Technological Innovations in Taekwondo

Stephen M. Sulack

Taekwondo has grown greatly in international prestige and in common acceptance over the past 50 years. From its beginnings in 1952 as a martial art taught to the South Korean Military to improve conditioning,[1] it has spread all over the world. After many years as a demonstration sport at the Olympic Games, it became a sanctioned sport in 2000, and arguably one of the more exciting ones at that. G*yoroogi*, or sparring competition, has greatly increased the public's exposure to taekwondo. On the one hand, competition is fun to watch for all, but on the other hand the safety of the players must be kept paramount. The equipment used in competition, as well as the rules of competition, has changed greatly over time for a number of reasons. This essay will briefly explore the contributions that technology has made to gyoroogi competition and how it may play a role in its future. In particular, the evolution of key protective equipment and how to analyze their effectiveness, the advent of digital scoring, and finally the possible use of sensors and other technology in competition in the future will be covered in this essay.

Protective Equipment

Early on, chest protecting sparring gear, typically called a *hogu*, was simply a collection of padded bamboo slats wrapped around the torso.

Unfortunately, the bamboo had a tendency to splinter and pierce through the padding and plunge into a competitor's chest, often causing serious injury. The next incarnation of gear was very similar to modern life preservers, although the thick absorptive foam was too bulky to be comfortable in competition. Bulky padding tends to constrict torso movement, which can have a very limiting effect on the hips, an important component of most taekwondo techniques. As materials science progressed, a lightweight hollow tubing chest protector was developed that worked quite effectively but was also too bulky. Most modern chest protectors feature a semi-rigid plastic layer with padding on the inside and outside to minimize injury to both the defender and attacker.

Figure 1: Hogu with edge cutaway. There are five layers to the hogu when viewed edgewise, but only 3 unique pieces. From outside in there is a plastic skin, a layer of low density foam, and a layer of high density foam.

These different types of chest protectors have focused on the two principal means of injury prevention: energy dispersion and energy absorption. In the case of energy dispersion, the equipment spreads the force of contact from a small area, the kicking surface of the foot, over the larger area of a torso. The localized force of the kick goes into moving the larger area plate, which is what actually transmits the force to the torso. In the case of energy absorption, the energy of the strike is taken in by the material of the chest protector and deforms the material, instead of the competitor. The full plate armor that a medieval knight would wear utilizes similar principles; by encasing his body in metallic armor the knight greatly reduced his chance of injury to critical areas. The armor could crumple to absorb energy and the way it was padded and affixed to the body would spread impact energy around.

Equally important as how much energy the material can absorb is how fast the material can recover.[2] A deformed polymer cannot absorb as much energy as a non-deformed one, so it must return to normal in as short a period of time as possible to provide protection for repetitive attacks. This is clearly important for typical high-level sparring competition where attacks will usually come as combinations of multiple kicks. The best example of this in current gear is the thick deformable helmets used in competition; when squeezed it gives quite a bit but quickly bounces back. The various other protective components all utilize combinations of these two energy-changing methods to prevent injury to competitors; typical examples of these for taekwondo competition are arm, shin, and instep guards, cups, and helmets.

Safety Standards

Another important consideration in the design of safety equipment is the principal means by which injury can occur. In taekwondo, injury is any physical condition that prevents the player from training or competing in their usual manner and would not include incidental bruises or cuts. In gyoroogi, the two principal scoring areas are the torso and the head, though a point may also be earned through legal contact that results in one player falling to the ground. Within certain guidelines, sparring rules allow foot contact to the head and chest, but only fist, or punching, contact to the torso. The way that heads are injured due to trauma is quite different from our torsos. These critical areas have already been examined for many years by another group concerned with blunt trauma to the body, the car industry.

The same sorts of injuries that appear in taekwondo also appear in typical car accidents, but there are differences in means of impact and scale. While it may be hard to believe, up until the 1930s it had not even occurred to anyone to establish a set of safety standards for automobiles. In fact, the government did not even begin regulating safety features in cars until the 1960s. Back in the 1930s, professionals in the car industry began to notice the high injury/fatality rate associated with their automobiles.[3] The efforts of private car makers and research institutions led to the development of two criteria, the *Viscous Criterion* (VC), and the *Head Injury Criterion* (HIC), to help predict the probability of injury during accidents. The VC is a measure of torso injury, which focuses primarily on the crushing or tearing of tissues due to the compressive forces on the body. The VC takes into account both the rate of compression, or how fast the kick happens, as well as the percentage compression of the torso, ie., the depth of penetration. This encompasses all major components of the strike to the body.

For head contact, the concern is to prevent the brain, at rest within the fluid of one's head, from hitting the interior of the skull and generating a concussive injury. If the head is jerked in a sudden manner, the damping action of the tissues inside of the skull may not be sufficient to reduce the impact velocity of the brain on the interior of the skull. The HIC takes the integration result of the acceleration of the head over time and divides it by the time interval in which this acceleration occurs. In this way the magnitude of head acceleration is measured as well as its duration.[4] Significantly more detailed descriptions of the sources of these criteria can be found in "Impact response of taekwondo headgear to kicks and falls," Madeleine Moffitt's 1995 Masters thesis in Mechanical Engineering at U.C. Berkeley. One interesting result from that thesis is shown in Figure 2 below. Because of differences in design, among the helmets there is a measurable variation in acceleration reduction. In some cases there can be up to a factor of two reduction in g's compared to no helmet. For anyone that has ever wanted a number justifying the suggestion to tuck in the chin when falling, note that a shoulders-first impact reduces head acceleration by around 30% when no helmet is worn! Note that these numbers are for cases that do not take advantage of other aspects of safe falling technique like arm and leg slapping, or rolling.

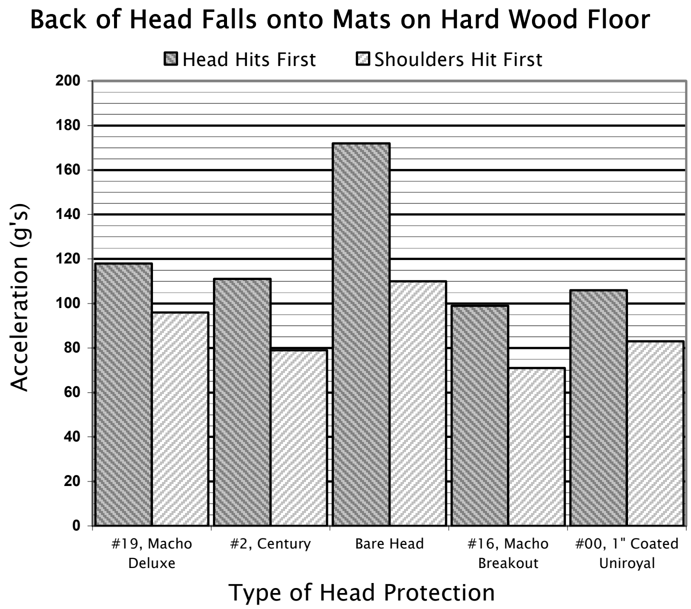


Figure 2: A plot of head acceleration for a rigid dummy body allowed to fall to the ground like a domino.[5]

Considering that these safety criteria are already extant, it greatly reduces the effort necessary to create a common standard of performance for competitive martial arts equipment. In fact, an impartial testing body, the American Society for the Testing of Materials, has recently completed a set of such testing standards, thus creating industrial benchmarks for martial arts sparring gear (see ASTM standards F1446[6] and F2397-04[7]).

Regardless of the intrinsic safety of the gear, some competitors, looking for an edge in competition, will modify their equipment. Lighter, thinner helmets with better fields of view, taping or compressing instep guards to deliver harder kicks, all negatively impact the safety of the competition. Competitor modification is secondary in importance, however, to enforcement and awareness of standards; at present there is no guarantee that vendors have produced equipment that adequately safeguards competitors in the first place. Hopefully the USTU and similar organizations will be able to persuade manufacturers of protective equipment to comply with these standards. One positive step towards this happened September 15, 2003, when Macho Products announced that they had begun developing a new type of hogu designed to comply with ASTM standards.[8] If the release of that product goes as scheduled for the summer of 2004, it will be the first ASTM certified hogu available for purchase, providing a verifiable level of safety for competition sparring.

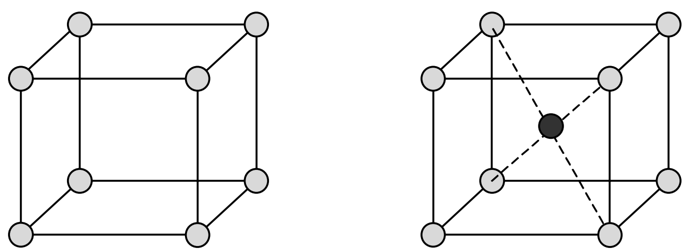
Digital Scoring

Technology is also being used to address the complexities of refereeing sparring competition. More precisely, technological advances have led to the advent of digital scoring systems that are now integral parts of modern competition. In traditional sparring, referees sit in the corners of the ring and note points for each competitor on paper. Multiple referees are used in order to get agreement on whether points are scored; however, in a paper setting there is no way to determine the time the point was scored per judge, and no way to know who had the clearest view of the attack. In order to score the point the judge needs to know that the blow hit a target area with sufficient force to induce *trembling shock*. It may seem like that would be easy to discern since attacks tend to be linear in movement, but the large rings allow the competitors to move about with a great degree of freedom. Moreover, it is entirely possible for one or more of the corner referees view of a particular exchange between the players to be partially or fully obscured by the relative positioning of the players and center referee, greatly complicating the accountability of scoring for the match. Since perfect knowledge of the competition is impossible for all the judges to have, electronic scoring systems allow for a degree of agreement to be achieved between the judges.

With electronic systems, each judge is given two handheld devices, one for each of the competitors, red and blue. For the chest blows the judge will press the one-point button for the appropriate competitor, and likewise the two-point button for head shots. In this manner the types of scoring attacks will be kept separately accountable. In a typical match, mediated by three or four corner referees, if any two judges signal a point for a given player within a pre-programmed period of time, the point will be scored. There are many different commercially available versions of such systems, and in some cases the digital systems can even log the data (the times when the judges signal a score) to provide a record of the actions of the judges. If desired, such information could be assessed to determine how judges are scoring relative to one another. In this manner the tournament directors could ensure that the quality of judging remains even across the board. While black belts train to the same sort of standards, as judges they have different concepts of *scoring* based on age, build, and many other factors. Digital scoring systems have been put to good use in world level tournaments over the past couple years and have become a staple of high profile competition. The days of paper and pencil are slowly coming to a close in our digital world.

Future Automation and Instrumentation

Another way in which we may see technology become a part of taekwondo competition in the future is through the use of sensors. There are a great variety of force, acceleration, and pressure sensors that could be added to the scoring areas of the sparring gear in order to provide definitive empirical values for the *scoring force* of a technique. One example of these are piezoelectric devices that utilize the natural properties of certain crystalline solids, such as quartz, to generate electricity from the application of pressure. This works equally well for a force since any applied force will have to act on the finite area of the crystal, thus exerting pressure on the sensor. Such piezoelectric solids have a lattice structure resembling a cage, with a semi-mobile ion contained within the interstitial (interior) spaces.[9]



simple cubic lattice *body centered cubic lattice*

Figure 3: Two examples lattice structures. Each dot represents the location of an atom or molecule; the lines represent chemical bonds.

As pressure deforms the lattice, the ions are mobilized, generating a net flow of charge and a readable difference in potential, i.e. voltage. The manufacturers of such devices gather data to correlate the voltage generated by the piezoelectric sensors in response to pressure, providing a pressure calibration curve.[10] In taekwondo competition, common sense tells us that bigger people kick harder but have larger feet, whereas smaller people kick less powerfully but have smaller feet. Accordingly, the pressure applied by competitors of all sizes against the hogu tends to fall within a relatively small range.[11] This trend would imply that an average pressure and characteristic distribution due to scoring force could be determined with sufficient experimentation.

Since real-life measurements tend to be imperfect, the piezoelectric sensor's ability to provide a range of voltages allows for some margin of error in the recognition of an attack. The software or electronics can be set to register a point if the force of the kick is close enough to the required scoring force threshold. Should the distribution be small enough, however, simple fixed pressure switches (ie., binary switches that trigger 'ON' once the appropriate threshold pressure level has been exceeded) would be sufficient to determine whether or not a point has scored. If any sensors are to be utilized in competition, other characteristics such as material robustness and bandwidth, or how quickly the sensor could register repeated attacks, would need to be carefully considered. Interestingly, piezoelectric actuators are most commonly found as watch or smoke detector beepers,[12] so one possible implementation of these for an self-scoring hogu could be to sense force with one piezoelectric sensor which then triggers another piezoelectric sensor to indicate that a point scored via an audible tone.

While it is certainly feasible to create a fully automated competition taekwondo scoring system using existing technology, certain problems need to be overcome in order to create a system that would work in compliance with all the rules of competition. For instance, the automatic system would need to measure the state of its wearer during the match when it registered a scoring point to determine if it was valid. Sparring is not allowed to proceed if one competitor is in an unsafe position, such as laid out on the ground or woozy from a previous attack, or if a *kalyeo* (halt) has been called.[13] Usually the center referee will have time to intervene in these situations, but that is not always the case during particularly fast-moving matches. Also, in competition, following up on an illegal move does not score a point, nor are points scored when competitors move outside of the ring—the list of exceptions could grow quite long. It would not be possible for the scoring system to have any of this information without the benefit of judges assessing the action, or more sensors being integrated to gear and competition ring. Also, depending upon system reliability, this could add quite a bit of complexity to the tournament itself if technical personnel would be required for equipment validation beyond diagnostics. Nothing could be worse than a system that was failing to register points; this would be an insurmountable barrier to victory for a competitor. While such an automatic scoring system would be an interesting addition to competition, unfortunately, it is doubtful that such a scheme will appear in tournaments anytime soon. The development costs would likely grow prohibitive before any such system that resolved all these issues would come to fruition. To be fair, it would also need to be proven that the system could offer a distinct advantage over the current system. While it would be a fascinating technical accomplishment, taekwondo sparring is likely not quite prevalent enough at present to provide a sufficient market for such a system.

Conclusion

With considerable help from the application of modern technology, Taekwondo competition is continually improving as a competitive art. Whether from safety improvement through advances in materials and standards, or the use of digital scoring systems, the impact has been clearly visible and beneficial for an art constantly growing in popularity and public exposure. Mass production technologies such as injection molding and assembly lines have greatly reduced the cost of producing sparring equipment as well as making them more widely available. It will be interesting to see how the confluence of technology and traditional taekwondo sparring rules and methods will promote further evolution of the sport in the future.

References

Beck, J.D. and Lieu, Dennis. "Electronically Assisted Scoring." *USTU Taekwondo Journal*, Spring 1997.

Lieu, Dennis. "Safety Equipment Function in Competition Taekwondo." *USTU Taekwondo Journal,* Winter 1996, pp. 2-3.

Moffitt, Madeleine, "Impact response of taekwondo headgear to kicks and falls." UC Berkeley Master's Thesis, 1995.

Endnotes

1 Biography of General Choi. Available at http://www.usadojo.com/biochoihong-hi.htm Last updated 2004. Accessed July 20, 2004.

2 Lieu, p. 3.

3 "The History of Crash Test Dummies." Available at http://www.ftss.com/history.cfm?c=1 Last updated 2002. Accessed July 20, 2004.

4 Lieu, p. 2.

5 Moffit, p. 36.

6 A summary of the F1446 standard is posted on the ASTM website at http://tinyurl.com/6g2db. The full document (in .pdf format) may be purchased from the summary page. Last updated 2003. Accessed July 20, 2004.

7 A summary of the F2397-04 standard is posted on the ASTM website at http://tinyurl.com/6toot. The full document (in .pdf format) may be purchased from the summary page. Last updated 2003. Accessed July 20, 2004.

8 Macho News Release Available at http://www.macho.com/doc/NEWS/5/XPHOGU.pdf Last updated September 15, 2003. Accessed July 29, 2004.

9 "Piezo Systems – piezo actuators & transducers". http://www.piezo.com/faq.html#ph1 Last updated June 24, 2003. Accessed July 14, 2004.

[10] "Piezoelectrics Definition & History." Available at http://www.morganelectroceramics.com/piezoguide1.html
Last updated June 15, 2004. Accessed July 14, 2004.

[11] Beck.

[12] "Piezo Systems – piezo actuators & transducers". http://www.piezo.com/faq.html#tech1
Last updated June 24, 2003. Accessed July 29, 2004.

[13] "A Summary of Korean Terminology for Taekwondo." Available at http://www.martialartsresource.com/korean/TKD.list.htm
Last updated unknown. Accessed July 29, 2004.