The Physics of Spring Style

Robert A. Loveman

In partial fulfillment of the requirements for Second Dan

Preface

It is commonly said that Taekwondo is scientifically based[1]. In the sense that it has been empirically found to be effective as a martial art, is easily taught, and an excellent form of exercise this is undoubtably correct. However, many statements given both in texts and in classes regarding the application of Newtonian physics are at best misleading, and are often simply incorrect. Even when explanations are physically correct, they are in general insufficient to determine what is 'good technique.' In particular, in analyzing why a particular way of performing a strike or block is effective, one must consider not just the laws of mechanics, but the structure and response of the human body. Finally, Taekwondo has been developed for its artistry as well as its efficiency[2], and this is the third ingredient of 'good technique.'

The purposes of this thesis are as follows: first, to correct or at least clarify some of the aspects of physics which apply to Taekwondo; second, to try and show the mix between the physiological constraints of the human body and the physical laws of nature, and to show how this mix in part determines 'good technique'; third, to give adequate examples of the appropriate phenomena so that students and instructors can better understand the physics behind what their bodies are doing; and finally, to try and raise the standard of 'science' which has been used to analyze Taekwondo techniques.

Introduction

For almost any technique in any style of martial art, power is generated by using the legs to drive the hips. Once the hips are moving, the energy of that motion has to be transfered to the striking or blocking tool. Paul Maslek states that the difference between 'hard' styles (such as Taekwondo) and 'soft' styles is that in hard styles the hip motion slightly preceeds the actual strike, where as in soft styles the hip motion is simultaneous with the strike[3]. This slight advance of the hips relative to the striking or blocking tool is the distinguishing feature of what we refer to as 'spring style.'

The basis for the discussion of the physics of Taekwondo will be Newton's three laws of mechanics and the properties of systems of interacting bodies which are derived from these laws. The three laws are: a body at rest tends to stay at rest, a body in motion tends to stay in motion; force is equal to mass times acceleration; and for every action there is an equal and opposite reaction. There are conserved quantities such as momentum, angular momentum, and energy which are useful to consider when analyzing the motion of a body. These quantities can be defined mathematically from Newton's three laws, but for this text they will only be treated qualitatively and in a colloquial sense.

Discussion

The legs contain the most powerful muscles in the human body. Any method of empty hand fighting relies primarily on the legs to generate power. Techniques of fighting varying from western wrestling to Taekwondo have been developed to take advantage of the strength of these muscles.

For an arm technique, such as a straight punch, the initiation of the power comes by driving the hips with the legs. In the Newtonian sense, this is where the equal and opposite reactions take place: the legs drive and the hips move one way while the earth moves the other. Because the earth is much more massive than the hips, it moves considerably less than do the hips. In fact, while the motion of the earth is real, it is completely negligible. The important fact is that forces always occur *between* two objects, and this is what causes the equal and opposite reactions. In the initiation of most techniques, this force occurs between the floor and the hips.

An excellent example of the importance of physiology to Taekwondo technique can be seen in the methods people use to drive their hips. In particular, some raising and lowering motions are an important part of spring style. It has been commonly implied in Taekwondo classes in the USTF that this is because one can gain speed and energy from the force of gravity. This is not true. The up and down motion is in general perpindicular to strikes which are primarily horizontal. In order to add speed in a horizontal direction, one must apply forces in a horizontal direction. The raising and lowering motions are important to generate maximum power for horizontal techniques because they allow more efficient use of the leg muscles. A particular example of this is the raising of the heels off of the ground. This does two things. First, it is clearly necessary to raise the heels off of the ground to use the calf muscles to their full extent. Second, this allows for a pivot of the on the balls of the feet so that the knees are not torqued. There is no gain directly from settling or falling however, the gain is essentially the result of increased mobility and the ability to involve more of the large muscles in the legs in generating the motion. Therefore, the important aspect of the raising and lowering motions during a technique is that they should be exactly as much as is necessary to get the maximum horizontal force from the legs, no more and no less. Put simply, this raising and lowering motion should be natural, not exaggerated.

With the driving of the legs, the energy is concentrated in the hips. Spring style may be viewed as a way to move this energy from the hips to the arms. For spring style, this energy is transfered by a wave. The transfer of energy by waves is as common as talking and listening. The larynx create sound and transfer energy to sound waves. These waves travel through a medium, usually air until they and their energy are absorbed. In the case of hearing some of the energy of initial sound produced is absorbed by the eardrum and causes it to vibrate. This energy is again transfered by waves from the eardrum to the small bones of the ear and in turn causes them to vibrate. Eventually, the vibration is sensed by nerves, which send signals to the brain telling us that energy in the form of sound waves is being directed at us; someone is speaking to us. For spring style, waves are produced by the hips and propogate through the medium, the torso, until they and their energy are absorbed. The initiation of these waves is automatic with the displacement of the hips. The efficient propogation of these waves is not automatic, but is trained. The tension of various muscles in the torso, the posture of the upper body, and the proportions of the torso and the hips are all important in determining how efficiently this wave and its energy propogate up the torso.

The most difficult aspect of spring style comes into play at the time when the energy contained in a wave reaches the shoulders. At this time, forces must be applied between the arms and the shoulders in such a way as to allow the maximum amount of the energy in this wave to reach the blocking or striking tool. If these forces are not applied with the correct timing or with the correct magnitude, the wave and its energy will simply reflect off of the shoulders, and eventually the energy in that wave will be absorbed by other parts of the body. In a similar way, sound may also be reflected. We've all heard reverberation in concrete hallways. This is caused by sound which bounce against the walls many times and arrive at the ear at a slightly later time than sound waves which have only bounced once or not at all against the walls of the corridor. Another example of reflection off of an interface between two media is reflection of an image (light waves) off of a clear pane of glass. This image is easily seen when one looks out a window of a lighted room at night. The image is always there, but it is very dim. Consequently, it is only visible when there is little light coming from the opposite side of the glass as in the above example. While reflections of waves off a barrier such as the walls or glass is somewhat simpler than the kind of reflection coming from the wave reflecting off of the shoulders, they are in principle similar. Any time a wave moves from one medium such as air, to another, such as concrete or glass, some of the energy is transfered, and some is reflected. The way to maximize this energy transfer is to make the new medium look identical to initial medium. That is, one has to give the second medium certain identical characteristics. In the case of sound or light, the new medium must have the same characteristic wave velocity. In the case of concrete, the velocity of sound is much higher than that for air ($\sim 4000-5000m/s$ vs. $\sim 343m/s$)[4]. Because there is such a large difference between these, the reflection is nearly 100 percent. In the case of glass, the speed of light in the glass is only slowed by about 30 percent. Because this difference is small, most of the energy is transmitted, and we can easily see through windows.

Ideally, one would like to make it appear to the wave that the torso does not end. An end to a medium through which a wave propogates is equivilant to a change of media, and there are reflections off of such a boundry. If one can make it appear to the wave that the torso 'continues' beyond the shoulders, the effect would be that the energy in the wave would be transmitted through the shoulders without being reflected. The shoulders themselves cannot be changed to make them look to the wave like a continuation of the torso. However, forces may be applied between the arms and the shoulders in such a way as to make it appear to the wave that the torso continues beyond the shoulders. The first result of the correctly applied forces is that the shoulders move as if they were simply a continuation of the torso. The second result of the correctly applied forces is that the momentum of striking arm or arms is greatly increased. For a straight punch, the momentum of the second arm is also greatly increased. The reason for the motion of the second arm is simply to maximize the efficiency with which energy transfer from the torso to the arms takes place. Once again, there is a case of equal and opposite reactions. In this case the force is between each arm and the shoulder it is attached to. It is not, as is often taught, between one arm and the other[5,6]. The probable reason for this confusion is that for a straight punch it is necessary to apply equal and opposite forces on either shoulder. This is due to the nature of the wave which is used to transfer energy from the hips to the arms for a straight punch. Specifically, the wave is a twisting or torsional wave. All of its energy is in the twisting motion, and there is none in translational back and forth motion. If only one arm is moved, both torque and translational forces are applied to the shoulders. The net result is some of the energy in the wave will be transfered to translational motion of the shoulders. If both equal and opposite forces are applied to both shoulders, than there is no net translational force applied to the shoulders, only a torque. Thus there is no energy lost to the translation of the shoulders. It is critical to note that the above arguments are valid for only some techniques. Many techniques which involve spring style do not have or require the motion of the opposite arm in the opposite direction. An example of such a technique is a twin vertical punch. In this technique, the initial wave is translational rather than torsional. Also, for this technique, the motion of the arms is in the same direction. This way, only translational forces and no torques are applied to the shoulders.

For a straight punch, the momentum is equal in magnitude for the two arms, but the the greatest concentration of energy is in the forearm-wrist-hand assemblage of the striking side. In general, the energy in the arms is primarily located in the part of the arms that is moving fastest. If spring style is correctly applied, some large portion of the energy which was once in the hips is finally in the striking tool. It will remain there until that tool makes contact with something, or muscles and joints in the body absorb it.

Summary

Spring style is a method of transfering energy from the hips to a striking or blocking tool. It is characterized by a rapid movement of the hips preceding the full extension of the strike or block. The energy of this hip motion is transfered by a wave from the hips to the arms. Correct arm motion, muscle tension in the torso, posture, and timing are all necessary to allow this wave to propogate from the hips through the shoulders, and then to be transfered from the shoulders to the arms. If the technique is correctly applied, some large portion of the energy in the hip motion is transfered to the blocking or striking tool.

Newton's third law of motion can be correctly applied to several parts of the motion. The third law states that for every action there is an equal and opposite reaction. An equivilant statement is that forces always occur between two objects. In the initiation of a technique, a force is applied between the floor and the hips by the legs. This force causes the hips to move one way, and the earth to move the opposite way. In creating arm motion, forces are applied between each shoulder and the attached arm. In both cases, the actions and reactions are equal. In the first case, the motion of the earth is extremely small simply because the earth is very massive. In the second case, the magnitudes of the motions are similar because the masses are similar.

Acknowledgements

The author would like to acknowledge useful remarks by Rob Tobin, Jonas Pologe, and Terisa Tobin.

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