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Original Article

Kinematic and kinetic analysis of throwing a straight punch: the role of trunk rotation in delivering a powerful straight punch

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Abstract:
Powerful straight punches create strategic advantage for boxers. However, there is discrepancy in theoretical and practical understandings of how to deliver powerful straight punches. This paper attempted to investigate the role of trunk rotation in straight punches. Trunk rotation was suggested as a critical component in delivering straight punches. However, no research has yet to address the importance of trunk rotation in straight punches. Three professional boxers who competed regularly in Muay Thai and boxing were recruited in this study. Both kinematic and kinetic analysis were performed. Straight punches were dissected into stages using ground reaction force. The result showed straight punches had 3 stages, i.e., (1) starting position, (2) lead toe off, and (3) lead toe in. The results suggested that the final stage, lead toe in, was the most important in delivering powerful straight punches, and boxers used trunk rotation to transform vertical ground reaction force to horizontal punch force.
Key Words*:* - straight punch, trunk rotation, boxing, punch force

Introduction

Straight punches, sometimes called rear straight punches or crosses, are key components to martial sports. Powerful straight punches create strategic advantage for boxers where they can use to score points, inflict injuries, or even knock his opponents (Lenetsky, Harris, & Brughelli, 2013; Smith, 2006). Ashker (2011) showed that winning boxers threw more straight punches than losing boxers in rounds 1 and 3. Several studies focus on kinematic and kinetic analysis of straight punches. Results from these studies vary depending on testing procedure, test equipment, and characteristic of participants (Buśko et al., 2016; Chadli, Ababou, & Ababou, 2014; Deliu & Băițel, 2013; Girodet, Vaslin, Dabonneville, & Lacouture, 2005; Halperin, Chapman, Martin, & Abbiss, 2016; Irina & Dan, 2014; Kimm & Thiel, 2015; Pierce et al., 2006; Turner, Baker, & Miller, 2011; Walilko, Viano, & Bir, 2005). In terms of kinematic analysis, researchers used accelerometer and motion analysis to analyse punching velocity as well as linear velocities of fist, elbow and shoulder. The upper extremity was preferred to the lower extremity because the lower extremity was relatively static compared to the upper extremity. For kinetic analysis, the measurement tools varied from punching bag embedded with dynamometer, force plate mounting on a wall, punching ball, or dummy head.

Throwing straight punches starts from the lower extremity before moving to the upper extremity (Dyson, Smith, Martin, & Fenn, 2007; Filimonov, Koptsev, Husyanov, & Nazarov, 1985; Lenetsky et al., 2013; Turner, Baker, & Miller, 2011). Filimonov et al. (1985) suggested that the lower extremity had more influence on punching force than the upper extremity. However, a recent study by Mack, Stojsih, Sherman, Dau, and Bir (2010) showed that punch force correlated more closely with hand than with 'sum of lower body force.' Since these two papers utilised different measurement techniques and different groups of participants. It is inconclusive how boxers generate punch force. Mechanically, ground reaction force (GRF) should have little influence on punch force because GRF is relatively perpendicular to the horizontal punch force. Lenetsky et al. (2013) suggested that trunk rotation was a critical component in creating powerful straight punches. To the best of our knowledge, research addressing the role of trunk rotation in straight punches is limited even if there is a large gap between theoretical and practical understandings of the mechanics of delivering powerful straight punches.

This paper attempted to investigate the role of trunk rotation in straight punches. The kinematic and kinetic analysis of straight punches were utilised to mechanically explain how to deliver powerful straight punches. Moreover, the paper found the movement pattern of straight punches using kinetic analysis. This paper will be the first attempt in breaking down movement pattern in straight punches, sincere there is no research dissecting the movement pattern of straight punches. The understanding of movement pattern in punching provided insightful instruction to generate powerful straight punches for coaches and boxers.

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Material & methods

Participants

Three male boxers who competed regularly in Muay Thai and boxing were recruited. All participants were local Muay Thai champions. The participants were between 22-24 years of age and were right handed. Two of the participants were in light weight and another was in welter weight. The average height and weight of the participants were 163.00±7.00 cm and 60.57±3.93 kg, respectively. All participants were trained regularly and in good physical condition with no injuries history in the previous 6 months prior to the study. The study was approved by The Ethics Committee of Health Science group, Chulalongkorn University, and all participants provided signed consent form.

Procedure

The kinematic data were obtained by using six high speed cameras (Qualisys Oqus 7, Qualisys AB, Sweden) and the kinetic data were obtained by using two force platforms (Kistler 9286BA, Kistler Group, Switzerland). The capture rate of camera was 300 Hz and force platforms sampling rate was 1500 Hz. The participants were asked to visit the laboratory once. Prior to the test, the participants were familiarised with the testing protocol. During this session, the participants were explained the protocol and were instructed to throw straight punches with their maximum effort. The participants selected and tested their preferred punching length. The participants were also asked to wear a body suit prepared for them.

Thirty five markers were placed over the whole body of the participants using SkinMarker placement. Before the testing protocol, the participants were asked to do their general cardio-vascular warm-up for 15 minutes. The normal warm-up included jogging, stretching, and shadow boxing. After the warm-up session, the participants were asked to step on two force platforms while a 5-kg punching ball was setup to the preferred punching length. After the setup, the participants were instructed to throw 10 straight punches with a 30-second rest between punches. The participants were signalled to start their straight punches and motivated to hit the target as hard as possible.

Data collection

Kinematic and Kinetic Variables

The kinematic variables recorded were the displacement, velocity, and acceleration of ankle, knee, hip, shoulder, elbow, and fist, and the acceleration of the punching ball. All kinematic variables were calculated using Qualisys track manager software (Qualisys, AB Sweden). The kinetic variables included GRFs of both legs and the punch force which was calculated using the Newton's second law of motion from the acceleration of the punching ball. While literature addressed several measurement techniques to evaluate punch force, a punching ball was selected to measure punch force. From our preliminary survey with boxers, boxers were more familiarised with the punching ball than other measurement techniques described in the literature. For example, mounting force plate on a wall created a mental barrier to boxers. Boxers felt that they were hitting the wall which obstructed them from performing to their maximum effort. Using punching bag required punching accuracy to hit at the dynamometer; otherwise, the punch force could not be accurately measured. Punching ball with motion capture solved all these difficulties and was, therefore, selected in this study.

Calculation of Trunk Rotation

This paper focused on trunk rotation during straight punching. The angle of trunk rotation was the angle between shoulder line (line between left and right acromion) and hip line (the line between left and right ASIS) projected onto transverse plane. The information about trunk rotation helped bridge the gap between theoretical and practical conundrum in straight punches.

Data Analysis

After obtaining the data, we selected the punch which provided the maximum punch force per body weight of each participant to report and discuss. The maximum punch force per body weight was used to take into account weight different and to be used as a model for powerful straight punches. Visual3D software (C-Motion, Inc., USA) was utilised to create movement pattern of each participant. Vertical GRFs from both force platforms were normalised by body weight. Both kinematics and kinetics data were normalised in time to report punching period as a percentage where 0% was the starting position, while 100% was the point where the fist hit the target. Time normalisation helped better distinguish among punching phase and see the pattern of straight punches among different participants.

Results

Kinematic and Kinetic Analysis of Straight Punches

Table 1 reported kinematic and kinetic variables of straight punches of each participant. The reported velocities were from the markers on the right side because the participants were right handed and punched with their right hand. Participant B2 generated the most powerful punch whose punch force was 1605 N or 24.65 N/kg. Participant B2 had peak velocity of his fist at impact compared to other participants whose peak velocity of their fists was achieved prior to impact. The mean normalized punch forces by participant's body weight of B1, B2 and B3 were 22.63 N/kg, 24.65 N/kg and 17.95 N/kg, respectively.

Table 1 shows kinematic and kinetic variables of straight punches

Kinematic variables								Kinetic variables	
Velocity (m/s) Time percentage at peak velocity (%)							Acceleration		
	Fist	Elbow	Shoulder	ASIS (hip)	Knee	Ankle	Punching ball (ms^{-2})	Punch Force (N)	Punch Force/BW (N/kg)
B1	5.84	5.53	2.64	1.55	1.21	0.65	263.36	1317	22.63
	97.03%	95.05%	91.09%	89.77%	79.21%	79.54%			
B2	6.63	5.53	2.02	1.5	1.02	0.33	321	1605	24.65
	100%	95.60%	90%	83.60%	76.80%	78%			
B3	6.62	5.51	2.87	2.27	1.83	0.61	209.59	1048	17.95
	97.41%	93.78%	87.05%	81.35%	73.06%	70.98%			

Each participant established a kinetic chain of throwing straight punches. The kinetic chain started from the lower extremity before moving to the fist. Punching started from ankle before moving to knee and to hip, respectively. Hip, then, acted as a bridge linking between the lower extremity and the upper extremity. The peak velocity of shoulder followed the peak velocity of hip before transferring velocity and forces to elbow and finally to fist. Our result supported the finding from Filimonov et al. (1985) where the lower extremity had large influence on punch force.

Movement Pattern of Straight Punches

GRFs of both legs from each participant were shown in the middle and the bottom panels of Figure 1. The patterns of GRFs of both legs were similar among every participant. Figure 1 revealed that punching phases or movement pattern of straight punches could be divided into 3 stages, i.e., starting position, lead toe off (LTO), and lead toe in (LTI).

(1) Starting position (Figure 1a-1b): boxers were at ready where the weight was totally rested on the lead leg before the boxers shifted their weight to the rear leg. The starting position ended when the weight was totally shifted to the rear leg as seen in Figure 1b. At this point, the toe of the lead leg was lifted; hence, there was no GRF in the lead leg. The pattern can be seen clearly in GRFs where GRF of left leg decreased while GRF of right leg increased (the middle and the bottom panels of Figure 1). Since the participants were right handed, the lead leg was left leg and the rear leg was right leg. In the first stage, boxers stored energy to their straight punch by shifting their weight to the rear leg. Shifting weight to the rear leg allowed boxers to create largest trunk angular displacement as well as the farthest punch length. The duration of starting position was about one third (1/3) of total punching time.

(2) Lead Toe Off (Figure 1b-1c): the second stage started when boxers exerted their weight to the rear leg and ended when the lead leg began to bear weight (Figure 1c). At this point, GRF of the lead leg was relatively zero, while the rear leg supported the body weight of boxers as seen in the middle and the bottom panel of Figure 1. At this stage, boxers began to throw straight punches. The average total duration of the second stage was around 28% of total punching time.

(3) Lead Toe In (Figure 1c-1d): the final stage started when boxers began to bear weight on the lead leg and ended when the fist hit the target (Figure 1d). At this stage, boxers used the lead leg as a pivot point and executed straight punches such that only lead leg supported the body weight and the rear leg bore no GRF. At this stage, GRF of the rear leg decreased, while GRF of the lead leg increased, which was exactly opposite from the starting position or the first stage. From Figure 1d, the directions of GRF of the lead leg and punch force were not in the same direction. As a result, the participants utilised the lead leg as a break to stabilise their movement. The time analysis of the final stage differed greatly among the participants ranging from 29.5% to 45% of total punching time. LTI was extremely important in delivering powerful straight punches. As seen in Figure 2, the kinetic chain of straight punches occurred after 70% of total punching time meaning that the whole kinetic chain was created and ended at this final stage.

Figure 1a corresponded to the starting position, while Figure 1b was 'Lead Toe Off' stage or the second phase. The 'Lead Toe In' or the final stage was shown in Figure 1c. Figure 1d was at impact.

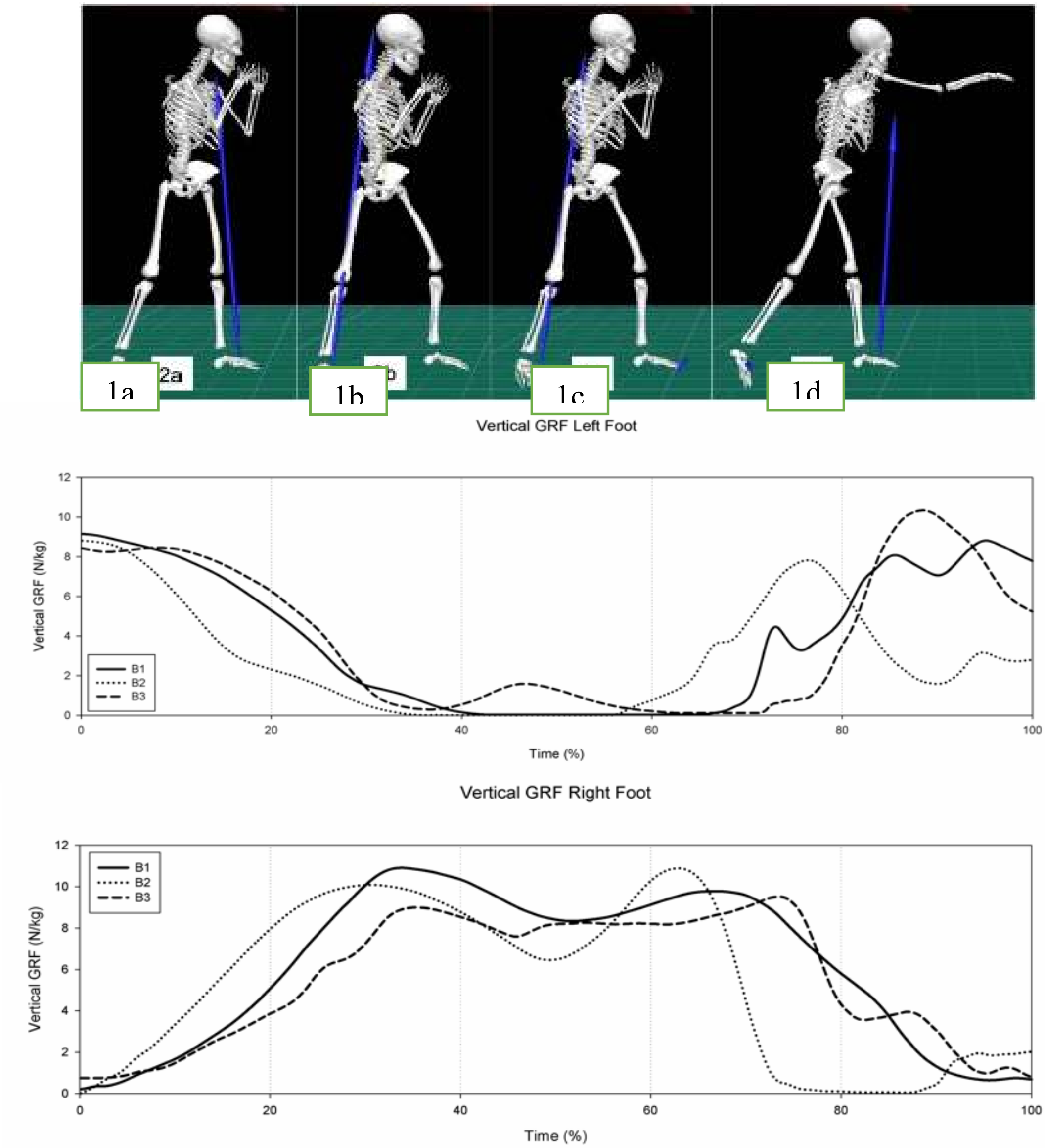

Figure 1 shows phases of straight punches and GRFs for both legs.

Trunk rotation played significant role in transferring kinetic chain from the lower extremity to the upper extremity. Our results showed that the trunk was relatively unmoved at the beginning of punching as shown in Figure 2. The movement of trunk started approximately after 70% of total punching time (the right panel of Figure 2). The angular velocity tended to increase after this point. The participants, then, sped up trunk rotation after 80% of total punching time until impact.

The trunk rotation played crucial role in LTI or the final stage of punching. At LTI, the displacement angle of trunk rotation was greatest (at 80% of punching time). Angular velocity of trunk rotation increased as GRF of the lead leg increased while GRF of the rear leg decreased. The lead leg acted as a pivot point, while the rear leg pushed the trunk and the whole body of boxers forward to create punching momentum and, thus, punch force. Therefore, trunk rotation mechanically transferred vertical ground reaction forces to horizontal punching force. The peak angular velocity of trunk rotation was achieved at impact.

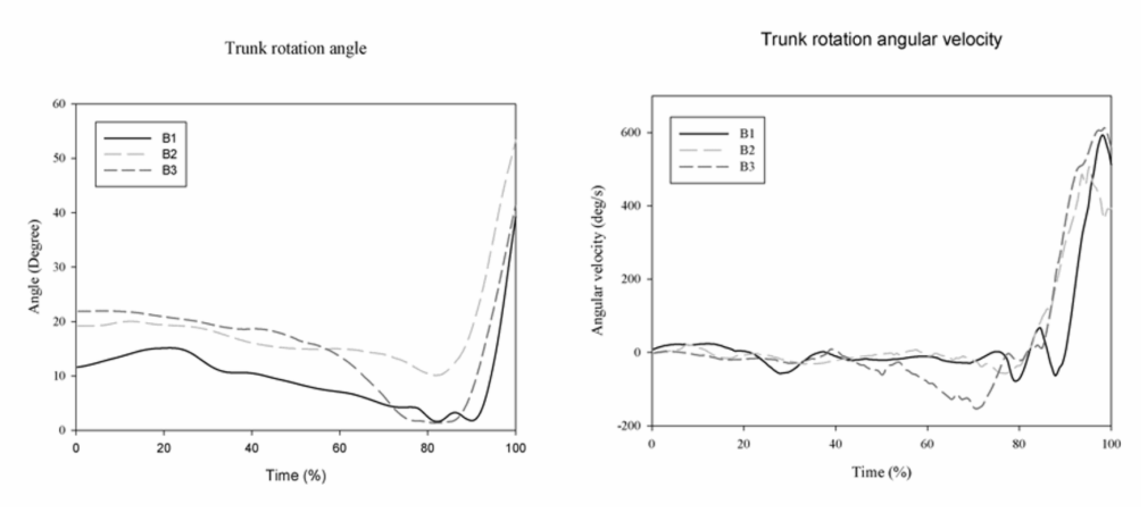

Figure 2 shows the angular displacement and velocity of trunk rotation.

Discussion

There is a literature gap addressing the importance of the lower extremity to the upper extremity in delivering straight punches. Mechanically, the lower extremity should have little or no influence on the upper extremity because GRF is relatively perpendicular to horizontal punch force. This paper attempted to answer how the lower extremity connected to the upper extremity in straight punches. Our results showed that the maximum punch force was between 1048-1605 N. The reported maximum punch force was lower than punch force reported in the literature. For example, Smith, Dyson, Hale, and Janaway (2000) reported punch force between 1604-4800 N. Smith (2006) reported maximum straight punch force at 2643-2646 N, and Walilko et al. (2005) reported punch force between 1990-4741 N. From the literature, punch force depended on the expertise level, weight of participants, and hitting target (body or head). However, our results reported higher punch force than the research by Pierce et al. (2006) whose mean punch force of super middleweight to light middleweight boxers was between 866-1150 N. The difference between punch force reported in the literature was due to smaller weight class participants and different measurement technique.

Participants showed good kinetic chain in throwing straight punches. The chain started from the lower extremity, namely, from ankle to knee and to hip. From hip, the chain moved upward to the upper extremity to shoulder, then to elbow, and finally to fist. The chain started after 80% of total punch time. Theoretically, the punch velocity or the fist velocity should be maximum at impact. The results showed that two participants had achieved peak fist velocity before impact suggesting that punching length was important. Two participants, thus, should have achieved higher punch force if they had selected proper punch length. This sub maximum punch velocity at impact can also be explained using speed accuracy trade-off where the participants sacrificed speed in order to accurately hit the target.

This paper dissected punching pattern into 3 stages, i.e., starting position, lead toe off, and lead toe in. The dissection utilised the pattern of GRFs and showed that the final stage (lead toe in) was extremely important in delivering powerful punches because the kinetic chain of punching started and finished in this stage. The first two stage acted as developing momentum or storing energy to deliver punches. At impact, the direction of GRF of lead leg was opposite to the direction of punch force. As a result, the lead leg acted as a break and discounted punch force. This finding was counterintuitive where the maximum punch force should be created such that the directions of GRF of the lead leg and straight punches were in the same direction. A further inquiry with boxers suggested that boxers rarely threw all their body to create maximum punch force. Boxers needed the lead leg to stabilise their movement. Otherwise, boxers were at a serious disadvantage if they could not hit the target, especially when they were during competition.

Our results proved the importance role of trunk rotation in delivering powerful straight punches. The finding supported the results from Filimonov et al. (1985) and the suggestion from Lenetsky et al. (2013) that trunk rotation was a critical component in throwing straight punches. Our finding suggested the importance of core strength in boxing agreeing with several findings indicating that sport performance was improved by stronger core muscle groups (Aguinaldo, Buttermore, & Chambers, 2007; Izumi, Miyakawa, & Miyamoto, 2007; Ramsey & Crotin, 2016; Solomito, Garibay, Woods, Õunpuu, & Nissen, 2015).

Conclusions

This paper attempted to bridge the gap between theoretical and practical discrepancy in straight punches. The literature was inconclusive whether the lower extremity had influence on punch force. We addressed this challenge by utilising kinematic and kinetic analysis of straight punches of three professional boxers. From our analysis, straight punches were divided into three stages, i.e., starting position, lead toe off, and lead toe in. The final stage, which was lead toe in, was crucial in delivering powerful force. The paper also discussed the importance role of trunk rotation in delivery of powerful straight punches. The paper suggested that trunk rotation bridged the lower extremity to the upper extremity causing the lower extremity to have great influence on generating powerful straight punches.

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