Original Article

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Biomechanical analysis of Yang's spear turning-stab technique in Chinese martial arts

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Abstract

The Yang's spear turning-stab was a legendary technique, applied in ancient battles in China. It resulted in numerous famous winnings. The mythical aspect of the technique is a victory in fleeing and back-facing a fighter. Now the skill is a spear technique of Chinese martial arts that is learned and excised by many Chinese Gungfu practitioners. Due to a dearth of scientific study on the skill, the uniqueness and its winning secretes are still unknown. The aim of this study is to demystify the skill by using a synchronized measurement of 3D motion capture (VICON 12 camera system), stab-force measurement (AMTI force platform). Six Gungfu athletes with more than 30 years training experience participated in the study. Both the Yang's spear turning-stab (used by a fleer) and spear forward-stab (used by a chaser) were measured and biomechanically analyzed. The results reveal that there would be six secrets for its historical successes. They are 1) showing weakness (i.e. pretend to be defeated), 2) shortening the stab for quick turning, 3) hiding the stab for a covert attack, 4) leaving less reaction time for opponent, 5) generating higher stab-force than opponent, and 6) leaning backward for a stable stab-posture. These secrets identify elements necessary for systematic training toward a reliable execution of the skill. This skill shows the delicate characteristics of Chinese martial culture. Learning and training the skill would benefit trainees both physically and culturally.

Keyword: 3D motion capture, force measurement, phases, hiding, sliding, relative motion.

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INTRODUCTION

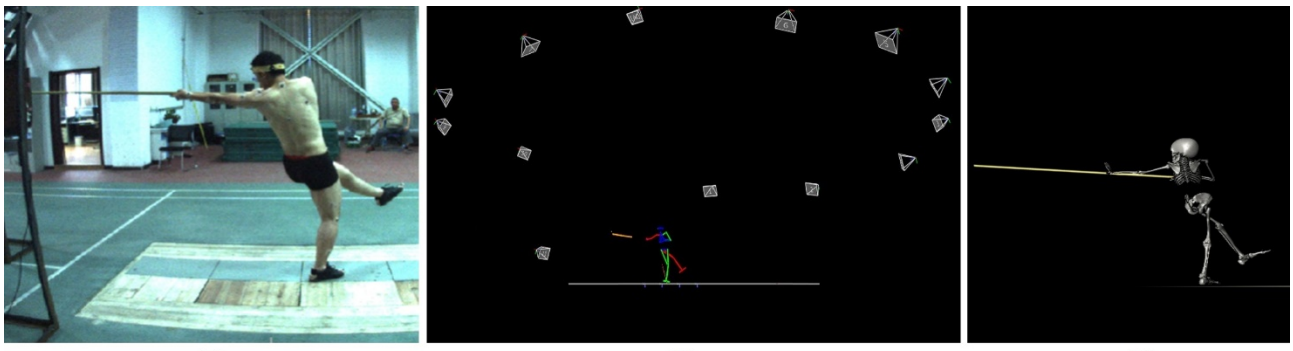
What makes the Yang's spear turning-stab famous is its counter-defeat move, i.e. performing a killing attack during fleeing with back-facing a fighter (running or horse riding). Qi Jiguang (1528 – 1588), a hero in Chinese culture, first documented the technique in his historical military manual "New Treatise on Military Efficiency". The manual was based on his experience as a martial educator and defensive planner in the Ming dynasty military forces. The mythically description is as follows: Two fighters battled each other; one was losing to the other, and turned quickly to escape. The winner took the chance to chase after the loser. While the winner approaching the loser, the loser suddenly turned back to stab the follower swiftly and killed him. Nowadays, one fighting strategy has been abstracted from the story: one deliberately shows a weakness (back-facing the opponent) during a fighting to seduce the challenger, and then surprises the pursuer with a powerful attack [3, 4]. The Yang's spear turning-stab had become a legendary technique, applied often in ancient battles in China. It resulted in numerous famous victories [5]. Now, it is a spear technique of Chinese martial arts that is learned and excised by many Chinese Gungfu practitioners.

Scientifically, it would be interesting to know why could Yang's spear turning-stab be successful? From the time perspective, the turning-stab (used by the escaper) should take more time to perform than the forward-stab (used by the chaser), because the escaper is back-facing his opponent and should take extra time for the turning before doing the stab. Due to a dearth of scientific study on the technique, the uniqueness and its winning secretes remain unknown. Hence, the aim of this study is to demystify the skill through a synchronized kinematic (3D motion analysis) and kinetic (stab-force) measurement.

MATERIAL AND METHODS

Participants and procedures

Biomechanical quantification was performed on six well-trained Chinese martial artists (age: 49±14 years; training time: 41±11 years; body height: 168±3 cm; body weight: 68±5 kg). The human-subject committee of Xinzhou Teachers University scrutinized and approved the test protocol as meeting the criteria of ethical conduct for research involving human subjects. The subjects were informed the testing procedures and voluntarily participated in the data collection.



(a) (b) (c)

Figure 1. Biomechanical quantification of the Yang's spear turning-stab. (a) a frame sample from the synchronized video; (b) the same frame sample from 3D motion capture, showing the set-up of cameras (12 VICON cameras + 1 Cam) and the 3D posture (stick-figure); and (c) the 15-segment full body model derived from the 3D raw data.

Figure 2. Spear length (~2 m, obtained from historical document) and the four markers' positioning.

During the test, the subjects were performing two different stabs, i.e. the Yang's spear turning-stab and the spear forward-stab. For each stab technique, the subjects performed three times. The data collection was done by a synchronized measure from three measuring systems: 3D motion capture, stab-force measurement and video. The last one of these was used referentially to ensure event synchronization, as well to provide a traditional method of skill analysis familiar to coaches and athletes [6-8]. 3D Motion capture technology permits considerable freedom of movement for participants without negatively influencing their motor skill control. Taking advantage of this, we placed no restrictions on subjects' movements within the capture volume in an effort to preserve their normal "style", i.e. their trained motor control style. Further, biomechanical modeling [9-13] was employed quantification and demystification of the Yang's spear turning-stab. Each of these processes is individually elaborated below.

3D Motion Capture and Biomechnaical Modeling

A 3D twelve-camera VICON motion-capture system (Oxford Metrics Ltd., Oxford, England) was used to tracking 39 reflective, 9mm markers on the body and 4 markers on the spear. The capture rate was 200 frames/s. Figure 1 shows the key posture (a video frame) and 3D computer reconstruction of the posture, including camera placement, and a rendered stick figure. Markers were placed on subjects as follows: 1) four on the head, 2) trunk markers on the sternal end of the clavicle, xiphoid process of the sternum, C7 and T10 vertebrae, right scapula, left and right anterior superior iliac, posterior superior iliac, 3) upper-extremity markers on the right and left acromion, lateral side of upper arm, lateral epicondyle, lateral side of forearm, styloid processes of radius and ulna, and distal end of 3rd metacarpal bones, and 4) lower extremities markers on left and right lateral sides of thigh and shank, lateral tibial condyle, lateral malleolus, calcaneus and big toe. Additionally, four makers were used to determine the kinematics of the spear (Figure 2). Calibration residuals were determined in accordance with VICON's guidelines and yielded positional data accurate within 1 mm.

From the captured 3D data a 15-segment biomechanical model was build (Figure 1c). The model segments were identified as follows: head, upper trunk, lower trunk, upper arms, lower arms, hands, thighs, shanks and feet. In such biomechanical modeling, inertial characteristics of the body were estimated using anthropometric norms found in previous studies [14, 15]. Such a full-body model is widely applied in the current 3D motion capture technology for demystifying and optimizing various motor skills in sports [16-24]. After model calculations, both techniques were analyzed and compared for finding the key/dominant factors linked to the secretes of Yang's spear turning-stab.

Stab-force measurement

Stab-force is a direct measure of the effectiveness of a spear stab. For this study, an AMTI force platform (Advanced Mechanical Technology, Inc. Massachusetts, USA) was mounted vertically into an iron frame as a target. The stab-force data was collected at a rate of 1000 Hz and synchronized with the 3D motion capture and a camcorder (CASIO, 50 f/s).

Parameters' selection and analysis

Since this study was the first 3D quantitation of the Yang's spear turning-stab and its goal was on revealing the secrets/uniqueness of the technique, identification of and discussion on the key/dominate factors should be a focus of the current study. Therefore, the fully analyses on our numerous 3D data were not presented here; instead, the selected key parameters were applied to supply a concise and straight-forward results. As such, the results and their interpretations would be

more clearly and easily understood by practitioners. The following key factors had been selected for illustrating the secrets of the Yang's spear turning stab:

- phase identification
- duration of each phase
- speed of spear-head (both maximum and stab-at-the-target)
- grab-distance between the two hands (both maximum and its change during stabbing)
- stab-force.

Such a focused communication would help readers/practitioners understanding the unique motor control of the turning-stab in a timely efficient way.

The average and standard deviation of the selected parameters were used to characterize both techniques. The Shapiro-Wilk test was carried out, which did not confirm the normality of the data distribution. Therefore, U Mann-Whitney's test was applied to identify any significant difference between the two techniques. The significant level was set at $p<0.05$. Statistic software SPSS V20 was applied for all data analyses. Additionally, correlation analyses were performed to identify to identify the strength of relationships between spear-head speeds and the other selected key parameters.

RESULTS

Our results show that the Yang's turning-stab should be divided into three phases (Figure 3), while the forward-stab should consist of two (Figure 4). Phase 1 in the turning-stab has two goals: 1) to covertly prepare a courter-attack, and 2) to create a condition/posture for a quick turn. Our 3D biomechanical modeling reveals the goal 1 is achieved through a natural back-swing of arm during running/fleeing (shorten the spear); the goal 2 is realized by lifting one arm to bring the spear close the body longitudal axis (enable a faster body-twist as well as use the body to hide the spear). Due to the kinematic characteristics and the concealment of the preparation, we name the phase as the shorten-hiding spear phase. The Phase 2 of the turning-stab is dominated by body twisting, therefore is named as a turning phase. The last phase (i.e. Phase 3) is named as the stabbing phase, because the stab control dominates the phase. On the other side, lifting the spear is the main control in Phase 1 and stabbing in Phase 2 for the forward-stab technique.

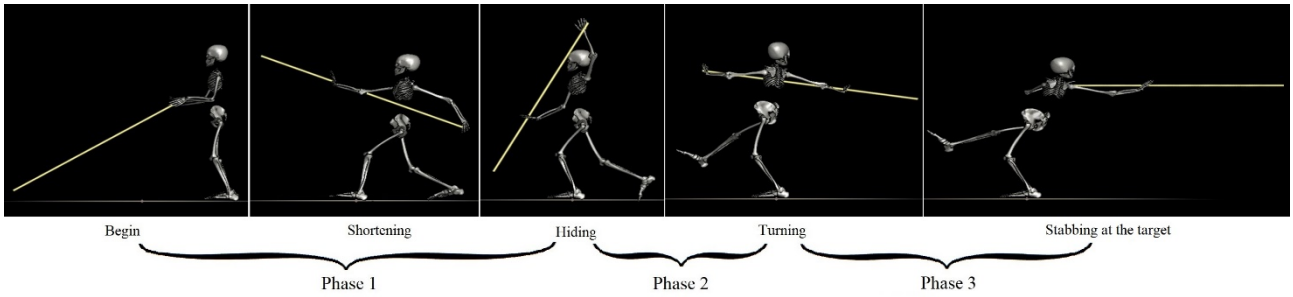


Figure 3. Phases identified in the Yong's spear turning-stab. Phase 1: shorten-hiding spear; Phase 2: turning back; Phase 3: stabbing.

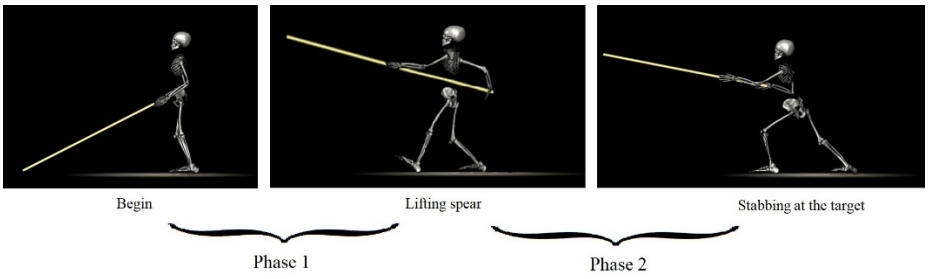


Figure 4. Phases identified in the forward-stab. Phase 1: lifting spear; Phase 2: stabbing.

Table 1. The duration average and standard deviation of each phase in both stabbing techniques.

Yang's turning-stab		Forward-stab	
Phase	Duration (s)	Phase	Duration (s)
1. Shorten-hiding spear	0.85±0.32		
2. Turning	0.70±0.39	1. Lifting spear	0.65±0.32 *
3. Stabbing	0.23±0.07	2. Stabbing	0.30±0.10 **

* $p<0.05$, ** $p<0.01$.

Table 2. The comparisons of the key factors between the two stabbing techniques.

Key Factors		Yang's turning-stab	Forward-stab
Max	Speed (m/s)	8.18±1.36	6.22±1.74 **
	D_{H-H} (m)	0.91±0.25	0.65±0.09 **
Stab-at-the-target	Speed (m/s)	6.91±1.38	1.51±2.33 **
	ΔD_{H-H} (m)	0.46±0.15	0.30±0.11**
	Stab-force (N)	115.43±17.65	106.21±25.77 *

D_{H-H} - grab-distance between the two hands, ΔD_{H-H} - change of grab-distance between the two hands during stabbing, * $p<0.05$, ** $p<0.01$.

DISCUSSION

The main aim of the current study is to demystify the Yang's spear turning-stab through 3D motion analysis and stab-force measurement. There are several unique aspects revealed by the current study. Due to a dearth of movement analysis/quantification on the technique, these unique characteristics revealed by the current study would help both researchers and practitioners to cognize the essentials of the technique.

Firstly, the top secrets of the success of Yang's spear turning-stab lies in the Phase 1. Based on the historical documents, one has to pretend to be defeated in an evenly-matched fight, quickly turns around and flees; during the escape, keeps waiting until the pursuer has approached; then turns the upper body suddenly around while moving forward and finishes the killing counter-attack [1, 2, 5]. This historical description could indicate three facts: 1) the escape would make the pursuer switching to focus on catch-up (not on one's defense); 2) the pursuer could not recognize a count-attack; 3) the counter-attack could be too fast for the pursuer to be avoided. The first one would be psychologically relevant for a killing counter-attack (1st secret). However, the vital causes would be that the pursuer could not recognize a count-attack (i.e. the 2nd point) and the counter-attack should be done so quickly before a defense reaction could be taken (i.e. the 3rd point). Our data indicate that the Phase 1 plays a decision role related to the 2nd and 3rd point. Although the preparation of the turning-stab is the longest phase, it could be done without being perceived. Through a nature back-up swing of an arm during running, one could finish the grab of the spear secretly, lead to "a shortened spear" (i.e. the spear is close to the trunk) during running and result in the most part of the spear invisible (i.e. hid the spear) to the pursuer (Figure 3). Further, due to the tight merge between the spear and the body, the moment of inertia of the spear-body system decrease dramatically, making a fast twisting realistic. Therefore, shortening and hiding are the other two secrets of the Yang's spear turning-stab.

Secondly, the opposite/head-on movement caused by the sudden trunk twist would make the motor-control change difficulty for the pursuer and delay his reaction for avoiding the counter-attack. Obviously, the sudden opposite movement between the two fighters should be unexpected to the pursuer. There are two consequences related to the unexpected change: 1) this relative motion will shorten the reaction time for both, requiring faster reaction hereafter than herebefore; 2) the initiator is prepared for the change, while the pursuer is not. These result normally in unequally reactions for both parties in the same situation [25]. Ergo, leaving less reaction time for opponent would be the 4th secret.

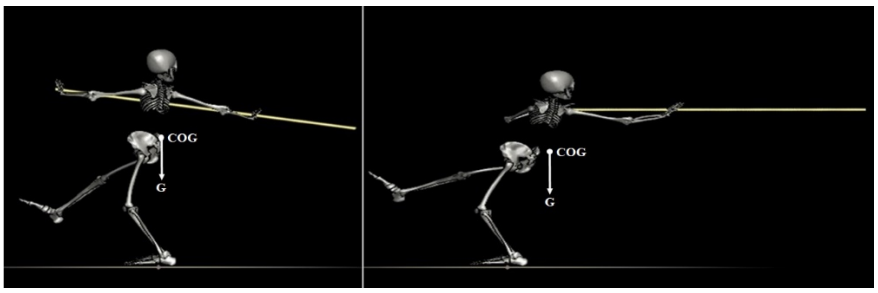


Figure 5. The change of the body posture during stabbing. COG: center of gravity, G: gravity/weight.

Thirdly, the difference between the hands techniques applied in both stabs would put the pursuer into even higher risk. Our data unveil that the turning-stab has more sliding distance between hands during stabbing than the forward-stab, resulting in a highly significant difference in spear speeds (Table 2). This difference would further shorten the time for the pursuer to react. Additionally, the stab-force data confirm that the turning-stab generates higher stab-force that the forward-stab, indicating the former technique is more effective than the latter one. To our surprise, the force difference is only 8.7% (the difference between max spear speeds: 31.3%, the difference between the at-the-target speeds: 357.6%). This might be due to a static target (not a dynamic one) employed in the test. Previous studies have revealed that the type of target affects the hit-force generation [26, 27]. In short, hand sliding stab would shorten opponent's time to react and generate higher stab-force of the counter-attack, as such it would be the 5th secret of the Yang' spear turning-stab.

Lastly, the trunk orientation and body posture of the attacker during stabbing supplies a solid base for the killing counter-attack. Due to a forward movement, mechanically, the reaction force received by the attacker could easily "push" the attacker fall forward in an upright trunk posture (Figure 5, left). However, the lean-backward of the trunk supplies a resistant torque against the potential forward fall (Figure 5, right). The torque created by the body weight will cause a clock-wise rotation against the forward "push" produced by the stab. The unique posture could further increase the counter-attacker's stab-force, which is implicit in some historical documentations [1, 2, 5]. Our data indicates that the implication should be correct. Therefore, the 6th secret of the Yang' spear turning-stab is the lean-backward posture.

CONCLUSION

In summary, through 3D motion capture and force measurement, the current study initiated a scientific quantitation of the Yang's spear turning-stab, one legendary skill in Chinese martial arts. In combination with historical documents, our study reveals that there would be six secrets for its historical successes. They are 1) showing weakness (i.e. pretend to be defeated), 2) shortening the stab for quick turning, 3) hiding the stab for a covert attack, 4) leaving less reaction time for opponent, 5) generating higher stab-force than opponent, and 6) leaning backward for a stable stab-posture. These secrets identify elements necessary for systematic training toward a reliable execution of the skill. This skill shows the delicate characteristics of Chinese martial culture. Learning and training the skill would benefit trainees both physically and culturally.

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