Simplified Physics of the Sine Wave, and an Argument for Hip Twist
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"*No doubt the maximum body weight is applied with the motion by turning the hip*" – General Choi, Hong Hi

Introduction

In the *Encyclopedia of Taekwon-Do*, General Choi Hong Hi explains why he introduced the "Sine Wave" motion into Taekwon-Do. His explanation of Mass in the Theory of Power alludes to "increasing the body weight" by utilising "a springing action of the knee joint" to drop the body weight into the motion. In the *Condensed Encyclopedia* he takes it one step further and introduces the concept of sine wave (vs saw tooth wave and horizontal wave), demonstrating that practitioners should be lifting the bodyweight off the ground and dropping downwards just before impact.

Rather than sine wave “increasing the body weight”, by which I presume Gen Choi meant increasing the effective mass behind a technique, another school of thought states that the benefit from sine wave comes from increased kinetic energy at the moment of impact.

Later publications by the ITF technical committee, specifically "*The Art of Taekwon-Do ITF*", talk about the physics of changing the mechanical potential energy in the muscles into kinetic energy to lift the body, which in turn creates potential energy by virtue of your body weight being lifted off the ground, and then back into kinetic energy when dropping back down just prior to impact.

There are many complex interactions in the physics of momentum, energy, force, impulse and work, even when looking at simple straight line, solid mass, objects. It obviously gets far more complicated when the human body is involved, given the array of energy sources, friction, tension, and motion involved.

Introduction to Important Concepts

Conservation of Energy

In physics, the law of conservation of energy states that the total energy of an isolated system remains constant—it is said to be conserved over time. Energy can neither be created nor destroyed; rather, it transforms from one form to another. (Wikipedia)

Gravitational Potential Energy (PE = mgh)

Gravitational potential energy describes the energy in an object raised off the ground. This object is said to have potential energy because when you let go of it it will immediately begin to move. Movement requires energy, and all energy is conserved, so this energy must have been present in the object prior to letting it go. The amount of gravitational potential energy is given by the formula PE = mgh = mass x gravitational acceleration x height.

Force = Mass x Acceleration (F=ma)

This formula (F=ma) is well known in physics, and is discussed in the *Encyclopaedia of Taekwon-Do*. However I believe there are some common misconceptions in the understanding of how this formula is applied in a collision (i.e. a punch or a strike).

In researching the topic of F=ma as applied to a punch, it is clear that many people think that to apply maximum force to a target, the fist needs to be accelerating. However this is not true at all.

To demonstrate this, imagine a car traveling along the road at 100kph, not accelerating, but at a steady 100kph. If this car was to drive into a wall, there would be a tremendous amount of force and energy involved in the collision. The acceleration of the vehicle at the moment before impact is Zero, and so if this acceleration is the acceleration referenced in F=ma, then the resultant force would be zero too. This is clearly wrong.

So, what does F=ma mean in this collision scenario?

The acceleration in a collision refers to the *change in velocity of the colliding object during impact*. The car will decelerate from 100kph to 0kph in a very short space of time. Acceleration can be described as (change in velocity) / (change in time), and given that the final velocity is zero, this is the same as saying the acceleration in this collision equals the initial velocity of the car, divided by how long it takes to come to a complete stop.

Short version: In an impact, whether it be a car hitting a wall, or your fist hitting an opponent, what is important in the calculation of Force is the VELOCITY of the strike prior to impact, and not the ACCELERATION.

Kinetic Energy (KE = ½mv^2)

Another way to look at the efficacy of a kick, punch or strike is to look at the Energy (specifically Kinetic Energy) involved in the collision. The more energy a technique has when it lands, the bigger the impact on the opponent, as that energy has to go somewhere! (Energy is conserved)

In the encyclopedia, General Choi refers to the formula P=½mv^2 (power = 1/2 mass x velocity squared). In Physics this is actually the formula for Kinetic Energy. Power is a separate metric which describes the amount of Force extended over a distance (properly known as Work) as a function of time (P=Fd/t=½mv^2/t)

So the formula should actually read: KE=½mv^2

As can be seen in this formula for kinetic energy, a doubling of the velocity of the attack will result in a quadrupling of the energy of the attack.

Again this points to VELOCITY of the strike being a critical factor in delivering powerful techniques.

If only it were that easy

Given all the above formulae, it should – in theory – be possible to calculate the energy and forces involved in a simple technique like a walking stance punch.

All of the above equations are for single bodies with all of the mass moving in unison, in a straight line. But in a Taekwon-Do technique, all the different parts of the body are moving at different

speeds. In a walking stance punch for example, the fist will be moving much faster than the body at the moment of impact. It is also impossible to determine the effective mass of a punch, such that you could use it in a simple equation like F=ma.

The human body is a complex machine, and trying to apply the theoretical physics to this system is near impossible. You would have to know the precise way every part of the body was impacting on every other part of the body in order to be able to sum up the entire mathematics of this system. Only then could you arrive at a mathematical proof that sine wave contributes to the effective power of the technique through the increased gravitational potential energy created as a result of lifting the body and dropping down.

What we do know is that:

- Increased Velocity = Increased Force
- Increased Velocity = Significantly Increased Energy
- Lifting the body off the ground imbues us with Gravitational Potential Energy (converted from our muscular energy)
- The Law of Conservation of Energy means that this energy must be converted to some other form of energy (mostly kinetic energy) as the body drops
- This energy must go somewhere – and the current teaching by the ITF indicates that this travels with the technique, making our techniques more powerful.

What we cannot determine is:

- How much of that kinetic energy from body dropping is transferred into increased velocity in the direction of the technique (and hence increased force), and how much of it is otherwise distributed within our muscles, or in the form of sound (and a little heat) when the foot hits the floor
- How other body mechanics created by the sine wave methodology are adding to the energy and forces within the system. For example: the methodology of performing sine wave in a walking stance punch involves the back leg being bent until straightened at the moment of impact. This straightening adds forward velocity to the system.

Sine Wave is not the only option

Early discussions about sine wave, such as the *Encyclopaedia of Taekwon-Do*, seem to focus entirely on how lifting the body increases the gravitational potential energy and converts it to kinetic energy at the moment of strike – with the assumption that this energy is made to travel in the direction of the strike (perpendicular to the actual direction of the force), thereby adding increased force to the strike.

In the book *The Art of Taekwon-Do ITF*, the concept of muscular energy is introduced, and it is explained how the muscular energy is used to create the state of gravitational potential energy in the first place.

(Potential energy in the muscles is converted to kinetic energy to lift the body off the ground, creating a state where the body has gravitational potential energy.)

However, what this model fails to discuss is that the muscular energy **could have been used differently**, or **it may be possible to convert more muscular energy into kinetic energy within the system.** Lifting the weight off the ground is only one of the available movement options.

What if, instead of lifting the body up to create potential energy, this muscular energy was used to create more horizontal velocity instead, thus increasing the kinetic energy through the formula $KE=½ MV^2$. Increase the velocity by 10%, and the energy will increase by 21%.

Even if you add body lifting to a technique, you can still recruit additional muscular energy to the technique via the use of the hip twist, either in the form of angular momentum in the case of a turning technique, or extra forward velocity in the case of a front-on straight technique. This conversion of muscular potential energy into kinetic energy is ADDED to the kinetic energy provided by body dropping.

Why walking stance front punch should include a hip twist

The current teaching by the ITF for a walking stance front punch requires us to utilise zero hip twist, but to rely on sine wave only. Presuming that we are attempting to generate maximum power with this punch, this seems to imply that the sine wave along with the stepping motion, with no hip twist, is the most effective way of generating maximum energy and force into the punch.

Velocity is additive. If I am on a train travelling 20km/h, and I roll a ball away from me at 10km/h in the direction the train is travelling, the ball will be travelling at 30km/h when viewed by an observer outside of the train

Let's say your fist speed (speed to move your hand from your hip to the target) is represented by *f.*
And your stepping speed (how fast your body is moving through space) = *st*
And, presuming you can translate your vertical potential energy from the sine wave into energy travelling horizontally, this energy must also be evident by an increase in velocity. Let this additional velocity from the sine wave be = *sw*.

Then the total velocity = $a + st + sw$

Now, add hip twist into the motion. Even though your hip will be travelling in an arc, there is still a component of velocity in the forward direction.
Let's say you can move your hip forward at a speed = *h*.

Presuming that the addition of hip twist does not affect your arm speed, your stepping speed, or the height of your sine wave then the total speed of your punch becomes = $a + st + sw + h.$

It's clear that the punch speed is higher with the addition of hip twist.

$$a + st + sw + h > a + st + sw$$

Remember that velocity is a critical factor in the Force ($F=ma = mv_f/t$), and Kinetic Energy ($KE = ½mv^2$)

An alternative way of looking at this question is to consider the energy in the system. As with velocity, energy is additive. If you add energy into a system, the total energy will be equal to the energy that was already in the system, plus the energy you added.

If your arm speed, stepping speed and sine wave remain constant, and you want to add hip twist, you will have to convert more muscular potential energy into kinetic energy to get the hip moving. This additional energy will be present at the final collision, and some will be imparted into the opponent on impact.

Whether you look at the problem from the perspective of velocity or energy, it is clear that adding velocity from a hip twist will increase the energy and force of the walking stance punch.

Conclusion

It is my opinion that too much emphasis is placed upon the sine wave as being the generator of power in Taekwon-Do techniques, and certainly trying to use the physics of kinetic and potential energy to prove the hypothesis is somewhat flawed given that the formulae are not easily applied to complex body mechanics.

To me, the example we now have of using no hip twist at all in a walking stance front punch, and other “straight line” techniques, completely undermines the proposition that General Choi was so strong on – that we are employing the *scientific* use of the body in Taekwon-Do techniques. The General himself even said "*No doubt the maximum body weight is applied with the motion by turning the hip*" – and yet now we’re completely removing it from some of our most basic techniques, even though it would add velocity at the moment of impact.

In other “rotating” or “turning” techniques we are being taught to use a bit of hip twist to generate power. And even though we *could* be adding some forward hip motion to generate power in a front punch, we’re told not to.

There may be other advantages to the sine wave. In particular it encourages other aspects of the theory of power – namely equilibrium and to a degree, breath control. It also encourages the practitioner to remain relaxed throughout the movement, which will help them develop more speed.

On the down-side, there may be disadvantages. For example, experienced Taekwon-Do practitioners have commented that they found themselves unable to keep up in a karate class. The karate practitioners had finished their techniques while the Taekwon-Do practitioners were still halfway through their sine wave!

Although I believe there is a place in Taekwon-Do for sine wave, I would like to see a more scientific approach to determining whether it really is as effective as it is claimed to be, rather than relying on simplistic physics applied to extremely complex interactions. Experiments with different styles of movement, recording punches on a force plate using different techniques for example, would yield results that can assist in this determination.