The Physics and Anatomical Principles of Karate Strikes

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**Introduction:**

Karate is a martial art with a long and rich history tracing back to China and India, with the modern form of karate being developed in Okinawa, Japan. The fundamental principle embodied by the name “karate”, which translates to “open hand”, is that this represents a weapon-less form of self defense. Over the centuries, karate has developed into many different styles with their own variations of kata, bunkai and kibonie; however, the basic premise remains that karate is a striking art that relies solely on the use of one’s own body to take down an attacker. With this in mind, and coupled with my profession as a medical doctor, I chose my black belt research project to further delve into the physics, anatomy, and physiology that underlies the attacks used in karate, and their various consequences.

Karate is a striking art that is also described by terms such as “hard” and “linear”. This means that karate uses fast and hard strikes to rapidly take down and incapacitate an attacker. Blocking, kicking, punching and take downs are the primary tools that make up the karate practitioner’s skill set. While some of the entry strikes in an attack sequence may be aimed at distracting and softening up an opponent, there is an emphasis on a devastating blow that will end the fight. Understanding the mechanism of injury of these karate strikes will lead to a better understanding of karate, and its potential in a combat situation.

**Physics principles of karate strikes:**

The injury inflicted by karate techniques is a direct result of blunt force trauma (also termed blunt injury and non-penetrating trauma). This contrasts with injuries sustained when an object, such as a knife or bullet, enters the body (these are referred to as penetrating trauma or penetrating injury). Blunt force trauma may lead to various injuries such as contusions, abrasions, lacerations and bone fractures. The severity of injuries inflicted as a result of blunt force trauma is dependent on many factors but, at its fundamental level, the severity of the injury is dependent on the amount of kinetic energy transferred by the technique, and the type of tissue to which the energy is transferred.

The kinetic energy associated with a moving object is equal to one half the mass of that object, multiplied by the velocity of the object squared. This is represented by the formula $E=0.5(MV^2)$, where $E$ is the kinetic energy, $M$ is the mass of the moving object and $V$ is the velocity of the moving object. velocity refers to the rate of change of position of an object, and is equivalent to a specification of its speed and direction. This formula illustrates that the blunt force damage inflicted by karate has, at its core, the variables of mass and velocity. It also follows, that due to the emphasis on velocity in the equation (i.e. $V^2$), a slightly lighter object travelling at high speed will cause more damage than a heavier object travelling at low speed. While the kinetic energy formula summarizes the physical elements that contribute to blunt force trauma, there are also other characteristics of the blunt force trauma that determine the severity and extent of the sustained injury. These include the characteristics of the blunt object (e.g. closed fist punch versus open hand chop, also called a shuto strike); the surface that is impacted (e.g. exposed mandible bone versus the soft tissue of the thigh); and the amount of time the two objects are in contact (shorter time of impact leads to greater injury).
Applying these physics principles, our aim is to strike our attacker with an object of maximum mass and velocity, using a technique that will dissipate energy on ourselves over a large area (to decrease the damage we take), but at the same time transfer the same energy to a strategic localized area on our attacker over a very short duration of impact to minimize the energy dissipation in the attacker. An example of applying this knowledge can be seen in how it applies to developing a more powerful and effective karate reverse punch or “gyaku-zuki”. The kinetic energy formula states that increases in the mass and velocity of our weapon (i.e. closed fist), will increase the energy we transfer to our attacker, and increase the effectiveness of our technique. While it is difficult to increase the actual mass of our fist (without adding weight such as brass knuckles or holding another type of mass in our closed fist), we can effectively increase the mass involved in our punch by rotating our hips during the punch, and, thus, incorporate the mass of our torso, hips and legs into the punch. This is exactly what we are taught to do when practicing this punch. Secondly, we can aim to increase the velocity of our punch, as any increase in this variable will result in a significant increase in energy due to the variable of velocity being squared in the equation. We can increase the velocity of our punch by continuing to train regularly, and by trying to obtain maximum punch velocity whenever we are training (i.e. becoming more experienced). We can also aim to increase our whole body, muscular strength with weight training, and we can incorporate punch-oriented pyometric drills to increase the recruitment of fast twitch muscle fibers into our punch to make it faster. Finally, we need to aim to impact the target at the point of maximum punch velocity, which is just prior to maximum extension of our arm in the punch.

Based on their study of karate punch velocity, Vos and Linkhorst reported that the velocity of the arm movement during a punch performed by highly experienced karate practitioners is 25% faster than that of moderately experienced karate practitioners, supporting the notion that greater experience leads to faster karate punches. In a separate published study of the physics of karate, Feld and co-authors developed a model that predicted the striking velocity required to break a 1.9 cm thick piece of pine wood, and a 4 cm thick piece of concrete. Their model predicted that to break the wood the hand must make impact with a speed of at least 6.1 meters per second (a speed within the range of a beginning student) while a speed of at least 10.6 meters per second would be required to break the piece of concrete (a speed that requires more years of training to obtain). Their results emphasize the fact that by increasing our punch velocity, we can dramatically increase the effectiveness of our punch.

Having focused on developing maximum energy in our punch to transfer, we now need to focus on where the best place is on our opponent to deliver that energy. Specifically, we need to aim for points on our attacker that have the least amount of plasticity, so as to lessen the energy dissipation. We also need to practice delivering the punch quickly (i.e. with snap) to minimize the time of impact. Both of these will maximize the amount of kinetic energy focused on, and restricted to, a localized area. Finally, by practicing a karate punch with an extended and rotated arm, and by contacting our attacker using our second and third metacarpals (index and ring finger knuckles respectively), we will allow the energy of the punch to be dissipated over a large area in our body (i.e. through the metacarpal bones to the carpal bones of the wrist; then through the ulna and radius and humeral bones of the arm; and finally into the shoulder and back), thus, greatly minimizing the effect on ourselves. Even a small error in our form, such as contacting the target with the fourth and fifth metacarpals, instead of the second
and third metacarpals will greatly decrease our ability to dissipate the energy in ourselves, and may result in an injury to ourselves such as a fracture of the fifth metacarpal bone (pinkie finger knuckle), also known as a boxer’s fracture.

Despite decades of intense martial arts training, there will always be a limit as to how much energy a martial artist can generate in a particular karate strike. Of course, there will always be some room for improvement, but the degree of strength increase will tend to diminish as we get closer to that elusive maximum strength potential in each of ourselves. This ultimate physical limitation is seen in all sports, and is exemplified by the best athletes in the world who can train intensely for years just to drop a fraction of a second from their 100 meter time. With this limitation in mind, it stems to reason, that in karate we must also focus on understanding that the body part that is targeted will also play an enormous role in determining the outcome of a particular technique. By combining a maximum-force strike with a thorough knowledge of striking points and their outcomes, we can become much more effective. For example, a shuto strike to the throat, at the level of the exposed larynx, can be deadly (i.e. if the larynx is collapsed to the point that the airway is occluded), while the same shuto strike, when applied to the shoulder girdle, is unlikely to have as devastating an effect and, as such, is not a typical target for this particular technique. This simple example illustrates the importance of understanding the possible outcomes of our techniques when used against different anatomical areas on our attackers. For this reason, when two highly experienced martial artists with equally skilled techniques and physical qualities are compared, the more successful practitioner will always be the one who understands where best to land the technique on their attacker and why.

Anatomical aspects of the targeted area:

The range of injuries that a karate technique can result in is very broad, and it is difficult to obtain true data about the true potential of the karate techniques that we practice because these are never performed at 100% intensity in the dojo or in tournaments. With this in mind, it is very instructive to go over the most common types of attacks that lead to the most severe injuries in street fighting scenarios. Looking at this real world data can show us what body targets are the most frequently, severely injured in street fights, and what types of attacks are typically used to result in this major damage. As detailed in Dr. Armstrong’s book on this subject [Street Fighting Statistics with Medical
Outcomes linked to Karate and Bunkai Selection), the most common types of attacks in street fighting situations that result in severe injury (defined as requiring medical attention), typically involve a strike to the head. Listed in descending order of frequency, the top seven attacks resulting in severe injury in street fights in one study were: 1. attacker pushes, defender pushes, attacker throws a swinging punch to the head; 2. a swinging punch to the head; 3. a one handed front clothing grab, followed by a punch to the head; 4. a two handed, clothing grab followed by a head butt; 5. a two handed, front clothing grab followed by a knee to the groin; 6. a lashing kick to the groin or leg; and 7. a fall related injury. These statistics do not necessarily reflect the most effective techniques that a karate practitioner will utilize in a given self-defense situation, but they illustrate that the vast majority of severe injuries in street fights result from strikes (the cornerstone of the striking art of karate), as opposed to the submissions seen in the grappling arts, and they emphasize the head as a target that is most often severely injured. As the majority of students of martial arts choose this study for the purpose of self defense, this information is also critical, as it allows them to train to prepare for the most likely attacks they may encounter in a self-defense scenario. The following sections detail the effects of strikes to different parts of the body.

**Head strikes:**

When the head is struck with a karate technique, there can be a wide range of outcomes (e.g. knock out, jaw fracture, loose tooth, bruised cheek, etc.). One way to view these different outcomes is to separate those head injuries whose main result is a change in brain function, from those that do not have a change in brain function. More simply, head injury with brain injury, versus head injury without brain injury.

Head injury that is accompanied by a transient loss of brain function is referred to as concussion or traumatic brain injury (TBI). The American Academy of Neurology defines three of grades of TBI. Grade I refers to confusion, no loss of consciousness, and symptoms less than 15 minutes; Grade II is as for Grade I, except that symptoms last greater than 15 minutes; Grade III refers to loss of consciousness, and is further subdivided based on whether the coma lasts seconds (IIIa), or minutes (IIIb). The most common symptoms of TBI, are those seen in mild-moderate degrees of concussion (Grades I and II above). These symptoms are typically headache, dizziness, vomiting, nausea, lack of motor coordination and lack of balance. By contrast, Grade III is defined by the most dramatic of brain symptoms, loss of consciousness. This immediate loss of consciousness is also referred to as a knock-out or “KO”.

The brain normally floats in a supporting liquid called cerebrospinal fluid (CSF). CSF cushions the brain such that small changes in acceleration and deceleration of the head do not result in the brain making significant contact with the surrounding skull bone. However, when a person is forcefully struck in the head, the skull can rapidly move backwards and make forceful contact with the underlying brain (this is known as a coup injury; see figure 1 below), and in some situations, the skull can then decelerate rapidly resulting in the underlying brain hitting the opposite side of the skull bone (known as a countercoup injury). The degree of injury to the brain tissue that contacts the skull depends on the force of the brain-skull interaction, and this then determines the degree of traumatic brain injury changes (i.e. symptoms ranging from a transient low grade headache, up to a knock out lasting many minutes). The
degree to which the skull moves following a strike depends on the energy of the strike, and on how much head support is present due to neck and jaw muscle contraction (i.e. the person sees the punch coming, so they brace themselves with neck and jaw muscle support). As such, the ability to obtain a knock-out relies heavily on the looseness of the opponent’s neck and jaw muscles. For this reason, the prime setting for a knock out is when a person has no idea that they are about to be hit, because the lack of tense supporting musculature will allow for maximum acceleration of the skull relative to the underlying brain. The type of knock out that occurs when someone did not see the punch coming is also known as a “king hit”. This is the reason why being able to time our punches, and to not telegraph our punches is critical for maximum effectiveness, as this leads to an attacker that is neither braced nor ready for a head strike. While it is obvious at a macroscopic level that the brain smashing against the skull is the cause of the brain injury, the exact pathophysiology at the cellular level is not certain. However, scientific consensus suggests a disturbance of brain function rather than a structural injury, and animal models of concussion suggest that the blunt force trauma results in temporary changes in neurochemical, metabolic or gene expression profiles in brain cells.

Figure 2: The left front punch causes the skull to rapidly move backwards, resulting in the brain colliding with the skull in the area highlighted in red (this is known as a coup injury to the brain).

The other form of head injury is where the head is struck, but there is no significant brain injury. The type of head injury sustained in this setting will obviously be directly related to the portion of the head that is struck, and the force of the strike. Forceful strikes to the mandible (jaw bone) can result in fracture of the mandible, damage to the temporomandibular joint, and damage to nerves and blood vessels that are intimately related to the mandible. While injuries to these structures in the jaw bone may not result in death, they can result in significant, long term morbidity. Strikes to the side of the head (temple region), may result in fracture of the underlying temporal bone of the skull that may, or may not, require surgery. A very serious complication of a strike to the temporal region results from tearing of veins and/or arteries just inside the skull in this area. Any uncontrolled bleeding in the space between the brain and the skull is very dangerous, because this is a closed space, meaning that it cannot hold any increase in liquid. As such, a bleed into this area results in a collection of blood (hematoma) that is under tension and, itself, causes the brain to be squeezed to the other side of the skull, and
sometimes down into the spinal canal (termed brainstem herniation). These are very serious conditions that can quickly result in death unless the hematoma is urgently evacuated by a neurosurgeon using burr holes.

Figure 3: Subdural hematoma. CT scan of the head as viewed from above, and illustration of a cross section of the head as viewed from the front. A strike to the temporal area can result in bleeding and blood clot (hematoma) formation between the brain and skull (white area in CT scan and red clot in diagram). The hematoma causes the brain to be pushed to the other side of the skull cavity, which can result in serious complications including death.

 Strikes to the center of the face can result in fractures to the nasal bones, the orbital bones that surround the eye socket, and the bones of the sinuses (boney air pockets) that are deep to the cheek. The commonly quoted scenario of driving the nasal bone up into the skull with resultant death is very unlikely; however, significant damage to the nasal bones may be associated with fracture of the cribriform plate, which represents the thin bone that separates the base of the brain from the nasal cavity. Fracture of the cribriform plate leads to direct communication between the intracerebral cavity and the nasal cavity, with resultant leakages of clear CSF into the nose. This is a dangerous situation due to the possibility for infection of the brain, and requires medical intervention to repair the breach. One of the consequences of striking to the face may occur if the teeth are struck, and the person punching sustains a laceration to their fist. The human mouth is known to be one of the most dirty mammalian mouths, as far as normal, oral bacterial flora is concerned. As such, a laceration to the fist that has oral bacteria introduced into it can result in a fairly serious skin infection, or cellulitis that requires medical treatment with antibiotics.

Neck strikes:

Strikes to the neck can include a direct strike to the carotid sinus. The carotid sinus lies at the bifurcation, or the splitting in two, of the common carotid artery, and it represents a type of receptor known as a baroreceptor that monitors blood pressure. When the blood pressure rises, the carotid sinus senses this increase and it sends a signal to the heart, via the vagus nerve, to tell the heart to lower the heart rate in order to lower the blood pressure back to normal. In a combat situation, if the carotid sinus is struck, the same signal is sent to the heart with an immediate decrease in the heart rate that can result in an inability of blood flow to keep up with the demands of the body, and subsequent loss of consciousness (see figure 4).
A forceful strike to the front of the neck in the area of the Adam's apple can cause compression of the larynx (indicated by the white arrow in figure 4). As the larynx is composed of cartilage, it can be relatively easily compressed to a significant degree, leading to severe compromise and collapse of the person's airway once they inhale. This inability to breath will result in marked panic, subsequent loss of consciousness, and death unless an alternative airway is not rapidly established.

**Rib, abdominal and leg strikes:**

Strikes to the ribs may result in fracture of the ribs; however, damage to the underlying lung is very unusual. Knowledge of the neurovascular structures that are intimately associated with the ribs is important when considering attacks on the ribs. Each rib has a tight neurovascular bundle that can be thought of as a three fiber cable, running along the lower portion of each rib. The three components of this bundle are a nerve (known as an intercostal nerve), an artery, and a vein. As such, if a strike to the rib, or a digging into the ribs with our knuckles, is performed, it will be more effective if this is angled from below in order to target the underside of the rib and to focus on the intercostal nerve.

**Figure 4:** Right neck illustration with cut out to highlight the carotid bifurcation which contains the receptors of the carotid body. Direct stimulation of the carotid body causes an immediate and inappropriate drop in heart rate that can result in loss of consciousness. Also note, the Adam’s apple indicated by the white arrow. This is the area of the trachea which can be compressed with a forceful blow, leading to airway obstruction.

**Figure 5:** Diagram of ribs and associated soft tissues. Note how the intercosatal nerve (yellow) is located just beneath the lower edge of the rib making it most accessible to strikes that come up from beneath the rib. The black arrow indicates the best direction to aim our attack in order to target the intercostal nerve.
 Strikes to the abdomen can result in bleeding within the liver (upper right corner of abdomen) and spleen (upper left corner of the abdomen). Perhaps the most common result of an abdominal strike occurs when the upper abdomen is struck in the area referred to as the solar plexus (also known as the celiac plexus: see figure 6 below). The solar plexus is a dense cluster of nerve receptors that are located in the region of the celiac artery, just below the diaphragm in the upper abdomen. Because this nerve plexus innervates the diaphragm, a direct blow to the celiac plexus will cause a sudden, uncoordinated burst of nerve impulses that will cause the diaphragm to spasm, which is perceived as being unable to catch one’s breath or having the “wind knocked out of you”. The nerve impulses return to normal fairly quickly, and this is why a blow to the solar plexus usually only results in a temporary incapacitation with subsequent return to full capacity.

Figure 6: Position of the solar plexus (celiac plexus)

Strikes to the limbs are usually not associated with significant injury outside of the setting of kicks to the knees. When properly executed, kicks to the knee can result in devastating injury that will severely incapacitate an attacker. The knee is a complex joint that is held together with cruciate ligaments, collateral ligaments, and menisci (see figure 7). The knee is a hinge joint that is susceptible to damage from a variety of angles; however, the knee is most susceptible from a force that comes from slightly behind, and outside the knee. This direction of impact puts stress on the most vulnerable ligaments and tendons of the knee joint (see figure 8). The next best angle of attack would be from a slightly forward, and outside, position, with the vector of force being toward the middle and back (see figure 9).

Figure 7: cross section of knee  Figure 8: best angle to strike knee  Figure 9: 2nd best angle to strike
Summary:

In summary, this research paper focused on the physics and anatomic principles of karate strikes, and how these determine the various outcomes of karate techniques. A karate strike is a weapon-less strike that uses blunt force trauma to deliver an injury to the attacker. The degree of injury inflicted is a direct consequence of the amount of kinetic energy in the karate technique that is transferred to the opponent, and the amount of kinetic energy in the technique is a direct result of the mass and velocity of the striking object. This is conveyed in the physics formula $E = 0.5(Mv^2)$. The second crucial factor that determines the effectiveness of a karate technique is the part of the body that is struck with our technique, and the readiness of the opponent. A thorough understanding of these two fundamental concepts gives a karate practitioner a solid knowledge base upon which to build and focus their karate skills. Combining proper karate training to continually improve our techniques and, to deliver more energy with an understanding of the various body targets and their particular vulnerabilities, will result in a more complete approach to martial arts training, a decrease in training-related injuries, more self-awareness and confidence, and a greater ability to handle self-defense situations.
Bibliography:


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