KINEMATICS OF BOARD BREAKING IN KARATE USING VIDEO ANALYSIS – A DYNAMIC MODEL OF APPLIED PHYSICS AND HUMAN PERFORMANCE

Dr. N. K. Rathee
Associate Professor, Delaware State University, Dover, DE
Dr. Jenny Magnes
Assistant Professor, Vassar College Poughkeepsie, NY
Justin Davis
Graduate Research Scholar Delaware State University Dover, DE

Abstract

Martial arts have fascinated the world with its fast paced actions and amazing feats. In this study the kinematics of a karate straight punch has been studied through slow motion video analysis in relation to momentum, velocity, acceleration and impact of force as a function of time to enhance the execution of the karate straight punch. It has been found that the impulse was significantly smaller when the board is broken.

From an educational perspective, this analysis will help in integrating some valid concepts of physics in teaching mechanical concepts of movements in sports. This quantitative analysis will enable the students to understand the movement technique to avoid the injuries. It will be helpful in devising training schedule for karate students and in teaching them karate skills in proper manner. A person, regardless of size and strength, if trained properly in the terms of body mechanics, kinematics, and physics of martial arts, can put out optimum performance and derive maximum benefits without unnecessary wastage of energy. The subjects had also completed the Concentration Grid to find out their concentration levels. The karateka who was successful in breaking the board has been found to have a higher level of concentration as compared to the unsuccessful karateka, indicating that this psychological parameter also has significant impact on the impulse leading to board breaking karate performance.

Keywords: Kinematics, human performance, karate, video analysis

The astonishing feats performed by practitioners of karate have mesmerized the world since long. Breaking the boards and bricks with fist blows, elbow drives and by striking the forehead have been performed time and again as a demonstration of harnessing the inner strength. In earlier times, people mastered these arts as a measure of self survival; they developed techniques to learn and improve their way of fighting to defend their lives from other men as well as wild animals.

A well-executed karate strike delivers to its target immense power within a very few milliseconds which is more than enough to break the blocks of wood and concrete. It might surprise many people to know that anyone can break boards with little efforts and training. By using proper body mechanics, appropriate use of twist of the body, high velocity, and a low time of impact one can easily break the boards. But such technical performance can never be learned unless its kinematics are analyzed thoroughly and understood in the light of relevant concepts and principles of physics (Shehata et al. 1996) and mechanisms of human movements. For this purpose, techniques of elite performers/ players can be used as a standard for evaluating technical performance. Analyzing skills continuously at different levels can help in predicting ideal performance from various perspectives (Hosam El-Din 1998) as well as in learning to avoid injuries.

Concentration is another strong mental skill and a selective activity of the mind that helps to channelizes one's attention towards a stimulus in relation to internal and external environment. Anything to be understood, learned and performed with much preciseness and perfection requires high/maximum concentration; thus concentration is an essence of perfection. Elite athlete are said to give outstanding performance only when they are in a state of one pointedness - a state of utmost concentration (Kamlesh 1998). What you focus on as you go into any competition, says Goldberg (2013), will dramatically affect your ability to stay calm and loose under competition pressure, and your level of self-confidence. Your training and health being equal, what you concentrate on is the main cause of your best and worst performance. Research indicates that high levels of concentration are associated with the occurrence of peak performances (Gould et al. 1992; McCaffrey et al. 1988). Research on focus of attention has consistently demonstrated that an external focus i.e., on the movement effect enhances motor performance and learning relative to an internal focus i.e., on body movements (Wulf, 2013). External focus of attention is most advantageous to performance and convey some benefits to learning, however, its effects appear to be stronger for performance than learning, and for precision than accuracy (Lohse et al., 2013). Concentrating or focusing on performing the punch will help the person to block the nerve impulse initiating muscle tension. Concentrating on the task will also help him generate positive flow

of muscular energy. It is truly mind over the body, strength is not the deciding factor.

Though research has been focussed on analyzing the karate skills by employing the principles of physics alone, but the present study, through application of concepts of physics in human performance, is an attempt to analyze the board breaking video recordings of karate performers executing a straight punch from physics-phy-ed perspective.

Method

Two highly ranked volunteer black belt performers, one female (subject # 1) and one male (subject # 2), were selected to participate in the study. The subjects were video filmed through a high speed camera in the sagittal plane using their dominant punching hand in front stance. They punched at a wooden board held by their instructor Hanshi at the level between their central point and xiphoid processes which is the standard target area for a straight punch. The board was positioned to ensure that the fist would strike the target with the forearm parallel with the ground, and perpendicular to the camera angle. Kinematic data were then transferred into a computer and analyzed through "Logger-pro" software.

Since ability to concentrate intently on a given task is a doorway to the state of "flow" required to perform optimally, the levels of concentration of the two subjects were also assessed through a comparative analysis utilizing Concentration Grid Exercise (Harris et al. 1984). This exercise comprised a 10 by 10 block grid with each block containing a two-digit number ranging from 00 to 99. The purpose of this exercise is to scan the grid and within a given time (usually one minute) to find and put a slash through as many numbers as possible in numerical sequence starting with number 00.

Results

Variables and equations:

Mass of the board (m2) =~ 0.5 kg

Mass of the arm = m1

Percentage of total body weight in a single arm of female = 4.97 (Plagenhoef et al. 1983)

Percentage of total body weight in a single arm of male = 5.7 (Plagenhoef et al. 1983)

Velocity of the punch at the point of contact = V_c

Velocity of the punch instant after the impact = V_I

Acceleration of the punch at the point of contact = a

Kinetic energy of the punch at the point of contact= $\frac{1}{2}mV_c^2$

Deformation energy (DE) is the energy lost to deformation during impact, and for inelastic collision using conservation of energy (Armenti1992):

$$DE = \frac{1}{2}\frac{m1m2}{m1+m2}V_c^2$$

(Note: The reasonable approximation of inelastic collision is made for the simplification of calculations. Also, assumption was made that energy lost in the form of heat due to impact is insignificant.)

Deformation energy required to break the board = 5.3 ± 2.8 J (Wilk et al. 1983).

Subject 1 (female, bodyweight = 54.43 kg, Mass of arm = 2.705 kg)

Attempt 1 (Unsuccessful)

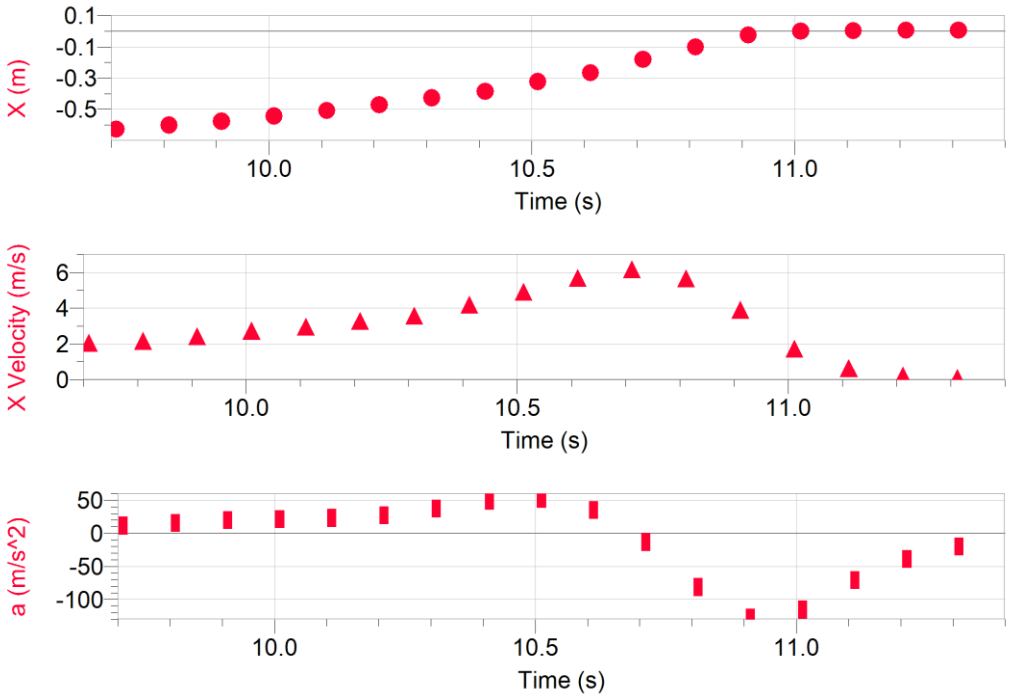

Figure 1: Plots of displacement (m), x-velocity (m/s) and acceleration (m^2/s) with real time(s) respectively for subject 1 (unsuccessful attempt).

At the point of contact

V_c = 3.861 m/s, a = -127.481 m^2/s.

Kinetic energy = 20.16 J

Deformation energy = 3.145 J

Attempt 2 (Successful)

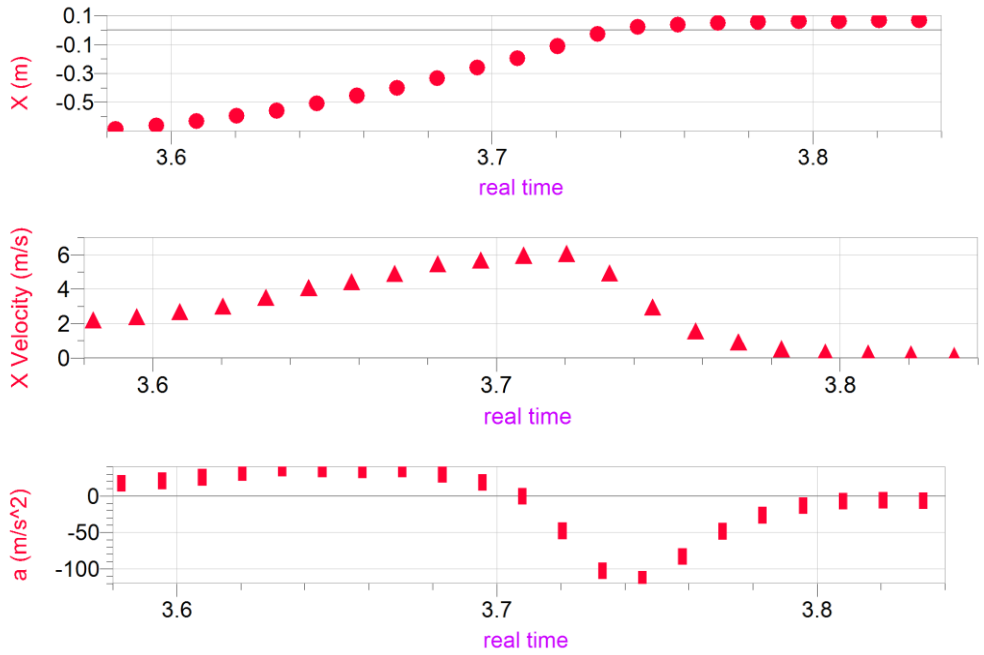

Figure 2: Plots of displacement (m), x-velocity (m/s) and acceleration (m^2/s) with real time(s) respectively for subject 1 (successful attempt).

At the point of contact
V_c = 4.885 m/s, a = -102.261 m^2/s.
Kinetic energy = 32.275 J
Deformation energy = 5.035 J

To further compare between attempt 1 and attempt 2, impulse was also calculated for each attempt. Impulse is given by $m1(V_1 - V_c)$ where V_1 for attempt 1 and attempt 2 were 0.592 m/s and 2.917 m/s respectively.

Attempt 1

Impulse imparted by board to the arm = -8.842 kg*m/s

Attempt 2

Impulse imparted by board to the arm = -5.323 kg*m/s

This suggests that impulse imparted was less when the board was broken. The negative sign just implies that impulse was in negative x-direction i.e. the momentum of the arm had decreased.

Subject 2 (male, bodyweight = 73 kg, Mass of arm = 4.161 kg)

Attempt 1 (Successful)

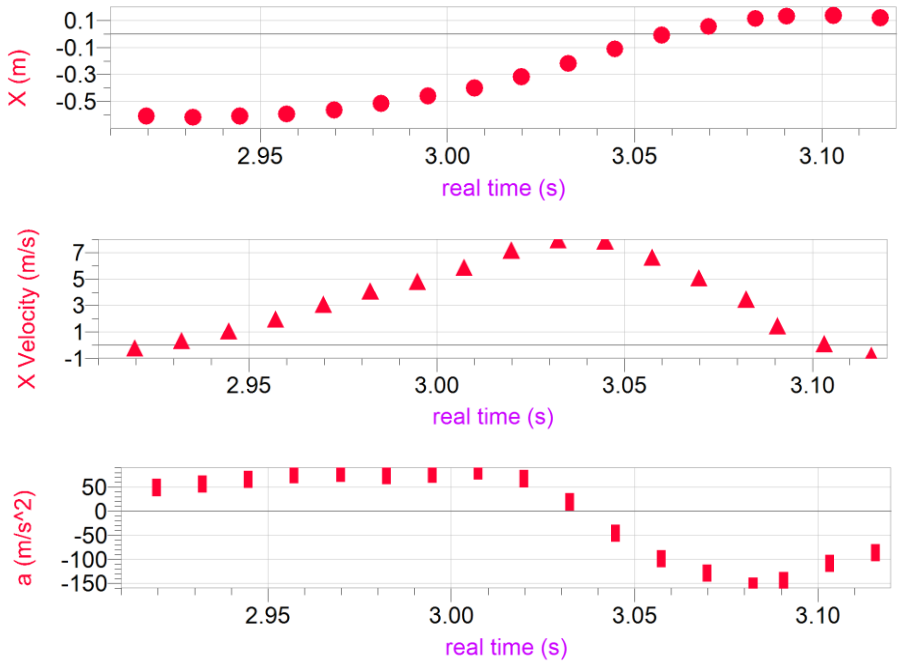

Figure 3: Plots of displacement (m), x-velocity (m/s) and acceleration (m^2/s) with real time(s) respectively for subject 2 (successful attempt).

At the point of contact
V_c = 6.588 m/s, a = -98.832 m^2/s.
Kinetic energy = 90.297 J
Deformation energy = 9.686 J

Results with regard to Concentration Gris Exercise:

Subject 1 was able to put a slash through 12 numbers in numerical sequence starting with number 00, whereas subject 2 was able to put a slash through 21 numbers. Therefore, their scores on concentration were:

Subject 1 = 12; Subject 2 = 21

Discussion

For subject 1, the results indicate a positive correlation between velocity and deformation energy i.e. increasing the velocity from 3.861 m/s (attempt 1) to 4.885 m/s (attempt 2) increased the kinetic energy and deformation energy by 60.094% and 60.095% respectively. The deformation energy (3.145 J) for breaking the board was in the lower standard deviation of the threshold value (5.3 ± 2.8 J) in the first attempt by subject 1 as compared to successful second attempt by subject 1 when 5.035 J of deformation energy was supplied to the board which is near the average threshold value for deformation energy. Therefore, the subject1 was just able to break the board in the second attempt.

In the case of subject 2 the velocity at the point of contact was 6.588 m/s i.e. the kinetic energy of the arm (90.297 J) and deformation energy supplied to the board (9.686 J) were 179.87 % and 92.37 % respectively more than the same were for subject 1 in attempt 2, which was successful.

These results indicate that velocity plays an important role in breaking of the board and lower deformation energy supplied due to low velocity of the arm at the point of contact in the first attempt by subject 1 might have been the cause for being unsuccessful in breaking the board. Whereas deformation energy supplied by subject 2 surpassed the upper limit of the threshold value (5.3 ± 2.8 J), thereby breaking the board with ease.

Acceleration of the arm at the point of contact for successful breaks was -102.261 m^2/s for subject 1 and -98.832 m^2/s for subject 2, therefore, lower the deceleration, higher is the velocity of the arm, higher is the deformation energy, better chances for successful break. The key to this is to keep the muscles of the upper arm relaxed, because if tense, these muscles will generate counteracting force acting in opposite direction of the board, thus, decelerating the punch.

Additionally, for subject 1, the results for impulse show that impulse imparted was less in successful (2^{nd}) attempt as compared to unsuccessful (1^{st}) attempt. This matches with the theoretical prediction that for unsuccessful breaking of the board, the decrease in momentum of the punch would be much more since the velocity of the hand comes close to zero after the impact. Thus, the impulse imparted would be more as compared to when punch is able to break the board for which the velocity does not come close to zero after the impact i.e. there is less decrease in momentum. The decrease in impulse imparted, from attempt 1 to attempt 2 was calculated to be 66.109 %.

With regard to the levels of concentration, subject 1 had scored 12 points on the concentration grid whereas Subject 2 had scored 21 points. As provided in Concentration Grid (Harris et al.1984), athletes who have the ability to concentrate, scan and store relevant cues will usually score in the

upper 20s and into the 30s during a one minute timed trial. Therefore, it is evident that Subject 2 had quite a higher level of concentration as compared to Subject 1. It has been found that Subject 2 had 75% higher level of focus concentration as compared to subject 1. It might be this factor which made a significant difference in their performance i.e. the subject 2 was able to break the board in the very first attempt whereas subject 1 succeeded in second attempt. Marchant et al. (2006), while examining the influence of different attentional focusing instructions upon muscular activity during biceps curl movements, concluded that attentional focusing strategies and instructions influence muscular activities that directly lay impact on specific skills execution.

Another reason of these differences may be that it was due to the gender difference among them. Nideffer et al. (1998) examined the differences between males and females in terms of their scores on TAIS concentration skills, and in terms of their dominant concentration style across individual sports including Karate. They noticed that females were 11.7% more likely to be distracted by external stimuli than males. Females were 7.7% more likely to become distracted by their own thoughts and feelings than males. Finally, females were 4% more likely than males to experience a breakdown in shifting from an external to an internal focus or vice versa. The sex differences in terms of external and internal distractibility had been found to be statistically significant. They also noticed that the ability to focus concentration is an important predictor of an individual's ultimate level of performance. The findings of present research are also in line with their study. However, contrary to the present findings, Ingalhalikar et al. (2013) suggest that in females, the neural wiring goes between the left and right hemispheres, suggesting that they facilitate communication between the analytical and intuition. They also found that females outperformed males on attention, word and face memory, and social cognition tests. Since the present study involved a very small sample, a study involving a larger sample might unfold the relationship between the level of focussed concentration of the karatekas and their skill performance.

Conclusion

The secret behind breaking the board is in technique - speed, impulse, kinetic energy and focus. Subject 2 was found to be better in all these areas. A karateka must achieve rapid accelerations and develop a high maximum velocity at the point of contact. The exceptional speed and power of offensive strikes demonstrated by expert karate athletes is well documented (e.g. Cavanagh et al. 1976; Wilk et al. 1983). In the arena of karate, the findings of this research will have considerable potential for highlighting the effective technique of executing a karate punch. Due to quite less movement

time, a karateka must deliver a punch along a straight horizontal line, resulting in shortening the potential radius of the arm and other body segments. Punching in a straight line will help the katateka to effectively use the mass to generate more force by putting his/her body behind the punch.

It can be concluded that the easiest way to break the board is to train effectively, be confident and focused enough to punch through the boards with precision. Movements of a karateka must be fluid and accurate**,** with no lose movements during the strike. Kinetic energy is the key factor, whenever speed is doubled, the kinetic energy is quadrupled: $KE = {}^{1}/_{2}\, Mass\ x\ (velocity)^2$ i.e., more deformation energy is supplied to the board. As the knuckles of hand make contact with the board, follow through should be with as much power and speed.

Apart from this, understanding the kinematics of physics and physical movements will help in avoiding the injuries as well. There are more chances of injury when the board is not broken. The reason being that the board, if not broken, will also exert substantial opposite force on the hand (Newton's 3rd law), and this may cause serious damage to the bones and the muscles of the arm. A person may not be able to break the board due to many reasons, for example, fear of injury creates hesitation in the mind of the person, disrupting his/her concentration, thereby producing tension in the muscle, eventually causing deceleration of the punch. Williams et al. (1998) also observed that in the face of stressful situations, a sportsperson gives a response which results in physiological changes such as increase of muscular tension, and change in attention such as inadequate focusing of attention, which increases the probability of getting injured. That's why the karate or martial art experts do not invoke the thought process for voluntary actions such as punching or kicking but rather after being trained constantly for many years, these actions become involuntarily. Hence, it is hypothesized that body conditioning and training will help in preventing injury to the body.

This study will also help in assessing the skill level of the athletes and in modulating their training schedules by including attention focus and concentration enhancing exercises and even yoga practices (Kauts et al. 2012). Focus is necessary to put all the force at a single point; mental preparation is an equally important aspect of executing any karate technique since all the obstacles are mental.

Further, one of the objectives of the present research was to present a dynamic model of applied physics and human performance through an interesting explanation of the concepts of physics in combination with psycho-physical principles involving sports. Thus, this research work will help the education, physical education and physics teaching community in

understanding about the use of sports and human movement examples to liven up the teaching process and to make the teaching of relevant concepts more appealing.

References:

Armenti, A. *The Physics of Sports*. New York: Springer-Verlag, 1992.

Cavanagh, P. R., and J. Landa. "A biomechanical analysis of the karate chop." *The Research Quarterly*. 47. (1976): 610-618.

Goldberg, A. (2013). Concentration: the master skill of mental toughness. *http://www.usaswimming.org/ViewNewsArticle.aspx?TabId=1504&itemid=5202&mid=9388*

Gould, D., R. C. Eklund, and S. A. Jackson. "1988 US Olympic wrestling excellence, I: Mental preparation, precompetitive cognition and affect." *The Sport Psychologist*. 6. (1992): 358-382.

Harris, D. V., and B. L. Harris. *The athlete's guide to sport psychology: Mental skills for physical people*. New York: Leisure Press, 1984.

Hosam El-Din, T. *Biomechanics: Integration between theory and application in sports*. Cairo: Dar Al-Ketab, 1998.

Ingalhalikar, M., Smith, A., Parker, D., Satterthwaite, T., Elliott, M., Ruparel, K., Hakonarson, H., Gur, R. E., Gur, R. C., and Verma. V. (2013). Sex differences in the structural connectome of the human brain. PNAS, December 2, 2013 DOI: 10.1073/pnas.1316909110.

Kamlesh, M. L. *Psychology in physical education and sports*. New Delhi: Metropolitan Book Co, 1998.

Kauts, A., and N. Sharma. "Effect of Yoga on Concentration and Memory in relation to Stress." *International Journal of Multidisciplinary Research*. 2. no. 5 (2012): 1-14.

Lohse, K. R., Sherwood, D. E., & Healy, A. F. (2013). On the advantage of an external focus of attention: A benefit to learning or performance?. *Human movement science*.

Marchant, D., M. Greig, C. Scott, & P. Clough, "*Attention focusing strategies influence muscle activity during isokinetic bicep curls."* Poster presented at the Annual Conference of the British Psychological Society, Cardiff, 2006.

McCaffrey, N., and T. Orlick. "Mental factors related to excellence among top professional golfers." *International Journal of Sport Psychology*. 20. (1988): 256-278.

Nideffer, R. M., and J. Bond. "A cross cultural examination of the concentration skills of elite level athletes." *Enhanced Performance Systems* (1998). Accessed August 6, 2012.

Plagenhoef, S., F. G. Evans, and T. Abdelnour. "Anatomical data for analyzing human motion." *Research Quarterly for Exercise and Sport*. 54. (1983): 169-178.
Shehata, M. E., M. G. Berekaa, and M. Baiomy. "Multi-media in mechanical analysis." *Theories and Applications Journal*. (1996): 46.
Wilk, S. R., R. E. McNair, and M. S. Feld. "The physics of karate." *American Journal of Physics*. 51. (1983): 783-790.
Williams, J., and M. Andersen. "Psychosocial antecedents of sport injury: Review and critique of the stress and injury model." *Journal of Applied Sport Psychology*. 10. (1998): 5-25.
Wulf, G. (2013). Attentional focus and motor learning: a review of 15 years. *International Review of Sport and Exercise Psychology*, *6*(1), 77-104.