tactics. Also, it will most likely reduce the possibility of human errors done by the referees.

There are number of sports which have been using sports technology to improve in making the correct call. Among the technology which are currently in use is the Hawk Eye, a device which monitors the trajectory of the ball in the field of play such as tennis and cricket (Bal & Dureja, 2012). The Hawk Eye technology provides 99.9% accurate visual replay and slow motion capture to referees before concluding a final decision and it has been tested against high speed camera with the capture rate of 120 MHz frames with the mean error rating of 3.6mm (Duggal, 2014).

On the other hand, Radio Frequency Identification Device (RFID) is now used for most long distance running competition (Quinlisk, 2013). It is used to register the start and ending time of all the runners accurately rather than using stopwatches which helps to eliminate human error. RFID had been evaluated and had correlation coefficients of the depreciation in read rates over distance in the ranges of 0.62 to 0.86 (Bolton, Jones, Punugu, Addy & Okate, 2017). This technology can also be used to perform timing data collection of each runner using a central computer to keep track of the data collected from each chip of the RFID device. Concurrently, digital line-scan is also used in most track and field events to verify finishing order. Pictures at 100 frames per second are captured at the end of the race especially in sprint events where time differences among sprinter are just a split of a second. With this digital line-scan, officials are able to see the athlete's ending position clearly without relying on naked eyes precisely (Quinlisk, 2013).

The sport of Taekwondo too has also incorporated new technology into the sport. Among others, there is now instant video replay to protest and review the decision made by referees. There is of course also the Protector and Scoring System (PSS) which uses electronic body protector and sensor socks to help keep scoring where points will only be given objectively whenever kicks land on the electronic body protector and surpasses the required impact threshold (Leveaux, 2012).

All these technological equipment have given advancement great impact to athletes in reducing biasness and to keep the excitement level of the spectators at the highest level. With these new innovations in sports, people are being more attracted and interested towards major sporting events as it can help to enhance the spectator's ability to understand the sport's game play rules, regulation and scoring system by providing sufficient objective information.

2.3 Taekwondo Protector & Scoring system (PSS)

The Taekwondo Protector & Scoring system (PSS) is a technology that was designed to eliminate biasness in Taekwondo competition. It requires a minimal impact threshold between the electronic body protector and the electronic socks to generate a valid score (Leveaux, 2012). According to the TK-strike user guide by Daedo International (2016), this system is based on Wireless Fidelity (Wi-Fi) technology. This requires an adapter to be plugged into the computer in order to receive the information from the body protector to the host computer whenever it senses an impact. Piezoelectric sensors which are placed in the electronic body protector are used to detect the impact received from the foot by creating a small quantity of electrical charge and sending it to the computer using Wi-Fi technology (Tasika, 2013).

The PSS is meant to support the judges in scoring due to judge's subjective judgment and inconsistency. The possible reasons why biasness occurs are either by visual error or because of the subjective scoring by the referees as there is not a proper standard operation procedure or judging criteria such as those used recently in gymnastic competitions (Papadopoulos et al, 2011).

Nevertheless, the PSS is supposed to be able to quantify and register all the impact from the kicking force towards the body protector by measuring its intensity, location and also the source of impact (Song, 2011). This made the competition more objective, and eliminates biasness during Taekwondo competition. The system uses piezoelectric sensors to detect the amount of force between the contact of electronic body protector and the socks worn on the athlete. Forces detected between the body protector and the sock were analyzed and displayed as kinetic energy.

During the delivery of kick towards the electronic body protector, a small quantity of electrical charge of the piezoelectric sensor will be created when the

electronic body protector and socks hardware touch or sense each other and it will send an analogous electrical output signal to the software. The signal will be analyzed and displayed on the monitor as scoring point if it received a minimal impact threshold required as a valid score (Chi et al., 2004). Minimal impact threshold will be set using the PSS software program and each weight division will have a different impact threshold which is set by the World Taekwondo (WT). For example, “26 kinetic energy” was set as the minimal impact threshold for male less than 54 kilogram category while for another male category of 54 to 58 kilogram the minimal impact threshold was set at “28 kinetic energy”.

By using this system, judges may now focus on technical points and punches which are still based on manual judging given by referees. This is because all the other valid points registered are based on the sensor's contact point between the foot and the electronic body protector. There are magnetic sensors in the sock which acts as “key” and the electronic body protector which act as an electrical conductor to detect the impact of kinetic energy and then it sends the detected signal to the software for further analysis. Without the socks, kicks that land on the electronic body protector will not be recorded even if it is a high impact kick.

This technology has been widely used in many official international Taekwondo championships since 2002 (Leveaux, 2012) including the London and Rio Olympics in year 2012 and 2016 respectively. Unfortunately, Leveaux (2012) found there are still many Taekwondo exponents and coaches who still question the reliability of this system and also the energy requirement to generate the threshold that is needed to produce valid scoring points. Leveaux (2012) had also interviewed Taekwondo competitors and found out that many competitors had firsthand experience of unregistered points even after landing a high impact kick on the electronic body protector, while at certain times a

very light impact kicks or contact is able to register hit points. Leveaux (2012) has also recorded frustration of athletes regarding the PSS's reliability.

A number of studies have been done involving Taekwondo competitors in the past few years especially on athlete's physiological characteristic (Campos, Bertuzzi, Dourado, Santos & Franchini, 2011) but there are not many studies that had been done on the PSS, as this technology had only recently been developed and used officially in competitions only for the past few years.

There are two related studies which had been done on the electronic body protector, and one of few who had done PSS testing was Ramazanoglu (2013), who found that the electronic body protector routinely scored points when low impact kicks were recorded as the leg landed on the electronic body protector. However, Ramazanoglu (2013) only studied one section of the body protector, which was the middle part of the body protector wrapped on a mannequin. In the real word, the whole surface of the body protector is used and kicked by athletes to obtain points during tournament, not just the middle part of the electronic body protector.

Ramazanoglu (2013) had done the test by using a mannequin foot to deliver a round house Taekwondo kick. The mannequin foot was attached to an elastic spring steel rod which acts as a catapult to transfer force from the mannequin foot to the electronic body protector. However, the consistency of the spring steel's strength and its flexibility is questionable whereby the single steel spring which was used throughout the whole test which possibly made the impact force inconsistent and unreliable. The strength of the steel spring reduces overtime due to the possibility of fatigue loading and spring relaxation (Valsange, 2012). Besides that, various spring steels were also found to have inconsistency of peak load and unload forces generated during spring activation and deactivation process (Maganzini, Wong & Ahmed, 2010). It may be more reliable if

the test was done by replacing a new calibrated spring steel after every trial to produce a set of consistent and reliable data collection.

Another possible issue is that body protector holder (mannequin) is made of wood covered with 3mm ethylene vinyl acetate (EVA). Although the target was made to imitate the sternum in terms of shape and texture, the force of impact of the spring loaded kick towards the target may be reduced due to the impact absorption of the (EVA) material (Westerman, Stringfellow & Eccleston, 2000) whereby the holder or target should be made of solid and rigid material so that there will be no unnecessary impact absorption which will affect the testing result during the release of the steel spring which acts similarly to a kick.

In another early study on the PSS, it was found that the electronic body protector showed poor accuracy, reliability and linearity which are a necessity required to act as a scoring tool in official competition (Tasika, 2013). The study did a drop test method with three different drop heights and the measurement of impact force is presented as kinetic energy. However, the drawback of Tasika's (2013) work was that the weights which were dropped repeatedly on the body protector remained intact and stuck onto the body protector after each drop. This long impulse time is not applicable in the real Taekwondo sparring kicking situation where every kick is retracted after landing onto the opponent's body protector. This is for the exponent to get ready for the next movement, therefore Tasika (2013) non-momentary data might be affected when the weight of impact was not removed. The weights were dropped on 3 different heights starting from 1.78m, 1.92m and lastly 2.00m and using the same 4 Kg weighted iron shot, this produces three corresponding kinetic energy values of 69.84 joule, 75.34 joule and 78.84 joule respectively by calculation.

Nevertheless, the reliability of the electronic body protector was found to be poor with ICC rating of 0.436 by Tasika (2013). Tasika's (2013) result was only justified based solely on one section. The body protector should be tested using the same method on each and every section to provide accurate data interpretation of each section on the electronic body protector.

Interestingly, the material that is used to make the electronic body protector is unknown to the public, other than the use of piezoelectric sensors which acts as an electrical charge. A standardized (non PSS) body protector is made out of 1.0 cm of polyester sponge and 1.5 cm of ethylene vinyl acetate copolymer for shock absorption to protect the athletes from receiving hard impact kicks from the opponent which may cause injury to the abdominal region (Woo, Ko, Choi, Her & O'Sullivan, 2013). However, there is no information about the electronic body protector from the manufacturer which made it impossible to determine whether the electronic body protector has the same thickness of polyester sponge and ethylene vinyl acetate copolymer material used on every sizes and sections of the body protector, hence the thickness of these materials may affect the sensitivity of the piezoelectric sensor between the electronic body protector and the socks due to the material's impact absorption characteristic. Besides that, there is no expiry date which is stated on the electronic body protector.

According to a joint research team between Germany's University of Constance and Korea Institute of Sports Science, energy which was absorbed by the body protector is measured in Joule (Vecchio, Franchini, Vecchio, & Pieter, 2011). Unfortunately, data from it has never been revealed or made available to the public by the PSS manufacturer. The measurement done in Tasika (2013)'s research, found that the impact force is actually presented as kinetic energy. To this day, the competitors still do not know how the PSS can be scored in the most efficient and effective way. Coaches and

exponents may find these information to be useful to help strategize their game plan and also help plan an athlete's training program precisely.

More recently, there has been cheating cases which transpired during tournaments, these exponents had been caught by officials after they had added extra hidden sensors into their socks to gain additional scoring advantages (Udo, 2015). This may be one of the limitations of the electronic body protector where it may become much more sensitive and easier to detect contact force if there are more sensors surrounding the contact point.

With the current PSS technology which is based on sensors, the electronic body protector can be also used to develop training program for the exponent to get familiarized with the actual competition scenario using the PSS. Apparently, a training program had been developed using a custom made multi target punching bag (Song et al, 2010). The punching bag was created using the same technology as the electronic body protector. Exponents are required to hit the target indicator that was computer controlled to achieve better kicking accuracy and intensity in scoring a valid point. In the training mode, all the target indicators on the punching bag are able to measure a kick's intensity which will be displayed on monitor whenever the electronic socks which are worn by the athlete's touches or make contact with the electronic body protector.

Nevertheless, there are also researchers who had done impact force studies. Punching bags which were embedded with accelerometer and strain gauge were found to be a good invention to detect the strike force that can be used in combat sports training to measure athlete's impact consistency (Busko, Staniak, Łach, Mazur-Rozycka, Michalski & Gorski, 2014). Although this invention was made to detect strike force much like the PSS, but it can only be used practically in a static position or in a

lab setting because the accelerometer is sensitive to movement whereby it is hard to define a kick. It would also be much more convenient if the system can be made wireless to improve the mobility of the user.

2.4 Piezoelectric sensor

The piezoelectric sensors in the PSS are used to detect the impact forced received from the foot (socks) towards the body protector by creating a small quantity of electrical charge and sending it to the monitor using Wi-Fi technology (Tasika, 2013). This technology is used because it is able to measure the impact force dynamically with wide range of frequency (Wang, 2013). Unfortunately, piezoelectric sensor can also be affected by the change of temperature. It was found that piezoelectric sensor is a temperature dependent technology where it has no temperature correction on a moderate range of operating temperature (Sirohi & Chopra, 2000).

Besides that, there will be changes in frequency detection when this piezoelectric sensor reacts to different temperature (Zhang & Yu, 2011). This may be one of the major drawbacks due to its sensitive reaction towards temperature and it might be inaccurate and inconsistent in detection of impact force towards the electronic body protector when it is used on different climates such as cold and hot weather, and athlete's body heat before and after sweating which may cause changes.

The primary reason this technology is being widely used in the electronic system is not just because it is the most common technology available for dynamic sensor detector but it is due to its stiffness and strength which can be used and restrain in a rough environment such as high impact knocking or contact between the sock and the electronic body protector (Chi, 2005). This is suitable for combat sports because Taekwondo athletes will be kicking hard repetitively with an average force of 2000 Newton towards the electronic body protector worn by their opponent (Vecchio et al.,

2011). However, if there is any malfunction of the equipment it cannot be objectively distinguished or detectable because even in the manufacturer's manual guide book (TK-Strike Manual, 2016) it does not have any guideline or a standard operation procedure to detect or check on the hardware or equipment. Also, it is not visible to officials if there is an error regarding about the PSS, therefore athletes might be competing using error prone equipment during tournament.

It has been said that the sensor socks will be quickly degrade, in terms of sensitivity and its tightness after several time of usage (Udo, 2015). Loose socks and less sensitive socks may affect its sensitivity during contact against the electronic body protector, which may jeopardize the exponent's winning chances. Interestingly, it is also not known if there would be any effect to the scoring system if the socks would be worn and used in wet condition or different climate.

2.5 Reliability, validity and statistical analysis of sports equipment

Reliability of equipment is an important factor to determine the consistency of the result during testing after a certain amount of repetition. There are many sports equipment which had been tested for its reliability. These items include mobile phones which were tested for its reliability in balance assessment of gymnasts (Marinsek & Slana, 2013). Using Cronbach's Alpha statistical analysis, researchers were able to determine the reliability index of the phone. Results showed consistency in measuring degree of rotation which is similar to the G-weight goniometer that had been used as a reliable device to monitor balance progress (Marinsek et al., 2013). All data which had been collected during the mobile phone test were correlated using the Pearson's Correlation coefficient (PCC) and using the comparison of Bland and Altman (1986), absolute reliability on both devices were compared by analyzing 95% limit of agreement between the devices.

Custom made device has also been tested and it has become a norm for researchers to conduct their studies using less expensive test equipment. For example, a portable impact testing device was built to assess the cushioning properties of athletic socks and has proven its reliability by achieving a reliable test result of $< 2.6\%$ for the no-sock condition, $< 6.9\%$ for the sock condition and $< 4.1\%$ for the basic shoe/sock condition (Blackmore, Jessop, Bruce-Low & Scurr, 2013). The testing procedure involves a custom made impact testing device, and the device reliability was also tested prior to the experiment. This testing device was done using five sock samples with five impact trials on each sample and the same procedure was repeated for two days with another five new sock samples under controlled laboratory atmosphere of 23 ± 2 °C. The device's reliability was determined using coefficient of variation while confidence interval was used to calculate and estimate the systematic biasness. It was set at 95% confidence interval trials between the two days; and the result were coefficient of variation $< 5\%$ adjusted for 95% confidence limits with no evidence of systematic bias between data.

Electronic technology and devices have also been found to be more reliable and have strong inverse correlation in assessing postural balance objectively (Patterson, Amick, Pandya, Hakansson & Jorgensen, 2014) compared to the current manual postural balance testing methods such as the balance error scoring system, Berg balance test and Tinetti balance assessment which require the administrator's skill, knowledge and experience to conduct a reliable test. The reliability of the electronic balance device such as the smartphone was tested using balance error scoring system (a known reliable balance index) while the validity was compared to clinical assessment associated with concussion, exertional fatigue, ankle instability and age. In another similar balance research using smartphones, test result acquired using the electronic device and clinical scoring were correlated with G-weight goniometer (the current standard range of motion

measurement), with a correlation as high as 0.99 (Marinsek et al., 2013). They found that a strong inverse correlation between the electronic device and the clinical trial which is based on combination of rotational vector sensors of accelerometer, gyro and magnetic field sensor.

In terms of the statistical procedures used, many sports related devices have been tested for its reliability by using the interclass correlation coefficient (ICC) such as reliability of GPS device (Duffield, Reid, Baker & Spratford, 2009). Differences between paired and mean observation values can be measured by conducting the test-retest method on each section or session. Paired t-test too was used to eliminate biasness in reliability measurement although there is a limitation of paired t-test comparison when it comes to multiple types of differences (Linnet, 1999). Among the devices which had been tested using these methods include the archery chronometer (Ertan, Kentel, Tumer & Korkusuz, 2005), Taekwondo electronic body protector (Tasika, 2013) and sprint timing system (Shalfawi, Tonnese, Enoksen & Ingebrigsten, 2011). Besides that, coefficient of variation has also been used to report the typical error of the inter-unit reliability between measurements which had been done on a GPS device (Duffield *et al*, 2009) and a portable accelerometer which is tested on Mixed Martial Art Athletes (Hurst, Atkins & Kirk, 2014). While one-way analysis of variance (ANOVA) was also used to measure the difference between respective measurements on the portable accelerometer (Gray, Jenkins, Andrews, Taaffe & Glover, 2010). In addition, Bland and Altman plot can also be used to measure the agreement between two measurements which is able to strengthen the reliability's result (Zaki, Bulgiba, Ismail & Ismail, 2012).

To study the validity of a device, measurement methods should be synchronized to find out the relationship between measurements while being tested on the equipment. For example, the archery chronometer was tested for its validity by comparing the

Clicker Reaction Time and Electromyography Reaction Time to justify their relationship, whereby it was proven for its validity because both of these measurements had correlated scores in their end result (Ertan et al., 2005). Besides that, validity testing on electronic devices was also tested using the same measurement method as reliability testing procedures but with different intensities. Subjects were given the same length of movement but with different direction to reach a destination to test the validity of GPS device. The accuracy of the GPS device was affected by the non-linear movement (Gray et al., 2010).

Most validity testing were evaluated based the agreement of two sets of data with the use of Pearson correlation coefficients for continuous variables. For example, change of direction and acceleration validity test (Lockie, Schultz, Callaghan, Jeffriess, & Berry, 2013) and jumping performance validity test (Cronin, Hing, McNair, 2004) have used the same statistical method (Pearson correlation coefficient) to find out the validity of their tested equipment.

The main reason validity testing of equipment were done was to ensure that each apparatus accurately measures what it is intended to measure. Technology in this era has improved tremendously, at a very fast pace which has enabled sports scientists to develop multiple testing devices that are much cheaper and portable at the same time (Comstock et al., 2011).

This PSS is one of the latest scoring technologies in Taekwondo competition. It was only officially used London 2012 Olympic Games and there are not many studies which had been done on the PSS. Taking into consideration the limitation of previous studies and the current gaps in knowledge, the objective of this study is to experimentally examine the reliability and validity of the electronic body protector (PSS) in a more methodological manner. This study consists of two parts, first

conducting a reliability test of the custom made mechanical pendulum. While for the second part was to test on the electronic body protector using the mechanical pendulum.

University of Malaya

CHAPTER 3: METHODOLOGY

3.1 Research Apparatus

3.1.1 Customized Mechanical Pendulum Apparatus

For the first part of this study, a specific measuring tool is needed to test the PSS therefore a customized mechanical pendulum apparatus was designed and built specifically for this purpose. The pendulum apparatus itself had to be tested for its reliability before it can be utilized as an experimental tool. The second part, is to test the reliability of the PSS using the customized mechanical pendulum apparatus which has been tested on its reliability.

The mechanical pendulum was built accordingly as per Figure 3.1 and Figure 3.2; to try mimic a kick hitting on the PSS, in the most consistent manner possible. It is made up of metal plates and tubular mild steel sections. Two sealed ball bearings were used to provide low friction rotational movement for the pendulum arm. The frame consists of four tubular sections with a height of 1.4 meter each, and slanted at a 15 degrees angle. The base is 0.63 meter wide and 0.41 meter long and it was bolted onto the concrete floor of the lab. The length of the pendulum was 0.94 meter. A metal plate was welded in between the front and back frame and has an adjustable clamp to hold the body protector in place.

The placement of the body protector (Figure 3.3) was adjustable; therefore the pendulum can hit on different parts of the electronic body protector.

The pendulum was held in place using an electromagnetic lock that was located on an extended tubular arm. The pendulum was released with a flick of a switch. The mechanical pendulum swings at the same distance and velocity and this produces the same amount of kinetic energy for every swing. The pendulum was purely driven by

gravity without having other external forces acting on it, wind resistance was negligible. More importantly, because of the 15 degree slant, the pendulum will not ‘stick’ to the body protector but instead swing back after the impact – very much like a real kick.

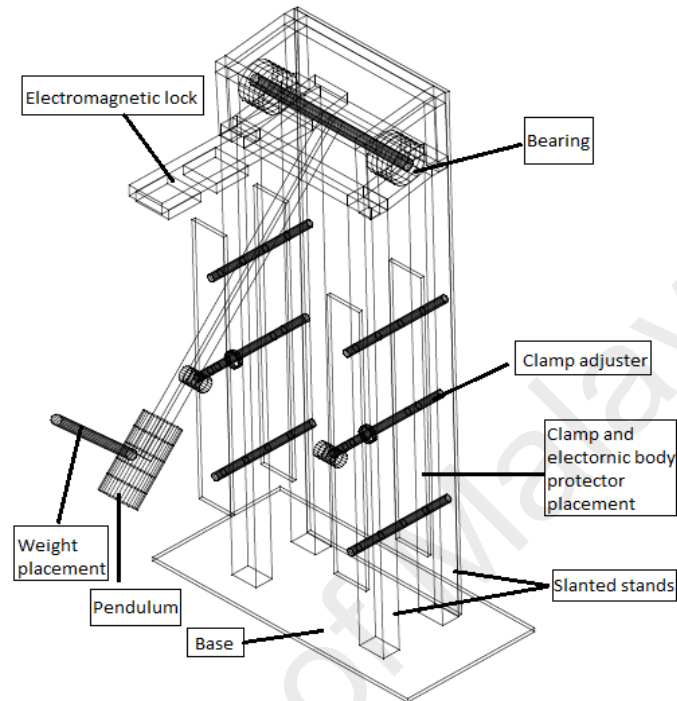


Figure 3.1: Diagram of customized mechanical pendulum apparatus



Figure 3.2: Customized mechanical pendulum apparatus



Figure 3.3: Placement of electronic body protector on the mechanical pendulum



Figure 3.4: Placement of electronic sock on the mechanical pendulum

3.1.2 Daedo TK-Strike Electronic Body Protector (PSS)

The main equipment of this study is the Daedo TK-Strike electronic body protector which is the major component of the PSS. The whole PSS setup consist of a body protector as in Figure 3.5, socks as in Figure 3.6 which are used to detect impact, a transmitter and a receiver as in Figure 3.7 that transfers signal to a Wi-Fi linked computer which are analyzed by the Daedo TK-Strike software.

The electronic body protector which was used in this experiment is a used unit, it was randomly picked from a batch of six units that were in use by a taekwondo association for competitions. The manufacturer and WT do not specify a use-by-date for the PSS, nor do they require any form of testing or calibration prior to use.

In this study, 12 sections of different parts of the electronic body protector which covers the body protector in whole. Hence, the test result among each section can be achieved by using the same testing method to obtain a more reliable result than before. It has been alleged that the scoring on the electronic body protector was limited due to the sensor's contact area which does not cover the electronic body protector thoroughly (Udo, 2015).



Figure 3.5: Electronic Body Protector



Figure 3.6: Electronic socks



Figure 3.7: Transmitter (left) & receiver (right)

3.2 Research Design

To test the apparatus's reliability, a calibrated Qualisys motion capture system (Qualisys, Sweden) was used to track and record the velocity at impact and the period of the pendulum (Figure 3.8). Two sets of data, consisting of 50 trials each were collected on two separated days (the next day), using two different testers but using the same

exact hardware settings and procedure. A host computer was linked to the eight Oqus Qualisys Motion capture camera with a capturing rate of 377 frames per second.



Figure 3.8: Oqus Qualisys Motion capture camera

Data were recorded and processed in the Qualisys Track Manager software Version 2.8 (Qualisys, Sweden). The released height of the pendulum magnetic lock was checked after every two trials to ensure that it was exactly the same height using a Stanley Fatmax25 measuring tape (Stanley, USA). A single 14mm reflective marker was securely fixed at the back of the pendulum. The motion capture system was calibrated prior to testing sessions with a RMS error for 3D reconstruction of 0.28mm to 0.26mm for day one and day two respectively. Pendulum's velocity of each trial was determined based on the velocity captured on the last frame of the motion capture before impact.

The PSS setup consists of a body protector, socks which act as a “key”, a transmitter and a receiver that transfers signal to a Wi-Fi linked computer which are then analyzed by the Daedo TK-Strike software. The mechanical pendulum test apparatus was designed to generate impact force on to the body protector while the

sock was be slipped on to the swinging pendulum as a key so as the contact is recognized by the Daedo TK-Strike software. The PSS was not synchronised with the motion capture; there was not a need to as the values compared are peak energy values. The PSS software, TK-strike is able to record and it displays energy values in Joules.

The electronic body protector was divided into 12 sections as in Figure 3.9; and each section of the body protector was given 100 ‘kicks’ on the same spot by the electronic sock (pendulum) and the electronic body protector. Each section consists of a size of a foot instep approximately ($0.15\text{m}^2 \times 0.15\text{m}^2$). The 12 sections of the electronic body protector were tested on two different days with 50 trials per day using the same exact procedures. The second trial was conducted the next day and each section took roughly ten minutes to complete.

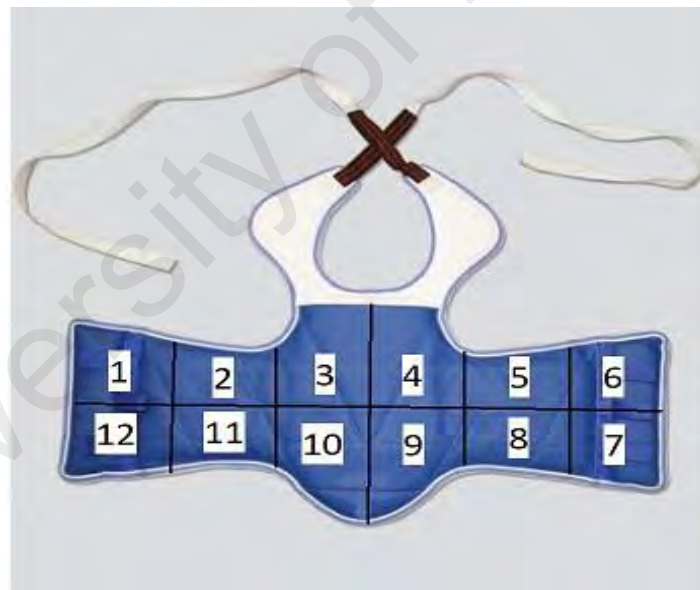


Figure 3.9: Sections of electronic body protector

A total 1200 kinetic energy values were recorded throughout the two days. The sequences of each section’s trial were randomized. The sequences of section’s trial are as per Table 3.1 and Table 3.2 which are the randomized sequence of testing. The selection of section was selected using a draw lots system. Temperature and humidity during the testing were monitored as well using the Acurite digital humidity and

temperature monitor (Acurite, USA). Time of procedure was specifically set at 12 pm for both testing days to minimize temperature and humidity variation during testing. The temperature and humidity were recorded at 26 to 26.5 degree Celsius and 77 to 80 percent of relative humidity for day 1 and day 2 respectively. Drop height of the pendulum was also measured after every two trials to ensure it was the same.

Table 3.1: Sequences of Day 1

	Section											
Sequence	1 st	2 nd	3 rd	4 th	5 th	6 th	7 th	8 th	9 th	10 th	11 th	12 th
Set 1	2	4	11	6	12	9	1	8	7	3	10	5
Set 2	10	11	4	9	3	12	5	2	1	6	8	7
Set 3	6	5	1	12	8	11	7	4	3	10	2	9
Set 4	1	10	7	4	9	8	12	2	11	5	6	3
Set 5	5	12	3	1	10	9	4	7	8	2	11	6

Table 3.2: Sequences of Day 2

	Section											
Sequence	1 st	2 nd	3 rd	4 th	5 th	6 th	7 th	8 th	9 th	10 th	11 th	12 th
Set 1	12	7	2	1	7	10	3	5	11	8	4	9
Set 2	3	11	5	7	12	9	8	1	4	2	10	6
Set 3	4	8	10	3	1	7	2	5	12	9	6	11
Set 4	10	4	1	5	8	2	6	3	9	11	12	7
Set 5	7	5	6	12	3	9	1	4	10	11	8	2

3.3 Statistical Analysis

3.3.1 Customized Mechanical Pendulum Apparatus

To test the mechanical pendulum reliability, data were analyzed using Statistical Package for the Social Science (SPSS) software Version 23 (IBM Corp, USA). Paired t-test, linear regression analysis and followed by Bland-Altman test were used to analyze the differences and agreement between the two data sets between Day 1 and Day 2 from the mechanical pendulum. The Bland Altman plot showed evenly distributed points in the scatterplot graph. Bland-Altman statistical analysis was chosen as the statistical analysis method in this study because it is able to find out the agreement between two different measurements (Zaki et al., 2012). Based on the Bland Altman plot, there was an agreement and no proportional biasness between the two data sets because of the evenly distributed points between the mean differences in the scatterplot graph (Giavarina, 2015). Boxplot method was applied to check on data's normality distribution.

3.3.2 Daedo TK-Strike Electronic Body Protector (PSS)

To measure the PSS reliability, paired t-test method comparing between Day 1 and Day 2 was used to analyse the internal consistency of the PSS. Homologous descriptive statistic was also used to group the sections which displayed the same amount of energy based on Kendall's statistical test. Boxplot method was applied to check on data's normality. Wilcoxon test was used to analyze non-normally distributed data

While to test for the PSS energy reading validity, kinetic energy which were displayed by the PSS system were compared with the calculated energy produced by the mechanical pendulum – the criterion value. Kinetic energy of the swinging pendulum

was calculated (joules) using the formula $\frac{1}{2}I\omega^2 = \frac{1}{2}\left(\frac{T^2mgD}{4\pi^2}\right) \times \left(\frac{v}{r}\right)^2$. The moment of inertia (I) was calculated using the formula of $\frac{T^2MgD}{4\pi^2}$ which equates to 5.04 kg. m². Weight of the rod (m) was constant at 8.8kg. Gravity (g) remained constant at 9.81ms⁻². Mean period of the pendulum (T) as measured by the motion capture system was 1.84 second. Distance of the pendulum from the center of mass to pivoting point (D) was 0.68m. While the angular frequency (ω) was calculated using the formula of $\frac{v}{r}$ which was equaled to 4.69 rad. s⁻¹ and the radius (r) of the pendulum was 0.94m. The average velocity (v) at impact of the swinging pendulum was recorded using the Oqus Qualisys Motion capture camera at 4.41ms⁻¹. Based on the kinetic energy equation, this resulted in an average kinetic energy value at impact of 55.52 Joules. Data was analyzed using Statistical Package for the Social Science (SPSS) software Version 23 (IBM Corp, USA).

CHAPTER 4: RESULTS

4.1 Customized Mechanical Pendulum Apparatus

To test the reliability of the mechanical pendulum, a total of 100 trials were recorded, 50 trials per set. Both sets were measured on separate days. Table 4.1 shows the mean velocity of the pendulum, standard deviation, standard error of the apparatus, mean differences between trials of Day 1 and Day 2 and significance value of mean differences between the sets.

Table 4.1: Mean \pm SD Mean velocity and Standard Error of mechanical pendulum

	Set 1 (S1) (n=50)	Set 2 (S2) (n=50)	(S1-S2)
Mean velocity of pendulum (ms^{-1})	4.41 ± 0.012	4.42 ± 0.012	-0.004
Standard Error (ms^{-1})	0.002	0.002	
t value			1.804

S1- Trials on Day 1
S2 - Trials on Day 2

The standard error of the pendulum apparatus was similar for both days at 0.002ms^{-1} . It was found that there was no significant difference between the two sets of data ($p = 0.08$). Points of differences between trials against mean of sets were plotted using Bland-Altman method (Figure 4.1). The Bland Altman plot showed evenly distributed points in the scatterplot graph.

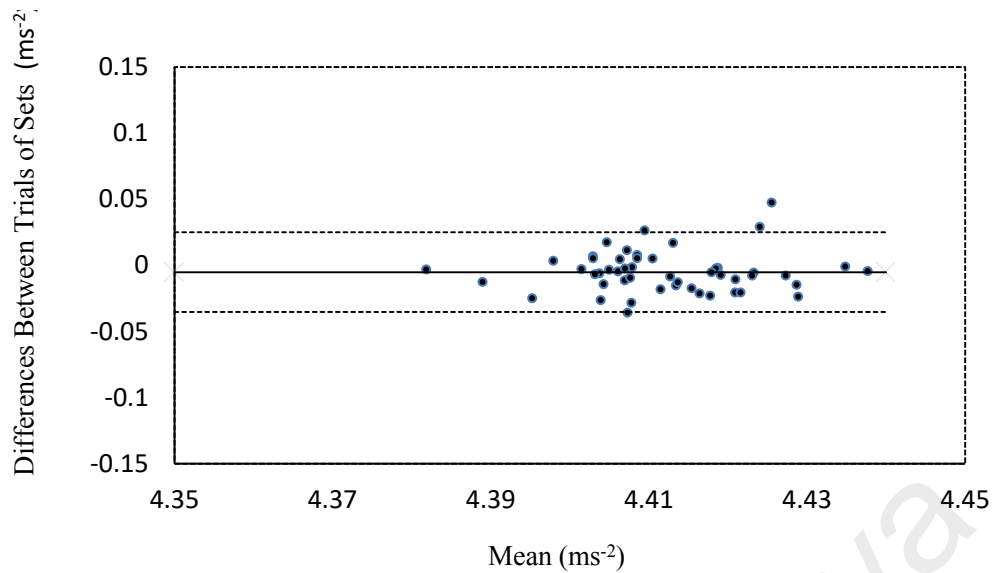


Figure 4.1: Bland-Altman plot for the mechanical pendulum (n=100)

Linear regression analysis was done to find the level of agreement between Day 1 and Day 2 data. Both day's data were found to have no statistically significant differences ($p = 0.80$) as in Table 4.2. This means that there was no proportional biasness and it does not show a trend whether it has more data point above or below the mean difference line on the Bland Altman plot between Day 1 and Day 2.

Table 4.2: Coefficient of linear regression of the mechanical pendulum

Predictor variable	β Estimate ^a
Mean between trials of sets	0.51
t value	2.51
p value	0.80

^aDifferences between trials of sets as dependent variable

4.2 Daedo TK-Strike Electronic Body Protector (PSS)

For the experimental trials, a total of 1200 trials were recorded. The test on the 12 sections was done on two different days where 50 trials were collected on each section on Day 1 while another 50 trial were collected on each section on Day 2.

Mean and Standard Deviation of sections on trials of Day 1 and Day 2 are presented in Figure 4.2 and Table 4.3. All these data were collected based on the Daedo TK-strike software. Among all the 12 sections, S2 recorded the highest kinetic energy score of 41.9 Joules on Day 1 and 39.7 Joules on Day 2. The lowest kinetic energy score which was recorded throughout the two days trial was S3 with the values of 21.4 Joules on Day 1 and 21.4 Joules on Day 2.

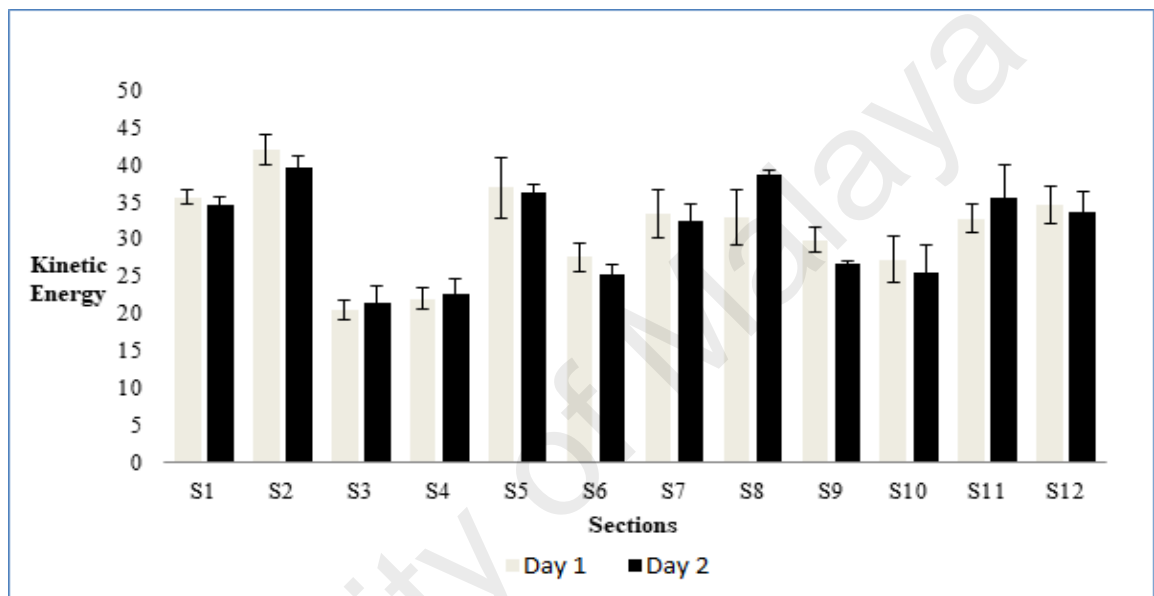


Figure 4.2: Bar chart of Mean and Standard Deviation of kinetic energy for each section between Day 1 and Day 2

Boxplot method was used to check on data's normality and S7, S10 and S12 are the sections that were normally distributed while the rest of the section were not normally distributed. Normally distributed data were analyzed using paired samples t-test while non-normally distributed data were analyzed using non-parametric method, the Wilcoxon test.

Table 4.3: Descriptive Statistics and comparison of mean and standard deviation of each section's kinetic energy on Day 1 and Day 2

Section	Day 1 (mean \pm SD) (Joules)	Day 2 (mean \pm SD) (Joules)	t/Z value
S1*	35.58 \pm 0.95 bc	35.00 \pm 1.45 d	5.30 ⁺
S2*	41.94 \pm 2.06 a	39.68 \pm 2.18 a	5.69 ⁺
S3*	20.44 \pm 1.37 i	21.42 \pm 2.05 h	4.65 ⁺
S4*	21.98 \pm 1.49 h	22.62 \pm 1.17 h	1.76
S5*	36.90 \pm 4.01 b	36.22 \pm 1.18 c	1.16
S6*	27.54 \pm 1.97 g	25.38 \pm 2.40 g	6.13 ⁺
S7	33.40 \pm 3.28 de	32.38 \pm 0.50 e	3.16 ⁺
S8*	32.88 \pm 3.61 ef	38.62 \pm 0.49 b	6.00 ⁺
S9*	29.90 \pm 1.62 f	26.64 \pm 0.48 f	6.20 ⁺
S10	27.28 \pm 3.18 g	25.54 \pm 3.70 fg	3.48 ⁺
S11*	32.78 \pm 2.02 e	35.56 \pm 4.43 bc	3.38 ⁺
S12	34.64 \pm 2.50 cd	33.5 \pm 2.90 d	1.66

*Non-normally distributed

⁺significantly different

[□] Means with the same letter are not significantly different

Among all the sections, for S4, S5 and S12 there were no significant differences between Day 1 and 2 where the P values were 0.079, 0.245 and 0.105 respectively. The rank of mean starting from the lowest kinetic energy are S3, S4, S10, S6, S9, S7, S11, S12, S1, S8, S5 and lastly S2 which has the highest mean kinetic energy. It was also interesting to note the standard deviation of the PSS varies from 1.03 Joules on S1 up to 3.43 Joules on S10.

All sections of the electronic body protector were analyzed using the homologous descriptive statistic which divides all sections into groups based on

Kendall's statistical test to compare the energy value of each section for Day 1 and 2 as in Table 4.3. The sections which were grouped together do not have significant differences among the sections. For Day 1, S6 and S10 were the only sections that are in the same group which was group "g" while on Day 2, S3 and S4 were the only sections that are in the same group which was group "a". Overall the electronic body protector is unreliable considering that two out of 12 sections, only two sections were in the same group for each day's trial, this translates to being only 16.7% reliable.

When the energy value displayed by the PSS was compared to the calculated energy value of the pendulum, both displayed and calculated pendulum kinetic energy were significantly different ($p < 0.01$). Based on the calculated kinetic energy which is the criterion value produced by the mechanical pendulum which was 55.52 Joules, it was markedly different compared to mean energy reading as in Table 4.4 which was recorded using the PSS software. The range of the mean kinetic energy which was recorded was between 20.93 to 40.81 Joules. The range of the kinetic energy was perpetually lower than the calculated kinetic energy produced by the mechanical pendulum.

Table 4.4: Differences between displayed Daedo TK-strike energy value and calculated kinetic energy of the pendulum

	Displayed PSS kinetic energy (\pm SD)	Estimated PSS kinetic energy (\pm SD)
Mean (joules)	31.14 \pm 6.46	55.52 \pm 0.34
Standard Error (joules)	0.19	0.01
t value		130.537 ⁺

⁺Significantly different

CHAPTER 5: DISCUSSION

The mechanical pendulum is much more convenient and practical to be used as a test apparatus for the electronic body protector compared to the other two methods mentioned by Ramazanoglu (2013) and Tasika (2013). Extra weights can be added to the pendulum during a test to produce higher kinetic energy during impact if needed. Also, more importantly, with its adjustable clamps, it can be used to test many different sections of the electronic body protector by moving the desired test section to the middle. It is also able to knock on each section accurately due to the fixed movement pattern of the pendulum. At the same time, with a solid metal structure, there is minimal dissipation of kinetic energy during impact (Zhang et al., 2015). It is also highly durable. In fact, this testing apparatus and test procedure can also be used to check on each and every electronic body protector's reliability before it can be used in the future tournaments.

Comparing the current study with previous studies by Tasika (2013) and Ramazanoglu (2013), both have shown that the electronic body protector has poor reliability. However, both of their testing procedure and apparatus were vague because it was not tested for its reliability before applying the test method onto the electronic body protector - this had made their result questionable. Ramazanoglu (2013) used a spring steel which acts as a catapult to hit on the electronic body protector while Tasika (2013) had done a drop method using iron ball which was released and drop on to the electronic body protector from different heights. However unlike the previous studies, this study had done a reliability test towards the testing tool first before proceeding to test the electronic body protector reliability.

The test apparatus was shown to be reliable where both P values for t-test and coefficient of regression were 0.08 and 0.80 respectively. Both these tests found no

significant differences in velocity at impact between the two days of testing ($p > 0.01$). Additionally, the Bland Altman plot was also used to corroborate the findings and the plot showed evenly distributed points in the scatterplot graph which means that there is an agreement and no proportional biasness because of the evenly distributed points in the scatterplot graph (Giavarina, 2015).

The customized mechanical pendulum is a reliable test apparatus possibly because it is purely gravity driven; and gravity is constant. Under the constant gravitational force, acceleration of the pendulum will also remain consistent for any number of given repetitions. By using this apparatus, one does not need to worry about the degradation of strength of the pendulum because it does not need external forces to move the pendulum such as for example when using the steel spring apparatus (Ramazanoglu, 2013). Steel spring will degrade in strength and flexibility after a certain number of repetitions (Salvange, 2012) and it will need to be replaced. This will cost more in terms of time to reset the same procedure and a higher operational cost. Even worse, if the same spring were to be used continuously, the reliability of the testing procedure would be questionable.

Although the concept of this apparatus is similar to one of the previous study by Tasika, (2013) which is the drop test method that also uses gravitational force - the impact force of the pendulum is only momentary due the slant angled design of the apparatus as opposed to a ball being stuck on the PSS (Tasika, 2013). This method is much more similar to an execution of a kick whereby kicks are retracted immediately right after contact. However, the inconsistent scores of the electronic body protector which was found by Tasika (2013) as most of the sections of the electronic body protector read and generate different reading although weights were dropped with the same amount of energy towards it.

The main purpose of this study is to study the reliability and validity of the Daedo electronic body protector which was used in the previous Olympic Games in 2012 and 2016. Once the reliability of the pendulum was established, the PSS was put through experimental testing, out of 12 sections, only three sections which were S4, S5 and S12 that had no significant differences ($p > 0.01$) between the two days of testing based on the t-test (Table 4.3). Overall, the PSS can be considered not reliable. The electronic body protector is unreliable considering that only two sections out of 12 sections that belong in the same group for each day's trial, this translates to being only 16.7% reliable as in Table 4.3. The PSS possibly should not be used in Taekwondo tournaments as it is not a reliable tool.

The energy from the mechanical pendulum was found to be consistent based on the Bland Altman plot which had shown agreement between two sets of data. The pendulum was able to generate 55.52 Joules based on the pendulum kinetic energy equation. However, from the attained results none of the 12 sections displayed kinetic energy reading more than 41.94 Joules on average. There were significant differences between the displayed energy values and calculated pendulum energy. Considering that the padding is rather thin, the possible energy loss and the resulting discrepancy between the PSS and actual energy of pendulum are surprisingly large (Zhang et al., 2015).

Based on the kinetic energy reading, S2 displayed the highest mean kinetic energy while S3 had the lowest mean of kinetic energy reading. Even though the same amount of energy was from provided by the mechanical pendulum the read out from PSS was markedly different. This made section 2 as the easiest section to score due to the high kinetic energy reading. While section 3 would be the most difficult section to score because it has the lowest reading among all 12 sections. A minimal threshold of kinetic energy detection is needed to validate as a score but surprisingly, not every

section of the body protector was able to consistently recognize the same impact energy. Therefore in this case, exponents would have to increase their kick's impact if it were to land on section 3 of the body protector to register a point. It would also be much more difficult to score in a higher weight category as usually officials set higher minimal threshold of kinetic energy to register points.

As the result has shown that the side of the electronic body protector was able to detect higher kinetic energy during impact using the same weight and procedure compared to the upper middle section. In this case, Taekwondo exponents and coaches are able to receive additional valuable information to strategize and emphasize scoring on the high impact reading sections which are on the sides of the electronic body protector. However, this unbalance kinetic energy reading should not have happened in the first place as it is an official scoring equipment especially in the Olympic Games. It should be able to detect kinetic energy consistently on every part of the electronic body protector to provide fair competition among athletes.

With this information, coaches may start to plan their training method to emphasize kicking on the high kinetic energy reading area such as making exponents to be trained specifically on the scoring area of the electronic body protector. It is not necessary to aim at section 3 and 6 even though their reliability are high because both of these section's mean average kinetic energy reading were lower compared to other sections which has higher energy reading during the experiment. However, exponents should aim for the easiest section that can be scored using the least effort or kicking impact which is S2 because it has the highest mean average among all the sections neglecting the section's reliability. The most effective and efficient way of kicking and scoring will be the key of success in Taekwondo tournament.

There are a few possible reasons to why the PSS is not giving out valid and reliable scores. One of the possible reason would be that electronic body protector was manufactured and produced in a flat shape. However over time, the shape of the electronic body protector has changed from flat to curved because it has to be bend and worn by wrapping around the exponent's body. Due to the changed shape, the sensors in the electronic body protector may have shifted position and stretched as well. Hence, the sensors which had shifted did not cover the electronic body protector thoroughly and caused some parts of the electronic body protector to be less sensitive. Other than that, wiring in the electronic body protector can also be stretched and damaged as well because of the bend which might interrupt the connectivity as well as the sensitivity between the sensors and transmitters.

The thickness of each section of the electronic body protector may have also caused the inconsistency of impact among sections. Degraded foam from thick to thin would have affected the impact of kinetic energy absorption (Verdejo & Mills, 2002) which changed the energy reading from the beginning to the end of test due to the high repetition of high impact knocking.

As an extension of the inconsistency between the sections, there is also an urgent need to find out the actual placement of all the sensors which is in the electronic body protector. Inconsistency between sections may also be due to the uneven arrangement of the sensors which has been built-in and placed in between the padding. Placement of sensors can only be seen clearly once the electronic body protector is cut open to expose the interior design and technology of the equipment. However, more funds will be needed to proceed with the exposure of the electronic body protector from inside out as this dissection will destroy the PSS. Besides that, no detailed information is available regarding the usage of the electronic body protector from the manufacturer, such as the lifespan or repetition of usage of the equipment. Although piezoelectric

sensor is able to withstand rough high impact knocking (Chi, 2005), there should be a limitation of impact and repetition knocking which reduces the sensitivity of the sensor and affects the accuracy of sensor's calibration (Sirohi et al., 2000). Without proper guideline from the manufacturer, it will be difficult to detect whether the electronic body protector has any defect or error. Hard and high repetition of kicks may have damaged the electronic parts in the electronic body protector. Hence, using damaged equipment during competition will also affect the result as a whole.

To study the reliability of electronic body protector further, procedures can also be improved by manipulating the environment and climate. Currently, there is no study yet which had been conducted regarding the effect of changes in temperature and humidity towards the electronic body protector's capability. It would be interesting to find out if there are any changes on impact energy reading between cold and hot environment such as winter and summer seasons because this scoring system is used worldwide and all seasons throughout the year. The reason behind of why climate control testing should be done is because this PSS technology uses piezoelectric sensors (Tasika, 2013) that can be influenced by temperature where it reacts differently under different temperature due to its sensitivity (Zhang et al., 2011).

There is also a need to identify the reason of inconsistency of the electronic body protector; such as product materials and issues with the software itself. Using unreliable equipment in Taekwondo tournament will cause unfairness among competitors and also tarnish the good name of the World Taekwondo (WT) as the world governing body for Taekwondo. This may jeopardize taekwondo as part of the Olympic event in the future due to the scoring system's reliability.

The findings support the inconsistency of scoring which was experienced by exponents, coaches and spectators in Taekwondo tournaments that used PSS (Leveaux,

2012). Previous studies Tasika (2013) and Ramazanoglu (2013) have found that the PSS is unreliable and has poor consistency which is aligned with Leveaux's (2012) finding. This study reaffirms the earlier findings as well as adding that the inconsistency is present in all sections of the body protector. The main objective of the PSS was to eliminate biasness and it was introduced to enhance Taekwondo as a sport to be more objective in term of judging and scoring (Chi, Song & Corbin, 2004). PSS was supposed to provide aids to referees by reducing human error and promote fair play among participant unlike the manually judged scoring system (Leveaux, 2010). This may jeopardize taekwondo as part of the Olympic event in the future due to the scoring system's reliability.

Overall, this equipment is not suitable to be used as an official sporting equipment because it does not provide fair play for athletes due to its poor consistency, this is in agreement with Leveaux's finding in 2010. As it is a single unit, therefore results must be viewed with some caution. That being said, the validity and reliability of the PSS is questionable at best.

CHAPTER 6: CONCLUSION

This study found that the PSS is unreliable because not every area of the electronic body protector was able to consistently recognize the same impact energy from the pendulum. The PSS is also considered not valid as the kinetic energy displayed by the electronic body protector was significantly lower than the calculated values. It is recommended that a more detailed examination on the PSS is carried out by the relevant authorities and the data be made available to the public. Every unit of the electronic body protector should be also carefully scrutinized prior to use in future tournaments.

Based on the result acquired, both hypothesis of this study are accepted. Firstly, not every area of the electronic body protector is able to consistently recognize the same impact threshold. Secondly, the kinetic energy measurement of the electronic body protector is not valid

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