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Research article

The effects of height and distance on the force production and acceleration in martial arts strikes

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Abstract
Almost all cultures have roots in some sort of self defence system and yet there is relatively little research in this area, outside of a sports related environment. This project investigated different applications of strikes from Kung Fu practitioners that have not been addressed before in the literature. Punch and palm strikes were directly compared from different heights and distances, with the use of a load cell, accelerometers, and high speed video. The data indicated that the arm accelerations of both strikes were similar, although the force and resulting acceleration of the target were significantly greater for the palm strikes. Additionally, the relative height at which the strike was delivered was also investigated. The overall conclusion is that the palm strike is a more effective strike for transferring force to an object. It can also be concluded that an attack to the chest would be ideal for maximizing impact force and moving an opponent off balance.

Key words: Sports, acceleration, Kung Fu, law enforcement, combat.

Introduction

Ving Tsung is a Kung Fu style that was developed in Southern China that can also be translated as Wing Chun, although different schools all over the world prefer one translation over the other. Ving Tsung is generally understood to be a close range self defence system based on the idea of attacking one's centreline (Reid and Croucher, 1983). The centreline can be described as the axis of the median plane which divides the body into right and left halves.

When a student begins to learn the techniques of Wing Chun, they learn a stance that involves the inversion of the feet and knees, and a lowered centre of gravity where the body faces forward. The hands are near the face with the elbows tucked in to protect the ribs. From this stance, the martial artist is able to throw a series of strikes in a short period of time.

The stance the students begin with is different from that of a boxer's stance. Since Wing Chun is considered a close quarter's system, the power of each strike is less than a boxer, but an accomplished martial artist may overtake an opponent with repeated strikes and precision. But, each strike should have the greatest effect possible. The force generated at each impact should be substantial and is therefore important to investigate with respect to martial arts impacts.

Although there are several factors that may affect how much force is generated with a given punch, in classical Physics, it can be simplified to: F = M x A

For impact, the peak force is related to the acceleration of that object at each instant multiplied by its effective mass. Effective mass is defined as all the mass being utilized at impact (Blum, 1977). Based on proficiency of the strike, the effective mass can range from the mass of the fist to the summation of the forearm, upper arm and the trunk (Nakayama, 1966). Proper technique is crucial for force to be generated throughout the body. Optimal force transfer is based on the body's ability to become a series of rigid links and proper anatomical alignment is crucial for developing this force (Bartel, 2006; Neto and Magini, 2008). It has been demonstrated that when a subject strikes a target and the wrist is not supported by the musculature, or is out of proper alignment, a great moment occurs on the wrist and the chain of force transfer will be broken (Waliko, 2005). In effect, a large amount of the energy will be absorbed by the motion between the hand and the wrist.

There have been studies that have investigated a better understanding of a basic punch. Researchers have looked into studying the resulting accelerations of a punch on surrogates by using accelerometers along with pressure mapping systems (Waliko, 2004; Waliko et al., 2005). Others have measured force by using punch dynamometers (Filamonov, 1983; Nakayama, 1966). Some researchers have also assumed effective masses and then used pendulum systems to calculate velocity at impact on humans and surrogates (Johnson et al., 1975). Still other researchers have made estimates of the effective mass of the arm and multiplied the acceleration of the arm on impact (Sherman et al., 2004).

There are several factors hypothesized to affect the force generated during a strike including; distance to target, height of the target relative to the shoulder and type of punch/strike. Two studies were identified in the literature that investigated how distances affect the force of a strike (Gulledge and Dapena, 2007; Neto et al., 2007). It was stated that as the distance to the target increased, the amount of force developed also increased. This of course was only to a certain distance. Based on this finding, three different distances were explored to see if a midrange strike would prove to be more effective at force production. It was also determined that the height of the target and type of punch may also affect the force generated upon impact. Therefore the goal of the current study was to investigate the relationships between accel-

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erations and force under different striking conditions. Strike distance, type of strike, and height of target were included in a protocol developed to investigate how these traits were interrelated.

Methods

Thirteen Moy Tung Ving Tsung martial artists, 10 males and 3 females, consented to participate in the experiment. The participants had 2 - 6 years average martial arts training time. The methodology was approved by the Wayne State University Human Investigation Committee, and all subjects provided their informed written consent. Practitioners of the Ving Tsung School were selected because they practice both palm and punch strikes. These martial artists punch with the lower metacarpals (MCP) joints with the knuckles perpendicular to the floor and palm strike with the hypothenar eminence.

Table 1. Strike protocol.

Strike	Target	Distance	Test Name
Palm	**Head**	Short	PHS
		Medium	PHM
		Long	PHL
	Chest	Short	PTS
		Medium	PTM
		Long	PTL
Punch	**Head**	Short	FHS
		Medium	FHM
		Long	FHL
	Chest	Short	FTS
		Medium	FTM
		Long	FTL

PHS = Palm Head Short, PHM = Palm Head Medium, PHL = Palm Head Long, PTS = Palm Thorax Short, PTM = Palm Thorax Medium, PTL = Palm Thorax Long, FHS = Fist Head Short, FHM = Fist Head Medium, FHL = Fist Head Long, FTS = Fist Thorax Short, FTM = Fist Thorax Medium, FTL = Fist Thorax Long

The subject's weight and height were recorded. A protocol similar to (Sherman et al. 2004) was used to take anthropometric measurements as well as hand and arm volumes. The subject placed their hand in a large PVC tube with a channel designed to direct water into another container. The water in the tube was filled to this channel and any overflow was determined to be the displaced volume of the fist, and then the forearm up to the elbow. The volume was then used to calculate the mass of each segment based on calculated average densities for those aspects of the body. A photograph of the subject's fist and palm was also taken. Subjects were also asked to wear an outfit that was marked at specific joints to be used for motion analysis. Each subject was asked to "warm up" by completing a pattern of movements, known as a form, that help develop their specific skills within the Art.

Following the warm up, subjects stood on a variable height platform. The platform was used to allow the subject to strike the target at the head and chest levels respective to his or her height. The head level target was lined up with the eyes of the subject and the chest level lined up the subject's sternum with the centre of the target. This allowed for the dimension of the pendulum to be held constant and provided for a quick transition during testing.

A strike protocol (Table 1) was developed for each subject with 12 different strikes randomly assigned. The subject stood on the platform and set their feet where they could deliver the greatest force for all the strikes and were requested not to move their feet during the rest of the testing. Strikes were stratified into palm versus punch strikes. Subjects were instructed to perform each of these strikes to both the head and chest from three different distances to the target. The shortest distance (Short) was defined as the length of the subjects' hands. The longest distance (Long) was defined as the distance from the chest of the subject to the target. The third distance (Medium) was approximately the average of the other two.

The participants were then informed of which strike they would perform upon hearing a sound stimulus that would occur within four to ten seconds after indicating they were ready for the test to begin. The sound stimulus was the "click" of a relay used to trigger the data acquisition system and cameras. The time that the sound was triggered was randomly assigned. None of the subjects expressed difficulty hearing the stimulus.

Video analysis

High speed video was collected at 2,500 Hz using two cameras (HG-100K, Redlake Inc.) placed orthogonal to each other. One camera was placed directly overhead and another placed laterally to the subject. The cameras were used to identify inconsistencies with technique and accuracy.

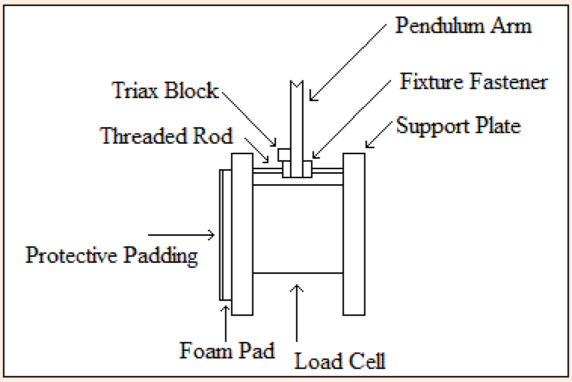

Figure 1. Load cell design.

Force collection

A load cell (model 7120 Syscon Inc.) was mounted with its sensing axis parallel to the ground. Custom pieces of aluminium were fabricated to mount the load cell to a steel arm that was attached to a hinge allowing the load cell to move as a pendulum. A foam pad with a thin ABS plastic covering was placed on the striking surface of the load cell to protect the hand. The thin plastic served as a method to prevent the deformation of the foam after repeated strikes. A diagram of this device is included (Figure 1). The measurement of force using this pendulum was validated by taking a known mass and attaching an accelerometer (model 7264D, Endevco Inc.) to the back of it. This instrumented mass was then suspended by a string, and therefore created its own pendulum system. This pendulum system struck the load cell from different

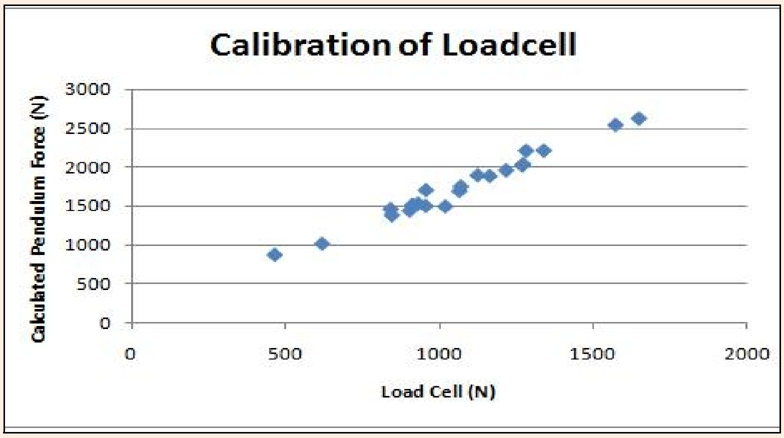

Figure 2. Calibration of load cell with a ratio of 1.6.

initial heights. The force was calculated by multiplying the mass of the weight by its acceleration at impact. This was then compared to the force calculated by the load cell. The ratio of the two forces was consistently 1.6 which was used as a conversion factor during the testing. The results of this calibration were reported (Figure 2).

Six accelerometers (model 7264D, 500G, Endevco Inc.) were used in this study. Three accelerometers were mounted on a tri-axial block and then secured to the subject's forearm. Another tri-axial block was attached to the arm of the pendulum near the centre of mass of the load cell. All instrumentation was collected at 10,000 Hz per channel using TDAS (Diversified Technical Systems Inc.), a data acquisition system typically utilized in crash testing.

Table 2. Mean normalized values by strike height.

Strike	Force	Arm Acc	Pen Acc
Chest	.736 (.159)	.562 (265)	.650 (.214)
Head	.664 (.174)**	.573 (.264)	.498 (.233)**
Effect size	.43	.04	.68

** denotes $p < 0.01$, respectively by ANOVA. Acc = acceleration, Pen = pendulum.

Statistical analyses

The data was entered into Microsoft Excel where the calculated force at the surface of the pad was determined by multiplying the calculated coefficient of 1.6 with the force reported by the load cell. The data was measured in Newtons for force and g's for acceleration and then normalized for each subject. The normalization procedure for this study was calculated by determining the maximum value of the 12 strike series for each respective measurement, (force, arm, and pendulum accelerations) then dividing all of the values in the series by these maximums. In a 12 strike series for a given measurement, the maximum value the subject generated would have a value of 1 and the other 11 strikes would be some percentage of this. Therefore a total number of 36 values were reported per subject. The data was analyzed with an ANOVA. Differences among groups with two means, such as strike type, were calculated with a t test and the resulting p value was reported. Additionally for two mean comparisons, an effect size was calculated and reported for the comparisons of strike type and strike height (Rosnow and Rosenthal, 1996). Significance was determined at an α level of .05. Analysis of strikes by distance was reported graphically to allow for a better understanding of the trends.

Results

Punch vs palm strike

The mean normalized force for the palm strikes for all participants was 0.735 ± 0.156. This was significantly higher ($p < 0.05$) than the normalized mean force of the punch strikes which was 0.668 ± 0.178. In terms of arm acceleration, the mean normalized value was 0.542 ± 0.28 for the punch strike and 0.594 ± 0.244 for the palm strikes. There was not a significant difference between the mean arm accelerations between the punch and palm strikes.

The punch had a mean ($p < 0.01$) normalized pendulum acceleration of 0.521 ± 0.199 in comparison to the palm strike with 0.629 ± 0.249.

Head strike vs chest strike

There was a significant difference in the mean forces that favoured the chest level strikes. There was no significant difference between the arm accelerations for the head and chest level strikes; however, there was a significant difference for pendulum acceleration in favour of the chest level strike. The analyzed data was reported to indicate the normalized values (Table 2).

Effect of distance

The force ($p < 0.001$; Figure 3) and the arm ($p < 0.001$; Figure 4) accelerations increased as the distance increased. The largest pendulum accelerations were seen with the palm strike at the chest level at the medium distance ($p < 0.001$; Figure 5).

Discussion

In terms of force, the palm strike proved to have the greatest average magnitude. It is believed that due to the rigidness of the target, force would transfer through the forearm more efficiently than the metacarpals. The high

Figure 3. **Analyses indicating difference in force at impact.**

speed video collected showed that for all strikes, regardless of experience of the subjects, there was always at least a small moment occurring on the wrist. Therefore it could be argued that a palm strike would be a better way to transfer force to the target. In boxing the wrists are supported by large amounts of wrapping, taping, other external support, mitigating this effect. In the current study, it was concluded that, although the mean force was higher for the palm, there was not a significant difference in the arm acceleration at impact between the punch and palm strikes. When the pendulum accelerations were compared, the palm had a significantly greater response. Based on these results it seems that the palm strike is more effective at transmitting force to a target. It can be speculated, that the discrepancy in efficiency between a palm strike and a punch would be even larger for novice practitioners, whose wrists are not as rigid and not as well aligned as experienced practitioners.

Both of the strikes, up to and during impact, were fairly linear in lateral and overhead views. There was a rotation employed in the sagittal plane when the strike was recoiled, but it was not a concern for the current study because peak impact was the point of interest.

The results also show that the amount of force generated at impact decreased in the head level strikes in comparison to the chest strikes. One possible reason for this could be the inability of the body to generate as great of an effective mass in the head level strikes. Although values of effective mass were not calculated, it is worth noting that there was no significant difference in the arm accelerations between the strikes to the head and chest level while there was a significant difference between the pendulum accelerations. The results showed that the chest level strikes developed more post-impact acceleration than the head level. Another explanation for the lower pendulum accelerations in the strikes to the head level could be that the impact vector in the head level strikes might have a greater Y- axis component, thus a larger part of the energy transferred to the pendulum would transfer up the pendulum arm into the ceiling.

There were important results found when investigating the distance, and how it affected the overall force seen on the target. In every situation, the long distance strike was significantly greater than the short distance strike in terms of force. This was also evident for the arm and pendulum accelerations as well. Therefore our results

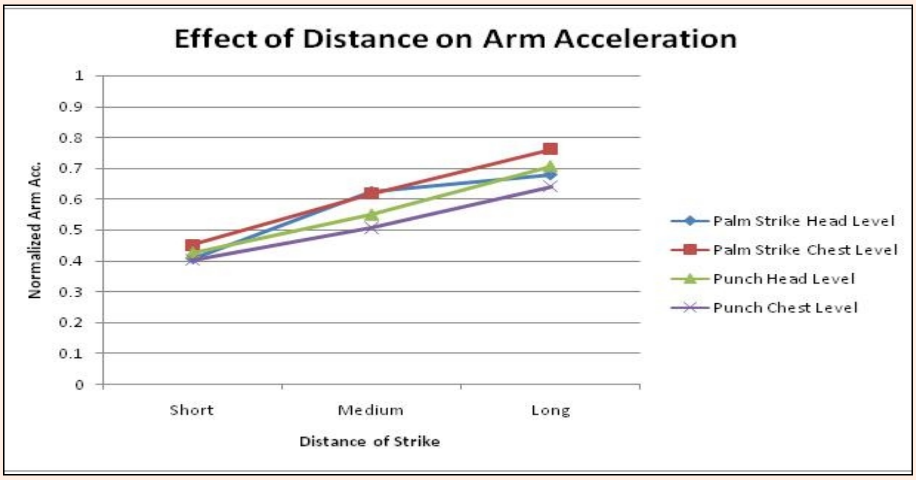

Figure 4. **Analyses indicating differences in arm acceleration at impact.**

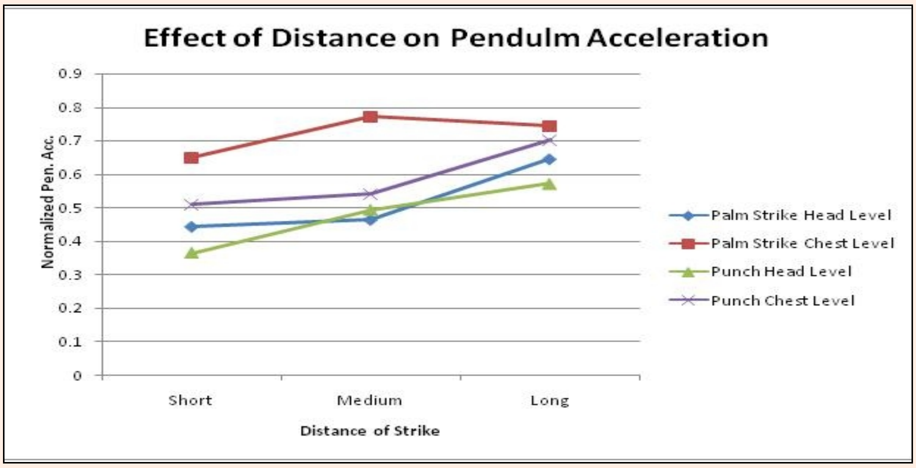

Figure 5. Analyses indicating the difference in pendulum acceleration at impact.

agree with (Gulledge and Dapena, 2007) and (Neto, 2007) with regards to an increase in force with an increase in distance. However, the middle distance strike was greater than the long distance strikes for the chest level palm strike with regards to pendulum acceleration. It is not certain if this was due to an acceleration or effective mass issue.

It should also be noted that if maximum force is to be applied, there has to be a maximum acceleration as well. Therefore the point of peak acceleration will be some percentage of maximum extension (Neto et al., 2007; Walker, 1975). This is why combative sport participants are taught that they must aim behind the target so that greater acceleration will be applied at time of impact.

In future studies, the effect of wrist deflection on production should be explored. It is hypothesized that as deflection increases, the output force will decrease. The study of masters from different schools but the same style should also be explored. By looking at a master's movement, it would be possible to identify key physical principles that can be employed to train athletes and other martial artists at a much faster rate and would decrease ambiguity that exists among the martial arts.

There are several limitations in this study. The first issue is that there were fewer females than males in the study. Although it is possible that this would have an effect on the results, the normalization procedure was able to minimize size and strength differences. Additionally males and females were not directly compared to each other. Another issue is that there was a large variation in the number of years practicing martial arts. This makes the sample less homogenous but allows for greater extrapolation to a larger population. The third issue is the subjects were not put under the type of stress of a real world life or death situation and therefore the motivation will be different when striking. But using these results one can practice the strikes that can be termed as the most effective, so that if a high stress situation occurs, the most effective techniques will be programmed.

Conclusion

The results of this study have many applications for all populations that are interested in any sort of martial arts or self defence training. For coaches of combative sports, the results indicate the need of the teaching of proper technique along with proper strength and conditioning training. There will always be at least a small moment on the wrist, therefore the forearm musculature must be strong enough to resist this movement and allow the proper technique to be applied. Proper positioning of the body must be taught to the combative sports athlete so that they may generate the maximum acceleration at impact. Additionally for martial arts teachers, it would be important to teach novice practitioners the palm strike early in training so that they may have a better chance to defend themselves in a high stress situation, or if the student is inherently weak the palm strike and be an alternative to the punch to deliver a stronger impact. Because of its greater force production capabilities and momentum transfer, the palm strike to the chest or solar plexus would be ideal for maximizing impact force and therefore moving an opponent off balance, as well as attacking harder surfaces that would not be applicable for other strikes.

This research is also applicable to soldiers and law enforcement officers that are exposed to close quarters combat on a regular basis. As indicated before, an officer that trains the most effective attacks for long enough will develop an innate ability to generate these attacks automatically and efficiently when under the highest stresses.

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References

Bartel, D.L., Davy, D.T. and Keaveny, T.M. (2006) *Orthopaedic Biomechanics*. Pearson Prentice Hall, Upper Saddle River.

Blum, H. (1977) Physics and the art of kicking and punching. *American Journal of Physics* **45**, 61- 64.

Gulledge, K.J. and Dapena, J. (2007) A comparison of the reverse and power punches in oriental martial arts. *Journal of Sports Sciences* **26**, 189-196.

Filamonov, V. I., Koptsev, K.N., Husyanov, Z.M. and Nazarov, S.S. (1983) Means of increasing strength of the punch. *Boks* **1**, 41-43.

Hobusch, F.L. and McClellan, T. (1990) The Karate Roundhouse Kick. *National Strength and Conditioning Association Journal* **6**, 84-89.

Johnson, J., Skorecki, J. and Wells, R.P. (1975) Peak accelerations in the head experienced in boxing. *Medical and Biological Engineering* 13**,** 396-403.

Nakayama, M. (1966) *Dynamic Karate.* Kodansha, New York.

Neto, O.P., Magini, M. and Saba, M.F. (2007) Role of effective mass and hand speed in the performance of Kung Fu atheletes compared with nonpractitioiners. *Journal of Applied Biomechanics* **23**, 139-148.

Neto, O.P. and Magini, M. (2008) Electromiographic and kinematic characteristics of Kung Fu Yau-Man palm strike. *Journal of Electromyography and Kinesiology*, **18** 1047-1052.

Reid, H. and Croucher, M. (1983) *The way of the warrior: The paradox of the martial arts*. Century Publishing Co., London.

Rosnow, R.L. and Rosenthal, R. (1996) Computing contrasts, effect sizes, and counternulls on other people's published data: General procedures for research consumers. *Pyschological Methods* **1**, 331-340.

Sherman, D., Bir, C., Walilko, T. and Boitano, M. (2004) Correlation between punch dynamics and risk of injury. *5th Conference on Engineering of Sport, UC Davis, CA.* Book of Abstracts. 110-116

Tsaousidis, N. and Zatsiorsky, V. (1996) Two Types of Ball- Effector interaction and their relative contriubtion to soccer kicking. *Human Movement Science* **15**, 861-876.

Waliko, T.J. (2004) *Biomechanical response of the temporomandibular joint from impacts in boxing.,* Doctoral Thesis, Wayne State University, Detroit.

Waliko, T. J., Viano, D.C. and Bir, C.A. (2005) Biomechanics of the head for olympic boxer punches to the face. *British Journal of Sports Medicine* **39**, 710-719.

Walker, J.D. (1975) Karate strikes. *American Journal of Physics* **43**, 845-849

Key points

- It has been determined that the palm strike is more effective than the punch for developing force and for transferring momentum, most likely the result of a reduced number of rigid links and joints.
- A strike at head level is less effective than a strike at chest level for developing force and transferring momentum.
- Distance plays an effect on the overall force and momentum changes, and most likely is dependent on the velocity of the limb and alignment of the bones prior to impact.
- The teaching of self defence for novices and law enforcement would benefit from including the palm strike as a high priority technique.

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