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THE EFFECT OF HAND DOMINANCE ON MARTIAL ARTS STRIKES

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Abstract

The main goal of this study was to compare dominant and non-dominant martial arts palm strikes under different circumstances that usually happen during martial arts and combative sports applications. Seven highly experienced (10 ± 5 years) right hand dominant Kung Fu practitioners performed strikes with both hands, stances with left or right lead legs, and with the possibility or not of stepping towards the target (moving stance). Peak force was greater for the dominant hand strikes (1593.76 ± 703.45 N vs. 1042.28 ± 374.16 N; $p < .001$), whereas no difference was found in accuracy between the hands ($p = .141$). Additionally, peak force was greater for the strikes with moving stance (1448.75 ± 686.01 N vs. 1201.80 ± 547.98 N; $p = .002$) and left lead leg stance (1378.06 ± 705.48 N vs. 1269.96 ± 547.08 N). Furthermore, the difference in peak force between strikes with moving and stationary stances was statistically significant only for the strikes performed with a left lead leg stance ($p = .007$). Hand speed was higher for the dominant hand strikes (5.82 ± 1.08 m/s vs. 5.24 ± 0.78 m/s; $p = 0.001$) and for the strikes with moving stance (5.79 ± 1.01 m/s vs. 5.29 ± 0.90 m/s; $p < .001$). The difference in hand speed between right and left hand strikes was only significant for strikes with moving stance. In summary, our results suggest that the stronger palm strike for a right-handed practitioner is a right hand strike on a left lead leg stance moving towards the target.

Keywords

Handedness; Motor Control; Kinematic Analysis; Kinetic Analysis; Effective Mass

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1. Introduction

Handedness or motor lateralization is a prominent feature of human motor control that has been well described through the identification of tasks that are preferentially performed with one of the arms (Oldfield, 1971). However, the effects of handedness on martial arts strikes have not been studied.

Although several studies have been made that investigate the effects of handedness on restricted arm movements reaching to a target (Elliot et al., 1993; Sainburg, 2002; Sainburg & Schaefer, 2004; Zhang, Sainburg, Zatsiorsky, & Latash 2006), there are not many studies that have investigated the effects of handedness on martial arts strikes. Out of the studies relating handedness and martial arts, there is one study from Layton (1993) that investigates the incidence of left-handedness to right-handedness in British Shotokan Karate masters, and another one from Mikheev, Mohr, Afanasiev, Landis, and Thut (2002) that analyzed motor control and cerebral hemispheric specialization in highly qualified judo wrestlers. The authors, however, are unaware of studies that have compared experienced martial artists right- and left-hand strikes. Surprisingly, there is no clear answer to basic questions such as: does a right-handed martial arts experienced strike faster and/or harder with his dominant hand than his non-dominant? If yes, how large is this difference, and what causes it mechanically? Which hand is more accurate? Furthermore, during martial arts applications, differences related to hand dominance may interact with other factors such as the lead leg of the stance used during a strike and whether the stance is stationary or moving during the strike. These factors raise other common unanswered questions within martial artists and combative sports athletes and coaches: does the lead leg of the stance influence the strength or speed of a strike? Does stepping towards the target enhance the strength or speed of a strike?

Southern styles of traditional Kung Fu (e.g., Ving Tsun and Yau-Man) are great models to study handedness in martial arts because they are highly symmetrical arts (Bolander, Neto, & Bir, 2009; Neto, Magini, & Saba, 2007). In these styles, martial artists spend the vast majority of their training time practicing forms, strikes with and without impact, a sparring drill named Chi Sau or “sticking hands” and sparring (Neto, Magini, & Pacheco, 2007; Reid & Croucher, 1983). Kung Fu forms are symmetrical. Additionally, Kung Fu practitioners consistently train strikes with both hands and spend equally amount of time training each. Sticking hands is also symmetrical; during this drill two practitioners maintain contact with each other’s forearms while executing defensive and offensive techniques (most often simultaneously). Sticking hands has the aim to teach practitioners how to counter an opponent’s movements precisely, quickly and with proper technique (Belonoha, 2005). Furthermore, different than in boxing, for example, where athletes are trained to use a lead hand (non-dominant) that normally perform jabs (quick punches), and a rear hand (dominant), that normally performs crosses (powerful punches), in southern styles of Kung Fu, because of the forms and specific sparring drills, practitioners are trained to spar without favoring one hand over the other.

The goal of this paper was to investigate possible differences between dominant and non-dominant palm strikes executed by a group of experienced southern style Kung fu practitioners with either a right or left lead leg moving or stationary stance.

2. Methods

2.1 Subjects

Seven southern style Kung Fu martial artists (mean age of 27 ± 6 years; $M \pm SD$), 4 males and 3 females, participated in the experiment. All subjects reported being healthy without

any known neurological problems and were right hand dominant according to a standardized survey (Oldfield, 1971). The participants were experienced martial artists with a 10 ± 5 years (minimum of 6 years) Kung Fu training age. Approval was granted by the Wayne State Human Investigation Committee, Protocol #: 011604M1E(R) prior to commencement of the study, and all participants provided their informed written consent.

2.2 Experimental arrangement

The participants were asked to warm up in their normal manner. Following the warm up, each participant was requested to palm strike eight times with maximum effort a load cell pendulum apparatus (further detailed later in this section). Kinetic and kinematic data was collected from every strike. During the experiment, subjects stood on a hydraulic variable height platform. The platform was used to allow the subjects to strike at the same relative heights. Height of the platform was determined so that the target was aligned with the sternum of the participants (Fig. 1).

2.3 Striking protocol

The protocol was designed to understand possible differences between dominant and non-dominant hand strikes under different circumstances that usually happen during martial arts applications. It simulates different conditions that often take place during training and competition, when either dominant or non-dominant hand strikes may be executed with a dominant or non-dominant lead leg stance, under dynamic or static stability conditions.

Three different factors were considered to develop the striking protocol: the hand used to strike (dominant hand - DH; non-dominant hand - NDH) the leg positioned closer to the target in their Kung Fu stance (right lead leg stance - RS; left lead leg stance - LS), and the possibility of performing a small step with the lead leg followed by a small step with the back leg in the direction of the target (stationary stance - SS; moving stance - MS). Each subject performed a total of 8 palm strikes to cover all possible permutations of the factors considered (i.e., DH-RS-SS, DH-RS-MS, DH-LS-SS, DH-LS-MS, NDH-RS-SS, NDH-RS-MS, NDH-LS-SS, NDH-LS-MS). The order of the strikes performed by each subject was randomly assigned.

2.4 Data collection and analysis

Two high speed cameras (HG-100K, Redlake Inc.) were used in this study. One camera was placed directly overhead of the subject (overhead camera). The other camera was placed laterally to the subject (lateral camera). The cameras were positioned orthogonal to each other and recorded each strike at 2500 Hz. Videos were collected using Motion Central 3.0.8.0 (Redlake MASD Inc). Visual inspection of the overhead camera videos demonstrated that the hand maintained a constant distance from the lateral camera during the strikes, describing a straight line trajectory perpendicular to the target. Thus lateral camera videos were sufficient to quantify values of hand speed. ImageJ 1.42g software (Abramoff, Magelhaes, & Ram, 2004) was used to analyze the lateral camera videos and collect wrist positions (x and y coordinates) from the last 20 ms (50 frames) prior to impact. Positions were determined by manually tracking a contrast marker placed at the lateral surface of the forearm near the junction between the hand and wrist. From the position coordinates collected displacements in the direction perpendicular to the target (x) were calculated. Then, a high degree polynomial was fitted to the x displacement versus time data. Finally, we defined hand speed (s) as the derivative of the fitted polynomial in the instant immediately before the impact (Neto, Magini, & Pacheco, 2007).

A load cell (model 7120 Syscon Inc.) was mounted with its sensing axis parallel to the ground. Custom pieces of aluminum were fabricated to mount the load cell to a steel arm

that was attached to a hinge that would allow 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. Data from the load cell was collected at 10,000 Hz using TDAS Diversified Technical Systems Inc. Peak force was determined using Diadem 10.2 (National Instruments Inc.). An algorithm written in Matlab 7.0.1 (MathWorks Inc) was used to filter the force data (Fourth order Butterworth low pass filter 500 Hz) and calculate areas under the curve at specified ranges of time.

A Tekscan pressure sensor (Model 9500) was placed between the load cell and the protective pad. The 4.23I Tekscan pressure system was used to determine the accuracy of the strikes. The sampling rate of the system was set to 216 Hz. All pressure data was reprocessed with Matlab 7.0.1 (MathWorks Inc). From each strike data, values associated to the accuracy of the strikes were calculated as the distance in centimeters between the center of pressure of the strike and the geometric center of the pressure sensor. This way, the higher the value measured the worse is the accuracy of the strike.

2.5 Dependent variables

Four dependent variables were chosen to quantify strike performance: peak impact force (peak force), instantaneous hand speed before impact (hand speed), effective mass of impact (effective mass) and accuracy of the strikes (accuracy).

2.6 Effective mass estimation

Arguably, the most important performance variable for martial arts strikes is the peak impact force. According to Neto, Magini, and Pacheco (2007) in order to improve peak impact force practitioners need to maximize their hand speed before impact and their effective mass of impact. Effective mass has been calculated in the past using the principle of conservation of momentum and considering the mass and the speed after impact of the targets being hit (Neto, Magini, & Saba, 2007; Walilko, Viano, & Bir, 2005). However, in this paper, since the strikes were aimed at a force transducer another equivalent physical approach is possible. So, Newton's second law in its differential form was used to obtain the values of the effective masses (m_e) of impact considering that only the interaction forces between the two bodies altered their accelerations during the collision, Eq. 1. This approach was convenient, since the effective mass and speed information of the target were not needed.

$$m_e = \frac{\int_{t_1}^{t_2} F dt}{s} \quad (1)$$

where F is the force data in Newtons, t_1 (s) is the instant of the impact and t_2 (s) is the instant that the hand stops (momentarily) during the collision (both found from visual inspection of the high-speed videos), and s is the magnitude of the instantaneous hand velocity before the impact. Note that the effective mass was calculated as the impulse of the strike divided by the hand speed before the impact.

2.7 Statistics

Power analysis was performed considering previous palm strike force data collected from Ving Tsun Kung Fu practitioners (Neto, Bolander, Pacheco, & Bir, 2009). A sample size of 7 subjects was chosen so that if the difference in peak force between dominant and non-dominant strikes was in the order of 15% our study would have power of 80% to yield a significant effect.

Four mixed four-way repeated measures ANOVAs (2 Genders $\times$ 2 Hands $\times$ 2 Stances $\times$ 2 Movement Conditions) with gender as the between-subject factor and hand, stance and movement as within-subject crossed factors compared the values of impact peak force, effective mass, accuracy and hand speed across all conditions. After we ran the 4 models, we examined the residual plots and applied diagnostic statistical tests to determine whether the models were adequate and the assumptions of regression had been met. Specifically, we checked: if there was a linear relationship between response and predictors; if the residuals had constant variance; if the residuals were not correlated with one another; if the residuals were normally distributed; if there were no unusual observations or outliers; and if the data were not ill-conditioned (Draper & Smith, 1981; Neter, Wasserman, & Kutner, 1985). Significant interactions from the ANOVA models were followed by appropriate post hoc analyses using Bonferroni corrections. Statistical analyses were performed using Minitab 14.12.0 (Minitab Inc.) and SPSS 17.0 (SPSS Inc., Chicago, IL). The alpha level for all statistical tests, except when corrected, was .05. Data are reported as mean $\pm$ standard deviation (*SD*) within the text and table, to show how much variation there was among individual observations, and as mean $\pm$ standard error of the mean (*SEM*) in the figures, to show how good the sample means were estimates of the parametric means (McDonald, 2009). Only the significant main effects and interactions are presented, unless otherwise noted.

3. Results

The overall mean peak impact force was 1323.09 ± 626.30 N. The great variability in the overall peak force data (Coefficient of variation (*CV*) = 43.3%) was caused in part by differences in gender. Males were significantly stronger than females, $F(1, 4) = 17.588$, $p = .014$; effect size = .815; males mean peak impact force was 1706.14 ± 557.03 N (*CV* = 32.6%), whereas female mean peak impact force was 828.18 ± 250.78 N (*CV* = 30.3%). ANOVA also showed a significant main effect for the factors hand, $F(1, 4) = 15.998$, $p = .016$, effect size = .800, stance, $F(1, 4) = 24.833$, $p = .008$, effect size = .861, and movement, $F(1, 4) = 16.400$, $p = .015$, effect size = .804. The significant main effects found indicated that in general peak force was significantly higher for the dominant hand strikes (1593.76 ± 703.45 N) compared to the non-dominant hand strikes (1042.28 ± 374.16 N), for the strikes performed with a left lead leg stance (1378.06 ± 705.48 N) compared to the strikes with a right lead leg stance (1269.96 ± 547.08 N), and for the strikes with moving stance (1448.75 ± 686.01 N) compared to the strikes with stationary stance (1201.80 ± 547.98 N). Furthermore, we found a significant Stance $\times$ Movement interaction, $F(1, 4) = 20.659$, $p = .01$, effect size = .838 (Fig. 2). Post hoc analyses indicated that the difference in peak force between strikes with left and right lead leg stances approached significance only for strikes with moving stance ($p = .063$). Furthermore, the difference in peak force between strikes with moving and stationary stances was statistically significant for strikes performed with a left lead leg stance ($p = .007$) and approached significance for the strikes performed with a right lead leg stance ($p = .074$) (Fig. 2). Thus, the stronger strike was a dominant hand on a left lead leg moving stance (1883.61 ± 899.8 N), whereas the weakest was a non-dominant hand on either a right (962.3 ± 363.89) or left lead leg (957 ± 436) stationary stance (Table 1).

The overall mean hand speed before impact was 5.54 ± 0.98 m/s. ANOVA showed a significant main effects for the factors hHand, $F(1, 4) = 8.494$, $p = .043$, effect size = .680, and movement, $F(1, 4) = 124.291$, $p < .001$, effect size = .969. The significant main effects found indicated that in general hand speed was higher for the dominant hand strikes (5.82 ± 1.08 m/s) compared to the non-dominant hand strikes (5.24 ± 0.78 m/s) and for the strikes with moving stance (5.79 ± 1.01 m/s) compared to the strikes with stationary stance (5.29 ± 0.90 m/s). Additionally, there was a significant Hand $\times$ Movement interaction, $F(1, 4) =$

15.912, $p = .016$, effect size = .799 (Fig. 3). Post hoc analyses indicated that the difference in hand speed between right and left hand strikes was only significant for strikes with moving stance ($p = .002$). Furthermore, the difference in hand speed between strikes with moving and stationary stances was only significant for strikes performed with the right hand ($p < .001$) (Fig. 2). Thus, the fastest strike was a dominant hand strike on either a left (6.53 ± 1.25 m/s) or right (5.97 ± 0.69 m/s) lead leg moving stance whereas the slowest was a non-dominant hand on either a right (5.13 ± 1.1 m/s) or left lead leg (5.22 ± 0.65 m/s) stationary stance (Table 1).

The overall mean effective mass was 1.20 ± 0.41 kg. ANOVA showed males exhibited significantly greater effective masses than females, $F(1, 4) = 13.687$, $p = .021$; effect size = .774. Males mean effective mass was 1.42 ± 0.302 kg, whereas female mean effective mass was 0.92 ± 0.32 kg. ANOVA also showed a significant main effect for factor hand, $F(1, 4) = 12.584$, $p = .024$, effect size = .759, demonstrating that effective mass was significantly higher for the dominant hand strikes (1.35 ± 0.44 kg) than for the non-dominant hand strikes (1.05 ± 0.30 kg). Additionally, effective mass values were significantly dissociated from hand speed values across all trials ($R^2 = .058$, $p = .076$; Fig. 4A). Furthermore, the product of the effective mass of impact and the hand speed before impact was significantly associated to the values of peak force ($R^2 = .853$, $p < .001$; Fig. 4B).

The overall mean accuracy was 4.56 ± 1.57 cm. ANOVA demonstrated that the mean accuracy was not significantly, $F(1, 4) = .553$, $p = .511$, effect size = .156, different between the dominant hand strikes (4.28 ± 1.73 cm) and non-dominant hand strikes (4.82 ± 1.40 cm).

4. Discussion

The aim of this paper was to investigate possible differences in dominant and non-dominant hand strikes performed by a group of experienced martial artists with different lead leg stances and stationary or moving stances. The results demonstrate the following novel findings: (1) dominant hand strikes were stronger and exhibited greater effective mass than non-dominant hand strikes; (2) strikes performed with a left lead leg moving stance were significantly stronger than strikes performed with stationary stances; (3) dominant hand strikes were faster only when strikes were performed with moving stances; (4) no significant difference in accuracy was found between the dominant and non-dominant hand strikes. Furthermore, we found that strikes performed by the dominant hand on a left lead leg moving stance (stronger condition) produced on average twice as much striking peak force than non-dominant hand strikes on either a right or left lead leg stationary stance (weaker conditions).

4.1 Differences in peak force due to handedness

Our results showed that for all types of strikes analyzed, on average, dominant hand strikes were approximately 50% stronger than non-dominant hand strikes (Table 1). The greater peak force of dominant hand strikes was caused by significant augmented hand speed values and effective mass values. On average, dominant hand strikes were approximately 10% faster and exhibited 30% greater effective mass than non-dominant hand strikes. Additionally, we found that values of hand speed and effective mass were dissociated (Fig. 4A), and that the product of the two variables was able to linearly predict approximately 85% of the variability in peak force across all trials (Fig. 4B). Thus, our results suggest that the difference in effective mass between the dominant and non-dominant arms is the main cause of the difference in peak force between the arms. The cause for the higher effective mass of the dominant arm, compared to the non-dominant arm, may be that the dominant arm has better inter-joint coordination than non-dominant arm (Hore, Watts, Tweed, & Miller, 1996; Neto & Magini, 2008; Neto, Magini, & Saba, 2007; Sainburg & Kalakanis,

2000) and/or difference in limb mass. The better performance of the dominant arm may also reflect its specificity in controlling rapid, ballistic components of movement that are dependent on planning (Sainburg & Schaefer, 2004).

4.2 Differences in peak force due to stance movement and lead leg

Our results showed that for all types of strikes analyzed, on average, strikes performed with moving stances (stepping towards the target) were approximately 22% stronger than strikes with stationary stances (Table 1). The greater peak force of strikes performed with moving stances was caused in part by significantly augmented hand speed values. On average, strikes performed with moving stances were approximately 10% faster than those with stationary stances. Effective mass was not affected by stance movement. It is possible, however, that strikes performed with moving stances were stronger also because of a greater “follow through” (Tsaousidis & Zatsiorsky, 1996). The “follow through”, or active pushing during the impact, is caused by an increase in the amount of mechanical work done during the impact by the muscles and hence can increase peak force.

Additionally, our results showed that, on average, strikes performed with a left lead leg stance were approximately 9% stronger than strikes with a right lead leg stance (Table 1). However, the difference in peak force between left and right lead leg stances was only significant for the strikes performed while stepping towards the target (Fig. 2); in fact, the left lead leg moving stance strikes were approximately 21% stronger than the right lead leg moving stance strikes. The fact that left lead stances augmented the gain in peak power resulting from stepping towards the target may indicate why most right handed martial artists prefer to strike using a left lead leg stance.

4.3 Differences in hand speed due to striking hand, stance movement, and stance lead leg

Our results showed that, on average, dominant hand strikes were approximately 11% faster than non-dominant hand strikes (Table 1). However, the difference in hand speed between dominant and non-dominant hand strikes was only significant for the strikes performed while stepping towards the target (Fig. 3); in fact, dominant hand moving stance strikes were approximately 18% faster than the non-dominant hand moving stance strikes. This result indicates the following: (1) during stationary stance strikes, differences in effective mass, and not hand speed, are responsible for the differences in performance between dominant and non-dominant hands; (2) differences in performance, in terms of movement speed, between dominant and non-dominant hands were observed only in the strikes where dynamic stability was required. Fig. 3 also shows that strikes with moving stances were faster than strikes with stationary stances only when strikes were performed with the dominant hand. This result indicates the following: (1) the reason for the non-dominant hand strikes being stronger with moving stance is probably related to “follow through” mechanisms, considering neither effective mass nor hand speed can be accounted for that; (2) stance movement is beneficial in terms of hand speed performance only for the dominant hand strikes.

4.4 Accuracy of dominant and non-dominant hand strikes

Our results showed no significant difference in accuracy between the dominant and non-dominant hand strikes. Our results contrast the right hand advantage for accuracy during rapid movements that has been previously demonstrated in several other studies (Elliot et al., 1993). This apparent contrast may be consequence of two main differences between martial arts strikes and restricted reaching movements previously studied. First, martial arts strikes constitute full body tasks that are performed at maximum speed. Second, the martial arts strikes analyzed in our study were trained for several years with the practitioners' concern in developing power, speed, and accuracy (Neto et al., 2009).

4.5 Difference related to gender

We found that males exhibited significantly greater strike force than females. The difference between the genders was caused by a significant greater effective mass for the strikes performed by the male practitioners compared to the female practitioners. However, the comparison across genders needs to be looked at with caution because of the small sample size we had in each group. Nevertheless, although it was not an specific aim of this study to investigate differences in striking related to gender, our results add to a very small literature on the differences in martial arts performance between male and female practitioners (Neto et al., 2009).

4.6 Magnitude of the effective mass values obtained

In this experiment, we found the overall mean effective mass to be 1.20 ± 0.41 kg. This value is similar to the mean value of 1.4 ± 0.7 kg obtained from punches of 10 well trained karate students (Voigt, 1989). However, the mean effective mass we found is much lower than the 2.9 ± 2 kg reported for elite amateur boxers punches (Walilko et al., 2005), and the 2.62 ± 0.3 kg reported for experienced Kung Fu practitioners palm strikes (Neto, Magini, & Saba, 2007). Differences in results are probably caused by the fact that different methods of quantifying effective mass were employed in these studies. Future studies may look deeper into why different methods of calculating effective mass can lead to significantly different results, and possibly determining what is the ideal way to quantify this variable in laboratory or sports performance settings.

5. Conclusions

In summary, the goal of our study was to investigate possible differences in dominant and non-dominant hand palm strikes performed by a group of experienced Kung Fu practitioners under different striking conditions. Our results demonstrated that dominant hand strikes are stronger than non-dominant hand strikes. Hand speed, however, was only greater for the dominant hand strikes when strikes were performed while the participants stepped towards the target. Stepping towards the target in a left lead stance was the stronger stance configuration for both dominant and non-dominant hand strikes. Additionally, we found no significant difference in accuracy between the dominant and non-dominant hand strikes. Overall, our results suggest that the dominant hand strikes are stronger because of greater effective masses and that the stronger strike for a right-handed practitioner is a right hand strike on a left lead leg moving stance.

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Research Highlights

1. Dominant hand strikes are approximately 50% stronger than non-dominant strikes.
2. Differences in effective mass are the main cause of peak force differences.
3. Dominant and non-dominant hand strikes are equally accurate.
4. Stepping towards the target augments peak force in 22%.
5. Stepping towards the target enhances hand speed for dominant strikes.

Fig. 1.

Experimental setup: The participants, standing on a variable height platform, were requested to palm strike with maximum effort a modified load cell a total of eight times. Kinetic and kinematic data was collected with: one overhead high speed camera, one lateral high speed camera, one load cell mounted as a pendulum, one protective pad, and one pressure sensor placed between the protective pad and the load cell.

Fig. 2.

Significant interaction in peak force between stance lead leg and stance movement. Difference in peak force between strikes with left and right lead leg stances approached significance only for strikes with moving stance. The difference in peak force between strikes with moving and stationary stances was statistically significant for strikes performed with a left lead leg stance and approached significance for the strikes performed with a right lead leg stance.

* $p = .007$; @ $p < .07$.

Fig. 3.

Significant interaction in hand speed between dominance and stance movement. Difference in hand speed between dominant and non-dominant hand was only significant for strikes performed while stepping towards the target; while, the difference in hand speed between strikes with moving and stationary stances was only significant for strikes performed with the dominant hand. * $p < .002$.

Fig. 4.

A: Scatter plot of hand speed versus effective mass values indicating no linear association between the two variables ($R^2 = .058$, $p = .076$). B: Scatter plot of the product of hand speed and effective mass versus peak force indicating a significant strong linear association between the variables ($R^2 = .853$, $p < .001$).

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$M \pm SD$ for the values of peak force (N), hand speed prior to impact (m/s), and effective mass of impact (Kg) for dominant and non-dominant (bold) palm strikes performed with left or right lead leg stances that were either moving towards the target or stationary.

Table 1

Dominant Non-Dominant	Peak Force (N)		Hand Speed (m/s)		Effective Mass (Kg)	
	Moving Stance	Stationary Stance	Moving Stance	Stationary Stance	Moving Stance	Stationary Stance
Left lead leg Stance	1884±900 1183±414	1461±680 957±436	6.5±1.2 5.3±0.8	5.7±0.9 5.2±0.6	1.4±0.5 1.1±0.3	1.3±0.4 1±0.4
Right lead leg Stance	1603±715 1087±321	1427±540 962±363	6±0.7 5.3±0.8	5.13±1.1 5.14±1	1.3±0.3 1.1±0.2	1.43±0.6 0.9±0.2