A Descriptive Study on the Strike Characteristics between a Heavy Bag, Focus Mitts, and Thai Pads

Biomechanics & Motion Analysis Laboratory

Tirzah Ruth D Talampas, Will W. Peveler

Allied Health Professions

Liberty University

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Abstract

The purpose of this study was to compare vGRFs during continuous strikes to three different modalities, a free-standing heavy bag, focus mitts, and Thai pads, and the punching velocities under these conditions. It was hypothesized for punches that punching velocity would be higher in punches thrown at a heavy bag, punching velocity would be faster in rear-hand punches, vGRFs would be higher in the lead leg compared to the rear leg of a punch at impact, and vGRFs would be higher in heavy bag punches compared to focus mitt punches. For kicks it was hypothesized that vGRFs of dominant and nondominant roundhouse kicks thrown at a heavy bag would be higher during all phases, dominant-leg roundhouse kicks would produce the highest vGRFs regardless of modality, and within each kick type, there would be differences in vGRFs throughout the entire movement. Fourteen trained and orthodox stance martial artists (9 male; 5 female) (Male - age: 26.00 ± 4.15 years, height: 178 ± 7.69 cm, body mass: 91.30 ± 27.60kg, body fat: 20.18 ± 12.01%, training duration: 4.94 ± 4.5yrs; Female - 23.4 ± 12.72yrs, height: 172.21 ± 6.57cm, body mass: 68.54 ± 10.77kg, body fat: 22.24 ± 7.64%, training duration: 6.4 ± 6.16yrs) ranging from recreational practitioners to competitive fighters, were tested. An AMTI force plate collected vGRFs for punches and kicks during each protocol. Ten punches, alternating between lead and rear hand straights were performed on a free-standing heavy bag and focus mitts. Ten kicks, alternating between dominant and nondominant roundhouse kicks, were performed on a free-standing heavy bag and Thai Pads. Significance was set at $p \leq .05$. Lead had punches for both modalities were significantly faster than rear hand punches ($p < .001$) and lead hand punches on the focus mitts were faster than on the heavy bag ($p = .039$). No significant differences were found between modalities for vGRFs, but lead-leg vGRFs were greater than rear-leg vGRFs for heavy bag, lead-hand ($p = .02$) and rear-hand ($p<.001$) punches and focus mitt lead-hand ($p<.001$) and rear-hand ($p <.001$) punches. For kicks, between modalities, phase 2 roundhouse kicks on the heavy bag produced greater vGRF ($p = .017$), and for switch kicks, phase 1b on the Thai Pads produced greater vGRFs. Comparing kick types on the heavy bag, switch kicks produced greater vGRFs at phase 1a ($p = .005$), but roundhouse kicks produced greater vGRFs at phase 2 ($p = .017$). On the Thai pads, switch kicks produced greater vGRFs at phase 1a ($p = .002$), but less vGRFs than roundhouse kicks at phase 1b ($p = .018$). Between phases of a kick, significant differences were found between every phase except between phase 1a and 3 for heavy bag roundhouse kicks and Thai pad roundhouse and switch kicks, between phase 2 and 3 for heavy bag and Thai pad switch kicks, and between phase 1a and 2 for Thai pad switch kicks. While results are mixed, they suggest several new areas of study for future research and highlight underlying patterns in continuous kicking and punching. Strength coaches may want to focus on kinetic linking to better utilize vGRFs and to improve kinetic linking and coordination between dominant and nondominant kicks.

Key words: martial arts, punching, kicking, ground reaction forces, velocity, force plate

INTRODUCTION

Vertical ground reaction forces (vGRFs) are commonly studied topics for basic movement patterns such as walking, running, and jumping. In martial arts punching and kicking can be considered basic attack and defense movement patterns that have been practiced for thousands of years across many cultures(32). However, only in recent history have styles such as taekwondo, karate, and judo gained worldwide popularity(24). With the even more recent rise in popularity of other combat striking sports such as kickboxing, Muay Thai, and MMA(3,32), research is now largely focusing on the specific strength and conditioning needs of these various disciplines(16,26,36,37,38). Researchers note that combat fighters focus largely on developing their punching and kicking techniques through various drills to allow them to use their strikes to create strategic openings, score points, or knock an opponent out during a match(5,25,35). To meet these goals, training focuses on improving the speed, power and force production of punches and kicks, and current research uses this concept to conduct sports needs analysis research(4,19,20,22), but very little research has focused on the GRFs that are the groundwork of these techniques.

It is well documented that improvements in strength and conditioning lead to improved force-velocity curves, power output (21), and kinetic linking in throwing and kicking sports(10). However, researchers are learning that martial arts have different training needs compared to similar high-intensity endurance sports like basketball, baseball, or football(13). Current martial arts research has focused largely on determining output variables such as punching speed, force, and power in order to develop better strength and conditioning programs for martial artists. These studies show that increased anaerobic capacity, upper- and lower-body strength(14,20), and methods to facilitate gym to sport-specific movement transfer(36,38) lead to better punching and kicking performance. While understanding these variables is important, direct measures of punching and kicking vGRFs and vGRF patterns that arise from these movements is still limited, even though research has shown high correlation between GRF-time data and peak power, peak force, and peak velocity(15).

Lenetsky et al., have produced various studies aimed at defining the phases of a punch (17), and the major contributors to punch force(18). One of the contributors highlighted is leg drive off the ground; however, with limited references available to them, Lenetsky, et al. extrapolate the importance and function of the legs and their contribution to punches from similar movements, but ultimately conclude that too little is known(18). At present, coaches must rely on training methods that train all loaded movements in all directions to help athletes increase power output. Of studies that do look at ground reaction forces and punching power, many prioritize single punches in order to determine key events(17) or to determine how to effectively utilize strength and conditioning principles to improve punching kinetics(13,18,22). One study demonstrated that punching speed is significantly lower in punches in combination compared to maximal effort(29). Other recent studies also point out that many lab studies do not take into account the competition dynamic of the sport, and that many of the power output values reported are significantly higher in the lab than those in competition(4,28). The need to be strategic and not over commit on punches largely affects these values, but how do these values compare in a continuous setting—such as training—where emphasis is placed on technique, conditioning, and power output. Lastly, of these studies that have measured output variables in punches, several studies utilized a free-standing heavy bag (9,14,17,18,20,29) on studied punching in competition

(28), but none studied punches thrown at focus mitts. The modalities used in these studies were secondary to the study, but no one has compared the differences, if any, in training modalities for martial artists.

Although there are studies that analyze punching GRFs in order to break down the phases of various punches, this has largely been understudied for kicks. Researchers have noted that kicks require effective kinetic linking of the lower body(12, 31) and that the GRFs produced modulate important kicking output variables such as kick velocity(23). While other kicking related vGRF studies are performed for other kicking sports, such as soccer, rugby, and football, these studies can only provide general understanding of loading mechanics(1), as these movements are inherently different. Of the recent studies that have studied martial arts kicks, most largely focus on taekwondo (4, 6,11,23,34,39) and karate(2, 30), and sparsely on kickboxing and Muay Thai (7,26,31). Two articles did directly compare roundhouse kicks between these three martial arts, and found that, even though there are several kinematic differences between these disciplines, the underlying pattern is similar(8,12). These studies, like punches, typically look at single effort strikes in isolation(7,31,34), without considering the effect performing multiple strike in a row have on GRF values. One study noted this difference and looked at the effects that repeated kick action has on karate athletes and focused on measuring kinematic variables and muscle activation patterns (30). While GRFs were not measured they did note modified kicking technique compared to technically proper kicking techniques. In competition, kicks are not often thrown in isolation, but rather as a part of a combination to effectively set up other strikes or the kick itself. In training, kicks are often practiced with free-standing heavy bags or pad drills, but current research has primarily studied vGRF in relation to kicks thrown at free standing heavy bags (6,11,12,30). The potential differences between these two modalities, has not been studied.

To our knowledge, there is currently no published research study examining strike characteristics during training. To continue bridging the gap between lab and competition values, understanding punching speed and the vGRF characteristics of punches and kicks in a training context is vital, especially as it pertains to using sport-specific modalities such as a free-standing heavy bag, focus mitts, and Thai pads. Therefore, the purpose of this study was to compare vGRFs during continuous strikes to three different modalities, a free-standing heavy bag, focus mitts, and Thai pads, and the punching velocities under these conditions. For punches the hypothesis was fourfold: 1) punching velocity would be higher in punches thrown at a heavy bag, 2) punching velocity would be faster in rear-hand punches, 3) vGRFs would be higher in the lead leg compared to the rear leg of a punch at impact, and 4) vGRFs would be higher in heavy bag punches compared to focus mitt punches. For kicks the hypothesis was also threefold: 1) vGRFs of dominant and nondominant roundhouse kicks thrown at a heavy bag would be higher during all phases, 2) dominant-leg roundhouse kicks would produce the highest vGRFs regardless of modality 3) within each kick type, there would be differences in vGRFs throughout the entire movement.

METHODS

Experimental Approach to the Problem

A repeated-measures, within-subjects design was used to compare the punching velocity, punching vGRFs of the lead and rear leg, and kicking vGRFs both within and between the heavy bag, focus mitt, and Thai pad training modalities. Kicking velocity was not measured. Because very few studies have looked at continuous punches and kicks, which are common parts of a training regimen in martial arts training, this study focused on the differences between straight lead hand and rear-hand punches and differences in dominant-leg roundhouse kicks and nondominant-leg roundhouse kicks, also called switch kicks. These strikes were chosen because they are universal techniques across different combat martial arts and have movement patterns that have been well defined (17,12).

For this study, peak vGRFs for punches were measured at impact, and this was defined as initial contact with the heavy bag or focus mitts. For kicks, four phases were defined, with the first phase being split in two, in order to understand the vGRFs throughout the duration of the kick. These definitions were based off of a different study(12) and are in Table 1.

To understand the contribution of each during each type of strike, the participants were asked to have each leg on individual force plates (32). In order to ensure that participants were striking as they would in practice, each participant was instructed to strike the heavy bag as they would when training. For focus mitt or Thai pad strikes, participants were told to only strike when the punch or kick was cued. To measure the vGRFs of each leg, an AMTI in-ground force plate was used. These force plates have been used in previous studies to determine movement phases in a variety of athletic movements, such as running, kicking, and punching (1, 17, 18, 29)

Subjects

Fourteen trained martial arts practitioners (male = 9, female = 5) ranging from recreational practitioners to competitive fighters volunteered for participation in this study. Descriptive statistics are presented in Table 2 and are represented as means and standard deviations. Eligible participants reported to the biomechanics laboratory well rested and hydrated. In addition, participants were required to bring their own personal training gear (gloves, wraps, and clothing) for testing. The inclusion criteria were as follows: 1) participation in at least one combat sport that utilizes punches and kicks, 2) at least six months of training in a combat sport(s), 3) age was between 18 and 65 years old. Approval for this study was obtained through the local institutional review board and all subjects completed an informed consent prior to participation.

Procedures

Each subject performed two punching protocols and two kicking protocols described below. Prior to participant arrival at the lab, four AMTI in-ground force plates (AMTI, Watertown, MA) were calibrated according to manufacture's instructions. A Logitech C922 Pro Stream Webcam (60 Hz) (Logitech, Inc, Newark, CA USA) was used to record visual data in the sagittal plane. Lastly, a Wavemaster XXL (Century, Oklahoma City, OK USA) freestanding heavy bag was placed approximately six inches away from the edge of the force plates. This placement was used to minimize artifacts during force plate recordings and to be close enough so participants would not feel as if they were overreaching to strike the heavy bag. Upon arrival, participants verbally confirmed their martial arts discipline, training duration and hand dominance. Body composition was then measured through bioelectrical impedance analysis (InBody 770, Cerritos, CA USA).

Familiarization

After descriptive data was collected, participants were shown the in-ground force plates. In order for participants to understand what was expected of them, the researcher performed a visual demonstration and also provided verbal instructions. It was stressed to each participant that only one foot be in contact with each force plate during the collection trials. Participants were then allowed to throw any combination of punches and kicks at the heavy bag, although they were informed to primarily practice straight punches and roundhouse kicks, in order to familiarize themselves with the force plates and to ensure their stance was normal. Participants were also given time to practice with the focus mitts and Thai pads while on the force plates and to get used to the researcher's cues.

Warm-Up

Once the participants felt comfortable on the force plates, they were asked to put on hand wraps. The hand wraps protected the participants hands and wrists while also holding the Hykso HWS-02 Punch Tracking Wearable Sensor (Hykso Inc., Costa Mesa, CA USA) in place. Trackers were used to only measure punching velocity; kicking velocity was not measured. The Hykso punch trackers recorded the number of strikes thrown, punch type, and velocity of each punch and these records were tracked on the corresponding Hykso app for iOS. Once the trackers were placed in the wraps according to manufacturer's instructions, they were checked one more time for placement and to ensure that they would not interfere with the participant's punching ability. The participant was then given five minutes to warm up.

Prior to each punch and kick trial, participants were asked to step off of the force plates for re-calibration. During the trials, the participant's feet were closely monitored to ensure proper foot placement.

Heavy Bag Protocol

Participants were instructed to perform a total of ten alternating straight punches (five with the lead hand, five with the rear hand). Aside from alternating between punches, the speed and power of the punches were self-determined as each participant was told to primarily focus on striking the heavy bag as they would when heavy bag training. After the ten punches were thrown, the participant was then instructed to perform a total of ten roundhouse kicks – five dominant and five nondominant – alternating sides. The speed and power were self-determined.

Focus Mitt and Thai Pad Protocol

An experienced pad holder held for all focus mitt and Thai pad protocols. Like the corresponding heavy bag trial, a total of ten alternating straight punches were thrown. Punches were cued as jab, cross, or jab-cross, or one, two, one-two, depending on which system the fighter preferred. Jab/one referred to the lead hand straight, cross/two referred to the rear hand straight and jab-cross/one-two referred to the lead hand straight followed immediately by the rear hand straight. The cued calling still alternated between straight punches but allowed the participants to react as if they were training.

Like the corresponding heavy bag trial, a total of ten, alternating dominant and nondominant roundhouse kicks were performed. Kicks to the Thai pad were initiated by the participant when the pad holder held the pads up and verbally cued the kick by saying “single.”

Statistical Analyses

Mean values for punching velocity in lead and rear-hand punches on heavy bag and focus mitts, vGRFs of lead and real legs for each punch type on each modality, and vGRFs of each kicking phase for each kick type on heavy bag and Thai pads (mean ± SD) were measured using a repeated measures ANOVA. Two-tailed significance was accepted at $p \leq 0.05$ and all statistics were performed with IBM SPSS Statistics Subscription (IBM Corporation, USA).

RESULTS

Punching Velocity

Complete results for punching velocity are given in Table 3. Significant differences were found between punch types in both heavy bag and focus mitt trials; heavy bag rear-hand punches were significantly faster than heavy bag lead-hand punches ($p < .001$) and focus mitt rear-hand punches were significantly faster than focus mitt lead-hand punches ($p < .001$). Between modalities, focus mitt lead-hand punches were significantly faster than heavy bag lead-hand punches ($p = .039$), but significantly slower than heavy bag rear-hand punches ($p = .006$). Focus mitt rear-hand punches were also significantly faster than heavy bag lead-hand punches ($p < .001$), but not significantly different than heavy bag rear-hand punches ($p = .629$).

Punching vGRFs

Results for punching vGRFs are given as direct measurements in Table 4 and are normalized by participant bodyweight (kg) in Table 5. At impact, vGRFs of the lead leg were significantly greater than rear-leg vGRFs for heavy bag lead hand ($p = .02$), heavy bag rear hand ($p < .001$), focus mitt lead hand (p = < .001) , and focus mitt rear hand ($p < .001$) punches. Significant differences between rear-leg vGRFs at impact were also found between heavy bag ($p = .047$) and focus mitt ($p = .005$) lead hand and rear-hand punches. For lead-hand punches, no significant differences were found between modalities for lead-leg vGRFs ($p = .203$) or rear-leg vGRFs ($p = .403$). For rear-hand punches, no differences were found between modalities. Normalized results did not reveal any new significant differences.

Kicking vGRFs – Between Modalities

Results for kicking vGRFs between modalities are given as direct measurements in Table 6 and are normalized by participant bodyweight (kg) in Table 7. When comparing the phases of a roundhouse between modalities, there were no significant differences except at phase 2 ($p = .017$). When comparing the phases of a switch kick between modalities significance was found only at phase 1b ($p = .036$). Normalized results did not reveal any new significant differences.

Kicking vGRFs – Between Roundhouse and Switch Kicks

Complete results for kicking vGRFs between roundhouse kicks and switch kicks are found as direct measurements in Table 8 and are normalized by participant bodyweight (kg) in Table 9. When comparing the two kicks on the heavy bag, switch kicks produced significantly greater vGRFs at phase 1a ($p = .005$), but significantly less vGRFs at phase 2 ($p = .017$). On the Thai pads, switch kick vGRFs were significantly higher during phase 1a (p = .002) and phase 1b (p = .018) compared to roundhouse kicks. Normalized data revealed no new significant differences.

Kicking vGRFs – Between Phases

Significant differences for kicking vGRFs between phases of each kick can be found in Tables 10. Starting with the heavy bag roundhouse kicks, significant differences were found between all phases except phases 1a and 3. Between phases of the heavy bag switch kicks, differences were found between all phases except between phases 2 and 3. For the Thai pad roundhouse kicks, differences were found between all phases except between phase 1a and 3. Lastly, for Thai pad switch kicks, there were significant differences between every phase except between phase 1a and 2, phase 1a and 3, and between phase 2 and 3. Normalized data revealed no new significant differences.

DISCUSSION

The purpose of this study was to compare vGRFs during continuous strikes between three different modalities, a free-standing heavy bag, focus mitts, and Thai pads, as well as punching velocities under these conditions. Looking at the results, it appears that modality has less influence on differences in vGRFs in lead and rear-hand straight punches and dominant and nondominant roundhouse kicks; however, there appear to be significant differences in punching velocity between modality and punch type, between lead and rear leg vGRFs of punches at impact, and in the initial phases of dominant and nondominant kicks. Hypotheses for this study were not fully supported, but rather mixed in regard to the results.

Punching

Lead hand strikes were significantly faster on the focus mitts compared to heavy bag. The faster speeds in focus mitt punches may have been due to participants simulating keeping an opponent out of reach, whereas heavy bag strikes may have been thrown to better set-up the rear hand punch; however, little is known about the effect modality has on outcome variables. Further research is required to see if this difference holds across all levels of experience and to see if different training modalities elicit different outcome responses.

Significant differences in punching velocity between lead and rear-hand straight punches is supported by previous research(29,33), as the lead-hand strike is usually a distance-managing strike that is performed often and at slower speeds (33), whereas the rear-hand strike is a power strike. Interestingly, the punching velocities recorded in this study were far lower compared to similar studies that looked at punching velocity (29). These differences may, in part, be due to the intent of the punch and level of experience. In similar studies, participants were usually amateur or professional level athletes (29,33), whereas this study recruited from a general population of martial arts practitioners ranging from recreational practitioners to competitive fighters. Also, participants in this study were instructed to perform lead and rear-hand strikes in succession, as well as with the cue to perform as they would during training. Studies have shown slower speeds in punches when performed in combination(Piorkowski), but no studies to date have looked at how participants performed training-like punches. In regard to this study, some participants may have thrown the punches to practice technique and form, which would lead to slower strikes, while others may have practiced to elicit power strikes. Overall, future studies should explore how outcome variables are affected by cueing, as different cues may lead to striking with different intentions.

In regard to punching vGRFs, the third hypothesis was supported, as significantly higher lead leg vGRFs were found across all punch types; however, no differences in vGRFs were found between modalities. The difference between rear and lead-leg vGRFs has been documented in previous studies (17,33), as this represents a key part of moving energy from proximal to distal aspects of the movement. Surprisingly, heavy bag punches did not elicit higher vGRFs despite the expectation that participants would attempt to power punch the heavy bag, creating more driving force off the ground. Although vGRFs did not differ between punches or between modalities, these results indicate that other aspects of the motion contribute to outcome variables as well. While driving off the rear leg (17,18) and stabilizing (29) with the lead leg are important parts of the punch, kinetic linking up the chain may play a larger role in producing more powerful punches at faster speeds. A study noted that mean punching force in a boxing match ranged from 935.1 ± 395.2 N in a junior light-heavyweight boxer to 1113.3 ± 569.4 N in a heavyweight boxer (28). The vGRFs at impact are lower than these values, indicating that forces may be conserved throughout the movement and into output, and the resulting higher force is due to the rotational nature of the punch; however, further studies are needed to determine the exact relationship between these variables.

Kicking

In the context of the kicks' vGRFs, significant differences were only found between modalities and between kick type during the initial aspects of the movement. For roundhouse kicks between modalities, greater vGRFs were found for the heavy bag at phase 2, as the kicking leg left the ground. This difference may be due to participants wanting to emphasize a more exaggerated step-out prior to the kick on the heavy bag compared to Thai pads. These results may also indicate differences in adjusting to pad-holder height and surface area compared to striking a large target area. In switch kicks, vGRFs were greater on Thai pads at phase 1b when weight shift had not yet occurred. These differences may be due to participants internally knowing when to start the kick, as opposed to responding to a cue. While no other differences occurred between modalities, studies looking at the role of the stance leg indicate that after initiation of the kick, it's primary focus is to act as a pivot point for the rest of the kick (6).

In looking at the difference between rear kicks and switch kicks on each modality, differences were once again only found at the initiation of each kick. On the heavy bag, roundhouse kicks produced greater vGRFs during phase 2, even though switch kicks produced greater push-off force at phase 1a. During a switch kick, it is common to jump in order to switch stances and initiate the kick, which would account for the greater initial push-off at phase 1a; however, differences in coordination of the dominant and nondominant legs may lead to more efficient weight transfer and acceptance in the stance leg of the dominant-leg kick compared to the nondominant-leg kick. While no differences were found throughout the rest of the movement, experience (7)—as well as other variables—may affect how participants compensate for differences in leg dominance (27).

When looking at each kick and differences in phases, significant differences were found between almost every phase except at a few specific points. In the roundhouse kick, for both modalities, no differences in phase 1a and phase 3 were observed. A similar pattern was also found in the switch kicks on the heavy bag. It is interesting to note that forces did significantly peak at phase 2 between these two phases, indicating that at toe-off large vGRFs were generated but not maintained through phase 3. One might expect higher vGRFs at impact compared to push-off; however, no difference at this point may indicate proper pivot and rotation of the stance leg for effective hip turnover and efficient force transfer up the kinetic chain (6,39). In switch kicks on the Thai pads, no difference was found between phase 1a and 2, phase 1a and 3, or phase 2 and 3. Because the vGRFs stayed largely the same across these phases, these result indicates that nondominant leg kicks—especially on a Thai pad—may be the least efficient at energy transfer up the kinetic chain. Further study on this topic may elucidate the exact energy transfer pattern of forces from the ground to kick impact, and this should be done on different kick types and modalities.

Different vGRF kicking patterns may illustrate the differences between kick phases and kick type. Participants of this study demonstrated the various kicking phases as defined in previous studies (12), and the force plates revealed at least two different vGRF stance patterns. The first is a two-peak splitting pattern (see Figure 1) where the stance leg shows vGRF peaks at toe-off and just after impact during recoil. In the second pattern (see Figure 2), the stance leg shows three peaks at toe-off, impact, and just after impact during recoil. The presence of the middle peak at impact may have implications for output variable outcomes and may be an interesting point of study for future research. Previous research on taekwondo athletes indicate that ankle position may play a large role in impact force for roundhouse kicks(34), and these peak patterns, in conjunction with the differences found between phases, may play a role in understanding proper kicking technique.

Conclusion

This study's hypotheses were not fully supported, but results have generated several areas of possible future research. One area that should be taken into consideration is the intent a person has when performing an action in a training context. Intent during practice is an important aspect of training and has not been well document in trained fighters. Understanding differences in a fighter's mindset when performing solo or partner training is another key point, as there may be potential differences in outcomes. While this study largely focused on punching velocity and vGRFs of punching and kicking across different modalities, it highlights the need to further understand vGRF in relation to outcome variables and how psychological aspects of the sport alter intent and motivation when training on different modalities.

PRACTICAL APPLICATION

While no differences were found between modalities, this study highlights that stationary footwork is transferable across modalities in trained individuals. Using an experienced pad holder may be able to elicit similar results compared to heavy bag training. Understanding how an athlete trains on different modalities is especially helpful for coaches to better program for their martial artists.

For kicks, coaches may want to focus on the initiation of the roundhouse and switch kicks, as differences were found at push-off of the kicking leg and weight transfer onto the stance leg.

While outcome variables were not measured directly for the kick, understanding how martial artists ground themselves throughout the movement has important implications for training and competition. Given the two-peak and three-peak patterns found in this study, coaches should understand when and how these arise in order to cue correct kicking technique in their martial artists. Strength coaches may also want to focus on kinetic linking to better utilize vGRFs and to improve kinetic linking and coordination between dominant and nondominant kicks.

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Table 1. Kicking phase definitions

Phase	***Definition***
Phase 1a – Push-Off	Peak GRF of kicking leg prior to weight shift onto stance leg
Phase 1b	Stance leg during peak GRF of rear leg.
Phase 2 – Toe-Off	GRF of stance leg when kicking leg loses contact with the force plate
Phase 3 - Impact	Peak GRF of stance leg while kicking leg is in contact with the heavy bag or Thai Pad
Phase 4 - Touchdown	GRF of stance leg when kicking leg makes contact with the force plate

Table 2. Participant descriptive data means ± standard deviations

Gender	***Age (yrs)***	***Height (cm)***	***Weight (kg)***	***Body Fat (%)***	***Hand Dominance***	***Training Duration (yrs)***	***Weekly Volume (days/week)***
Male (n = 9)	26.00 ±4.15	178.00 ±7.69	91.30 ±27.60	20.18 ±12.01	R = 9	4.94 ±4.50	2.22 ±1.48
Female (n = 5)	23.40 ±12.72	172.2 ±6.57	68.54 ±10.77	22.24 ±7.64	R = 5	6.40 ±6.16	2.60 ±1.34

Table 3. Punching velocity means ± standard deviations and p-values

Hand	***Heavy Bag (m/s)***	***Focus Mitts (m/s)***	***p-value***
Lead Hand	3.32 ± .82	3.68 ± .71	**p = .039**
Rear Hand	4.56 ± 1.14	4.46 ± .86	p = .629
p-value	**p < .001**	**p < .001**	

Table 4: Punching vGRFs means ± standard deviations and p-values

Hand Leg		***Modality***		***Significance***
Table 4		Heavy Bag (N)	Focus Mitt (N)	
Lead-hand punch	Lead Leg	629.66 ± 292.90	643.89 ± 227.75	p = .872
	Rear Leg	346.226 ± 200.39	281.02 ± 190.30	p = .403
Significance	**-**	**p = .02**	**p < .001**	**-**
Rear-hand punch	Lead Leg	733.45 ± 320.97	712.14 ± 323.31	p = .823
	Rear Leg	241.45 ± 86.13	176.93 ± 133.15	p = .103
Significance	**-**	**p < .001**	**p < .001**	

Table 5. Normalized punching vGRFs means ± standard deviations and p-values

Hand	***Leg***	***Modality***		***Significance***
		Heavy Bag (N/kg)	Focus Mitt (N/kg)	
Lead-hand punch	Lead Leg	7.51 ± 2.86	7.75 ± 1.48	p = .820
	Rear Leg	4.25 ± 2.47	3.37 ± 2.10	p = .369
Significance	**-**	**p = .030**	**p < .001**	**-**
Rear-hand punch	Lead Leg	8.74 ± 3.06	8.45 ± 2.36	p = .808
	Rear Leg	2.98 ± 1.10	2.20 ± 1.66	p = .108
Significance	**-**	**p < .001**	**p < .001**	

Table 6. Kicking vGRF types between modalities means ± standard deviations and p-values

Kick Type	***Phase***	***Modality***		***Significance***
		Heavy Bag (N)	Thai Pad (N)	
Roundhouse Kick	Phase 1a	973.80 ± 298.67	941.71 ± 303.18	p = .203
	Phase 1b	185.50 ± 165.89	223.19 ± 186.84	p = .501
	Phase 2	1167.30 ± 289.11	1093.19 ± 313.24	p = .017
	Phase 3	994.01 ± 345.99	997.04 ± 366.89	p = .955
	Phase 4	744.24 ± 281.33	746.04 ± 234.23	p = .959
Switch Kick	Phase 1a	1318.85 ± 400.62	1209.67 ± 368.37	p = .070
	Phase 1b	188.86 ± 212.91	377.25 ±324.42	p = .036
	Phase 2	1055.88 ± 303.84	1158.12 ± 436.06	p = .354
	Phase 3	1062.40 ± 447.15	1030.25 ± 416.94	P = .339
	Phase 4	780.49 ± 338.06	735.41 ± 245.24	p = .428

Table 7. Normalized kicking vGRF types between modalities means ± standard deviations and p-values

Kick Type	***Phase***	***Modality***		***Significance***
		Heavy Bag (N/kg)	Thai Pad (N/kg)	
Roundhouse Kick	Phase 1a	11.90 ± 2.69	11.46 ± 2.71	p = .152
	Phase 1b	2.44 ± 2.15	2.82 ± 2.36	p = .608
	Phase 2	14.22 ± 1.79	13.18 ± .99	**p = .010**
	Phase 3	8.85 ± 1.70	11.89 ± 1.89	p = .955
	Phase 4	11.46 ± 2.71	8.95 ± .76	p = .805
Switch Kick	Phase 1a	16.27 ± 4.58	14.94 ± 4.39	p = .051
	Phase 1b	2.48 ± 2.73	4.67 ± 3.54	**p = .025**
	Phase 2	12.80 ± 2.05	14.17 ± 5.33	p = .393
	Phase 3	12.75 ± 3.99	12.33 ± 3.34	P = .348
	Phase 4	9.28 ± 2.16	8.78 ± .73	p = .365

Table 8. Kicking vGRF between types means ± standard deviations and p-values

Modality	***Phase***	***Kick Type***		***Significance***
		Rear Kick (N)	Switch Kick (N)	
	Phase 1a	973.80 ± 298.67	1318.85 ± 400.62	**p = .005**
	Phase 1b	185.50 ± 165.89	188.86 ± 212.91	p = .902
Heavy Bag	Phase 2	1167.30 ± 289.11	1055.88 ± 303.84	**p = .017**
	Phase 3	994.01 ± 345.99	1062.40 ± 447.15	p = .278
	Phase 4	744.24 ± 281.33	780.49 ± 338.06	p = .271
	Phase 1a	941.71 ± 303.18	1209.67 ± 368.37	**p = .002**
	Phase 1b	223.19 ± 186.84	377.25 ±324.42	**p = .018**
Thai Pad	Phase 2	1093.19 ± 313.24	1158.12 ± 436.06	p = .544
	Phase 3	997.04 ± 366.89	1030.25 ± 416.94	P = .497
	Phase 4	746.04 ± 234.23	735.41 ± 245.24	p = .646

Table 9. Normalized kicking vGRF between types means ± standard deviations and p-values

Modality	***Phase***	***Kick Type***		***Significance***
		Roundhouse (N/kg)	Switch Kick (N/kg)	
	Phase 1a	11.90 ± 2.69	16.27 ± 4.58	**p = .005**
	Phase 1b	2.44 ± 2.15	2.48 ± 2.73	p = .913
Heavy Bag	Phase 2	14.22 ± 1.79	12.80 ± 2.05	**p = .015**
	Phase 3	8.85 ± 1.70	12.75 ± 3.99	p = .191
	Phase 4	11.46 ± 2.71	9.28 ± 2.16	p = .260
	Phase 1a	11.46 ± 2.71	14.94 ± 4.39	**p = .004**
	Phase 1b	2.82 ± 2.36	4.67 ± 3.54	**p = .011**
Thai Pad	Phase 2	13.18 ± .99	14.17 ± 5.33	p = .516
	Phase 3	11.89 ± 1.89	12.33 ± 3.34	P = .472
	Phase 4	8.95 ± .76	8.78 ± .73	p = .541

Table 10. vGRFs between phases of a kick p-values

Phases	***Modality – Kick Type***				
	Heavy Bag - Roundhouse Kicks				
	Phase 1a	Phase 1b	Phase 2	Phase 3	Phase 4
Phase 1a	-	**p < .001**	**p = .025**	p = .801	**p < .001**
Phase 1b	-	-	**p < .001**	**p < .001**	**p < .001**
Phase 2	-	-	-	**p = .008**	**p < .001**
Phase 3	-	-	-	-	**p < .001**
Phase 4	-	-	-	-	-
	Heavy Bag - Switch Kicks				
	Phase 1a	Phase 1b	Phase 2	Phase 3	Phase 4
Phase 1a	-	**p < .001**	**p = .036**	**p = .025**	**p < .001**
Phase 1b	-	-	**p < .001**	**p < .001**	**p < .001**
Phase 2	-	-	-	p = .938	**p = .008**
Phase 3	-	-	-	-	**p = .036**
Phase 4	-	-	-	-	-
	Thai Pad – Roundhouse				
	Phase 1a	Phase 1b	Phase 2	Phase 3	Phase 4
Phase 1a	-	**p < .001**	**p = .039**	p = .480	**p = .003**
Phase 1b	-	-	**p < .001**	**p < .001**	**p < .001**
Phase 2	-	-	-	**p = .033**	**p < .001**
Phase 3	-	-	-	-	**p < .001**
Phase 4	-	-	-	-	-
	Thai Pad - Switch Kicks				
	Phase 1a	Phase 1b	Phase 2	Phase 3	Phase 4
Phase 1a	-	**p < .001**	p = .669	**p = .119**	**p < .001**
Phase 1b	-	-	**p < .001**	**p < .001**	**p = .005**
Phase 2	-	-	-	p = .318	**p < .001**
Phase 3	-	-	-	-	**p = .003**
Phase 4	-	-	-	-	-

Figure 1. Three peak splitting pattern for rear kick

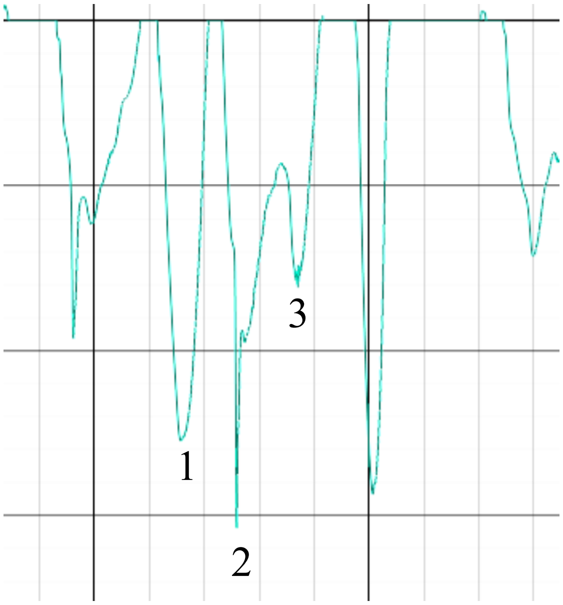
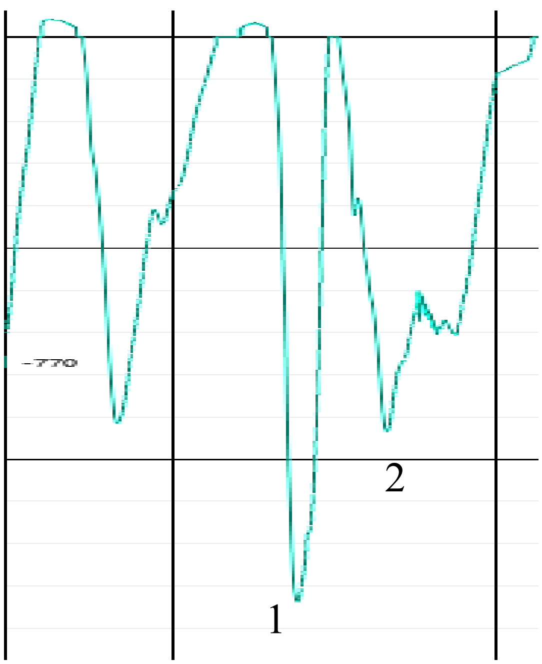


Figure 2. Two peak splitting pattern for rear kick



REFERENCES

1. Ball, K. Loading and performance of the support leg in kicking. *Journal of Science and Medicine in Sport* 16: 455–459, 2013.,
2. Beránek, V, Votápek, P, Stastny, P. (2020). Force and velocity of impact during upper limb strikes in combat sports: A systematic review and meta-analysis. *Sports Biomechanics:* 1-19, 2020.
3. Bishop, SH, La Bounty, P, Devlin, M. Mixed martial arts: A comprehensive review. J Sport Human Perf 1: 28-42, 2013.
4. Buśko, K, Nikolaidis, PT. Biomechanical characteristics of Taekwondo athletes: kicks and punches vs. laboratory tests. *Biomedical Human Kinetics 10*: 81-88, 2018.
5. Chaabène, H, Hachana, Y, Franchini, E, Mkaouer, B, Chamari, K. Physical and physiological profile of elite karate athletes. *Sports Medicine 42*: 829-843, 2012.
6. Cheng, KB, Wang, Y-H, Kuo, S-Y, Wang, K-M, Huang, Y-C . Perform kicking with or without jumping: joint coordination and kinetic differences between Taekwondo back kicks and jumping back kicks. *Journal of Sports Sciences 33:* 1614–1621, 2015.
7. Chinnasee, C, Mohamad, NI, Nadzalan, AM, et al. Lower limb kinematics analysis during roundhouse kick among novices in Muay Thai. *Journal of Fundamental and Applied Sciences 9* 100, 2018.
8. Diniz, R, Del Vecchio, FB, Schaun, GZ, et al. Kinematic Comparison of the Roundhouse Kick Between Taekwondo, Karate, and Muay Thai. *Journal of Strength and Conditioning Research 35:* 198–204, 2021.
9. Stanley, E, Thomson, E, Smith, G, Lamb, KL. An analysis of the three-dimensional kinetics and kinematics of maximal effort punches among amateur boxers. *International Journal of Performance Analysis in Sport* 18: 835–854, 2018.
10. Ellenbecker, TS, Aoki, R. Step by step guide to understanding the kinetic chain concept in the overhead athlete. *Current reviews in musculoskeletal medicine 13*: 155–163, 2020.
11. Estevan, I, Freedman SJ, Jandacka, D, & Falco, C. Segment coupling and coordination variability analyses of the roundhouse kick in taekwondo relative to the initial stance position. *Journal of Sports Sciences 34:*1766–1773, 2016.
12. Gavagan, CJ. Sayers, MG. A biomechanical analysis of the roundhouse kicking technique of expert practitioners: A comparison between the martial arts disciplines of Muay Thai, Karate, and Taekwondo. *PLOS ONE*, *12*: 2017.
13. Gochioco, M, Brown, L, Coburn, J, et al. A comparison of the physiological profiles of mixed martial artists and football, basketball, and baseball players. *Journal of Strength and Conditioning Research 25*: 2011.
14. Guidetti, L, Musulin, A, Baldari, C. Physiological factors in middleweight boxing performance. *Journal of Sports Medicine and Physical Fitness 42*: 2002.
15. Hori, N, Newton, RU, Kawamori, N, et al. Reliability of performance measurements derived from ground reaction force data during countermovement jump and the influence of sampling frequency. *Journal of Strength and Conditioning Research*, *23*(3), 874–882, 2009.
16. James, LP, Haff, GG, Kelly, VG, Beckman, EM. Towards a determination of the physiological characteristics distinguishing successful mixed martial arts athletes: a systematic review of combat sport literature. *Sports Medicine 46*:1525-1551, 2016.
17. Lenetsky, S, Brughelli, M, Nates, RJ, et al. Defining the phases of boxing punches. *Journal of Strength and Conditioning Research 34*: 1040-1051, 2020.

18. Lenetsky, S, Harris, N, Brughelli, M. Assessment and contributors of punching forces in combat sports athletes. *Strength and Conditioning Journal 35*: 1-7, 2013. Loturco, I., Artioli, G. G., Kobal, R., Gil, S., & Franchini, E. (2014). Predicting Punching Acceleration From Selected Strength and Power Variables in Elite Karate Athletes. *Journal of Strength and Conditioning Research*, *28*(7), 1826-1832.
19. Loturco, I, Artioli, GG, Kobal, R, Gil, S, Franchini, E.Predicting Punching Acceleration from selected strength and power variables in elite karate athletes. *Journal of Strength and Conditioning Research 28:* 1826-1832, 2014.
20. Marshall, J, Bishop, C. Turner, A, Haff, GG. Optimal training sequences to develop lower body force, velocity, power, and jump height: a systematic review with meta-analysis. *Sports Medicine*: 2021
21. Monteiro, L. Assessment and contributions of grappling and punching forces in combat sports athletes: implications for the development of strength and conditioning. *Revista De Artes Marciales Asiáticas 11:* 14, 2016.
22. Moreira, PV, Paula, LV, Veloso, A. Segmental kick velocity is correlated with kick specific and nonspecific strength performance in a proximodistal sequence. *Archives of Budo 11*: 271-283, 2015.
23. Origua Rios, S, Marks, J, Estevan, I, Barnett, LM. Health benefits of hard martial arts in adults: A systematic review. *Journal of Sports Sciences 36*: 1614–1622, 2017.
24. Ouergui, I, Davis, P, Houcine, N, et al. Hormonal, physiological, and physical performance during simulated kickboxing combat: differences between winners and losers. *International Journal of Sports Physiology & Performance*, *11*: 425–431, 2016.
25. Ouergui, I, Hssin, N, Haddad, M, et al. Time-motion analysis of elite male kickboxing competition. *J Strength Cond Res* 28: 3537–3543, 2014.
26. Palucci Vieira, LH, Cunha, SA, Santiago, PR, et al. Dominant/non-dominant support limb kinematics and approach run parameters in futsal kicking of stationary and rolling ball. *The Journal of Sports Medicine and Physical Fitness*, *59*: 2019
27. Pierce, JD, Reinbold, KA, Lyngard, BC, Goldman, RJ, Pastore, CM. Direct measurement of punch force during six professional boxing matches. *Journal of Quantitative Analysis in Sports 2*: 2006.
28. Piorkowski, BA, Lees, A, Barton, GJ. Single maximal versus combination punch kinematics. *Sports Biomechanics, 10*: 1-11, 2011.
29. Quinzi, F, Camomilla, V, Di Mario, A, Felici, F, Sbriccoli, P. Repeated kicking actions in karate: effect on technical execution in elite practitioners. *International Journal of Sports Physiology and Performance 11*: 363–369, 2016.
30. Riansoi, Y, Prajongjai, V, Chinnasee, P, et al. Mechanical analysis of supporting leg during roundhouse kick in muay thai beginners. *Journal of Sports Science and Technology, 19*: 2019.
31. Seungmo K, Greenwell TC, Andrew DPS, Lee J, Mahony DF. An analysis of spectator motives in an individual combat sport: a study of mixed martial arts fans. *Sport Marketing Quarterly* 17:109-19, 2008.
32. Stanley, E, Thomson, E, Smith, G, & Lamb, KL. An analysis of the three-dimensional kinetics and kinematics of maximal effort punches among amateur boxers. *International Journal of Performance Analysis in Sport*, *18*: 835–854, 2018.

33. Thibordeeand, S., & Prasartwuth, O. (2014). Factors Influencing the Impact Force of the Taekwondo Roundhouse Kick. *Chiang Mai University Journal of Natural Sciences*, *13*(1). https://doi.org/10.12982/cmujns.2014.0020
34. Tong-Iam, R, Lawsirirat, C, Rachanavy, P. Kinematic and kinetic analysis of throwing a straight punch: The role of trunk rotation in delivering a powerful straight punch. *Journal of Physical Education and Sport, 17*: 2017.
35. Turner, AN. Strength & conditioning for Taekwondo athletes. *Professional Strength & Conditioning* 15: 15-27, 2009
36. Turner, AN. Strength and conditioning for muay thai athletes. *Strength & Conditioning Journal 31*: 78–92, 2009.
37. Vecchio, L, Stanton, R, Macgregor, C, Humphries, B, Borges, N. Effects of a six-week strength and power training program on punching and kicking impact power in amateur male combat athletes: a pilot study. *Journal of Athletic Enhancement 8:* 2019.
38. Wang, Y, Kuo, S, Wang, L, Chen, K. Kinematic analysis of the supporting leg between different weight divisions in the roundhouse kick of taekwondo. *Portuguese Journal of Sport Science* (11): 2011.