A biomechanical assessment of fajin mechanisms in martial arts

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A Study Design
B Data Collection
C Statistical Analysis
D Manuscript Preparation
E Funds Collection

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Abstract

Background & Study Aim: As a martial arts technique, fajin ("exerting strength") is a reasonable and efficient method of utilizing muscle strength. The purpose of this study was to explore fajin movement mechanisms in terms of muscle activation.

Material & Methods: A three-dimensional motion analysis system, force plates, and a wireless electromyography system were used to simultaneously collect kinematics, kinetics, and muscle activation from eight martial arts trainees who were familiar with fajin techniques. Statistical analysis was performed using Kendall's coefficient of concordance at a significance level of α=0.05.

Results: The results revealed that the maximum joint angular velocities, maximum joint angles, initiation of muscle activations, and peak muscle activations occurred in a fixed sequence.

Conclusions: The fajin motor pattern is initiated by a push from the rear foot, which produces a ground reaction force and moves the center of gravity forward. All of the joint operations and muscle activation timings occurred in a fixed sequence in this study.

Keywords: action sequence • electromyography • ground reaction force • martial arts • muscle activation timing

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Introduction

Fajin – method and process of releasing power from the human body for attacking

Muscle activation timing – timing of onset of muscle firing

Ground reaction force – force supplied by the ground to human body

The fajin technique ("exerting strength") exists in most forms of traditional Chinese martial arts, including Shaolin Boxing, Tai Chi, White Crane Boxing, Wing Chun (Spring Chant Fist), Baji Quan (Eight Extremes Fist), and Xingyiquan (Form-Intent Boxing). It is a reasonable and efficient use of power from the human body. More specifically, fajin refers to a method and process of releasing power. In this study, a common fajin form was be operating, i.e., push with two hands. Fajin involves the formation of a kinetic chain through body-wide joint interactions and centre of gravity movements. This chain channels force from the proximal to the distal limb segments and then transmits it to an opponent. Although individuals who have not learned fajin can push their opponents, they typically require longer action times than those who are familiar with fajin [1]. Furthermore, a pushing force is inefficient due to antagonistic muscle responses and their accompanying waste of energy. Thus, a martial artist exercises control over related muscle groups in fajin, achieving coherent, synergistic muscle movements in relevant parts of his body. The ground reaction force helps create maximal power in a short duration, allowing a maximal impulse to be instantly transmitted to another party. Body-wide muscle coordination occurs during transmission of the ground reaction force and is a key contributor to the quality of fajin movements [2]. When the fajin is released from the body, all of the joints in the upper and lower limbs shift from flexion to extension. Large joints, including the hip of the pushing foot and the shoulder joints, start extending once contact occurs. The shoulder joints continue extending throughout the action period. In the lower limbs, joint extension begins with the rear pushing foot and extends to the front supporting foot, whereas in the upper limbs, joint extension occurs in a bottom-up manner throughout the fajin motion [3]. The movements of the limb segments and joints are mainly produced by muscle contraction, which is activated by nerve potential that are conducted to the muscle fibers. The speed and tension of the muscle contractions correspond to these nerve potentials [4]. Thus, muscle group activation in fajin movements merits exploration. Muscle activation may be analysed through electromyography (EMG) [5-7]. Based on an EMG analysis of a Tai Chi master's "ji" and "an" movements ("squeeze" and "press,", respectively), Chan, Luk, and Hong [8] found that the medial hamstrings and the medial head of the gastrocnemius exhibited low activity during an "an" action, while higher EMG values were observed in the lumbar erector spinae. The greatest activation was observed in the rear foot's rectus femoris (68.3% of a maximal voluntary contraction (MVC)). However, this study did not clearly describe the activation sequence of various muscle groups and only analysed a single subject's exercise routine. Thus, these results are not truly reflective of the muscle activation reactions during fajin movements. Nian [1] investigated the muscle activation status in the trunk and upper limbs of four Tai Chi athletes who were skilled at fajin. Their results indicated that non-identical muscle activation occurred at different times. Nearly all previous fajin studies examined only a single individual or a small number of participants. Fajin can be further quantified if the number of subjects is increased and the muscle activation pattern is examined in the lower limbs. Therefore, the purpose of this study was to investigate the muscle activation status of fajin mechanisms (the muscle activation affected the variables like the sequence of maximum joint angular velocities and the sequence of the maximum joint angles) in the martial arts.

Methods

Subjects

Eight martial arts practitioners who were skilled in fajin participated in this study. Their average age, height, weight, and training duration were 28.38±4.66 years, 171.62±3.84 cm, 72.35±9.81 kg, and 6.50±3.27 years, respectively. A healthy young man served as the fajin recipient. The experimental procedures were explained to all of the study participants, and each participant signed an informed consent form. This study was reviewed and approved by the local Joint Institutional Review Board.

Instruments

A three-dimensional motion capture system (MX13+, Vicon) with ten-cameras was used to monitor and record the reflective markers attached on the specific position of the participants at a frequency of 300 frames/s as the participants performed fajin movements. Two force plates (9281 and 9287, Kistler) and an EMG instrument (DTS, Noraxon) were used to simultaneously collect the ground reaction force and muscle activation, respectively, during the fajin process. A sample acquisition frequency of 1500 Hz was used for both the force plates and the EMG instrument.

Method

Reflective markers were attached to specific body positions to collect the fajin movement data. More specifically, 15 body segments, including the head, trunk, pelvis, and bilateral upper arms, forearms, palms, thighs, lower legs, and feet, were defined based on the spatial positions of the reflective markers. The activations of 16 muscles in the limbs and trunk, including the bilateral gastrocnemius, quadriceps, hamstrings, gluteus maximus, and gluteus medius, as well as the right infraspinatus, trapezius, pectoralis major, latissimus dorsi, triceps brachii, and brachioradialis, were also synchronously recorded during fajin movements. The subjects were asked to perform fajin with a double-pressing action and a fixed step. The upper limb movements were roughly symmetric in this sequence. Thus, EMG signals were only acquired from the right side of the upper body. After the reflective markers and EMG electrodes were attached, the participant placed his feet on the force plates, with the right foot in front and the left foot behind, and performed fajin on the designated recipient (Figure 1). Experimental data were collected from three successful fajin actions per subject. The most rapid action was selected for analysis. Five reflective balls attached to the fajin recipient's body: one ball in the T10 vertebral region and four balls on the pelvis (on the left and right sides of the anterior and posterior superior iliac spines (ASIS and PSIS, respectively) were used to track the post-fajin movements.

Figure 1. Experimental setup for fajin movement.

Data processing

The spatial locations of the fajin practitioners' reflective markers were substituted into Dempster's body segment parameters. Three-dimensional kinematic parameters (the angle and angular velocity of each joint) were obtained via the VISUAL3D (C-motion) software package. Low-pass filtering (10 Hz) was used to smooth the trajectories of the marks. Additionally, the three-dimensional ground reaction forces were converted to human movement coordinates (using the X, Y, and Z axes to refer to the forward to backward, left to right, and vertical movement directions, respectively) to calculate the timing of the peak ground reaction forces on the practitioner's front and rear feet. The timing that the recipient's moved was also recorded by determining the marker position. The EMG signals were processed by full-wave rectification and band-pass filtering (10-500 Hz). The initiation of muscle activation was considered to occur when the EMG's amplitude exceeded its average preliminary baseline value plus twice the standard deviation. Similarly, the end of muscle activation was defined as the next time at which the EMG was less than its mean preliminary baseline value plus twice the standard deviation. The EMG's average amplitude was calculated during each activation period and normalized to the MVC. In this investigation, a fajin movement was defined as the period from the minimum ground reaction force on the front foot to the maximum ground reaction force on the front foot. This duration was treated as the entire the movement period (100%), and all other time-related data were standardized accordingly.

Statistical methods

In this study, descriptive statistics, including mean, standard deviation, and coefficient variance (standard deviation/mean), were calculated for the maximum joint angular velocity, the time required to reach a particular joint angle, the time at which muscle activation was initiated, the time of peak muscle activation, and the duration of muscle activation as a percentage of the fajin duration. Kendall's coefficient of concordance was used to assess the consistency of the fajin motion patterns with respect to their maximum joint angular velocities, the sequence of particular joint angles, the initiation order of muscle activation, and the sequence of peak muscle activations. The IBM SPSS 19.0 software package (International Business Machines Corp) was used for statistical analysis, and the p=0.05 was considered to indicate significance.

Results

The peak values of the kinematics and kinetics are shown in Table 1. Flexion movements were noted in the shoulder joints, as well as the right hip, knee, and ankle; all of the other joints exhibited extension.

Each joint's maximum angular velocity occurred after the maximum ground reaction force was produced by a push from the rear leg (Tables 2-3). These maximum angular velocities occurred in the following order. The maximum angular velocities were first attained in the left knee, right wrist, and waist. At this point, the fajin recipient started moving backwards.

To judge the degree of dispersion in the consistency among the eight test subjects, a smaller coefficient of variation indicates higher consistency of the data.

Subsequently, the maximum angular velocities were observed in the left ankle, left wrist, left hip, right shoulder, left elbow, and right elbow. Then, the ground reaction force on the front foot reached its maximum value, followed by the generation of the maximum flexion angular velocity in the left shoulder. The

Table 1. The kinematic and kinetic data of the participants' body segments during a fajin action.

Parameter	Unit	Value	Standard deviation
Fajin duration	Sec	0.39	(0.16)
Rear foot: maximum ground reaction force	BW	1.45	(0.14)
Both feet: maximum ground reaction force	BW	1.55	(0.23)
Front foot: maximum ground reaction force	BW	1.02	(0.22)
Left ankle: maximum plantar flexion angular velocity	deg/s	173	(128)
Left knee: maximum extension angular velocity	deg/s	243	(109)
Left hip: maximum extension angular velocity	deg/s	127	(83)
Waist: maximum extension angular velocity	deg/s	98	(36)
Left shoulder: maximum flexion angular velocity	deg/s	296	(52)
Right shoulder: maximum flexion angular velocity	deg/s	303	(64)
Left elbow: maximum extension angular velocity	deg/s	566	(132)
Right elbow: maximum extension angular velocity	deg/s	636	(129)
Left wrist: maximum extension angular velocity	deg/s	190	(73)
Right wrist: maximum extension angular velocity	deg/s	231	(145)
Instantaneous backwards speed of the opponent	m/s	883	(485)
Left ankle: maximum plantar flexion angle	Deg	-3	(17)
Left knee: maximum extension angle	Deg	-4	(5)
Left hip: maximum extension angle	Deg	2	(9)
Right ankle: maximum dorsiflexion angle	Deg	8	(6)
Right knee: maximum flexion angle	Deg	-60	(11)
Right hip: maximum flexion angle	Deg	71	(10)
Waist: maximum extension angle	Deg	24	(10)
Left shoulder: maximum flexion angle	Deg	103	(13)
Right shoulder: maximum flexion angle	Deg	105	(13)
Left elbow: maximum extension angle	Deg	28	(9)
Right elbow: maximum extension angle	Deg	30	(11)
Left wrist: maximum extension angle	Deg	-63	(28)
Right wrist: maximum extension angle	Deg	-71	(20)

Table 2. The sequence of ground reaction forces and maximum joint angular velocities during a fajin action.

Sequence of events	Statistical result	
Front foot: minimum ground reaction force	Significance (p-value)	0.000
Rear foot: maximum ground reaction force		
Both feet: maximum ground reaction force		
Left knee: maximum extension angular velocity		
Right wrist: maximum extension angular velocity		
Waist: maximum extension angular velocity		
Recipient begins to move		
Left ankle: maximum plantar flexion angular velocity	Kendall's coefficient (W)	0.613
Left wrist: maximum extension angular velocity		
Left hip: maximum extension angular velocity		
Right shoulder: maximum flexion angular velocity		
Left elbow: maximum extension angular velocity		
Right elbow: maximum extension angular velocity		
Front foot: maximum ground reaction force		
Left shoulder: maximum flexion angular velocity		

$p<0.05$ is considered significant. The Kendall coefficient of concordance (W), ranged from 0.5 to 0.7, indicating a moderate correlation.

Table 3. The timing of the maximum joint angular velocities during a fajin action.

Joint movement	Percent of fajin time period		
	Mean	Standard deviation	Coefficient of variation#
Left knee: extension	53	(24)	0.45
Waist: extension	55	(21)	0.39
Right wrist: extension	60	(36)	0.59
Left wrist: extension	66	(37)	0.57
Left ankle: plantar flexion	66	(33)	0.50
Left hip: extension	80	(60)	0.75
Right shoulder: flexion	94	(45)	0.47
Left elbow: extension	97	(40)	0.42
Left shoulder: flexion	101	(35)	0.35
Right elbow: extension	102	(41)	0.40

maximum joint angles were attained after the maximum ground reaction force was produced by a push from the rear leg (Table 4-5).

Table 4. The sequence of the maximum joint angles during a fajin action.

Sequence of occurrences	Statistical result	
Front foot: minimum ground reaction force	p-value	<.001
Rear foot: maximum ground reaction force		
Front knee: maximum flexion		
Maximum ground reaction force		
Rear hip: maximum extension		
Front ankle: maximum dorsiflexion		
Target moved		
Right wrist: maximum extension	Kendall's W	.771
Left wrist: maximum extension		
Front hip: maximum flexion & Waist: maximum extension		
Rear knee: maximum extension		
Front foot: maximum ground reaction force		
Rear ankle: maximum dorsiflexion		
Right elbow: maximum extension		
Right shoulder: maximum flexion		
Left shoulder: maximum flexion		
Left elbow: maximum extension		

A p-value less than 0.05 is considered significant. Kendall's coefficient of concordance (W) ranged from 0.5 to 0.7, which indicates a moderate correlation.

Table 5. Time points of the occurrence of the maximum angle in each joint; 0%-100% refers to the period required for a "fajin" action.

Joint movement	Percent of fajin time period		
	Mean	Standard deviation	Coefficient of variation#
Front knee: flexion	39	(32)	0.81
Rear hip: extension	55	(26)	0.47
Front ankle: dorsiflexion	65	(29)	0.45
Right wrist: extension	72	(40)	0.55
Front hip: flexion	78	(47)	0.60
Waist: extension	79	(27)	0.34
Left wrist: extension	83	(30)	0.36
Rear knee: extension	85	(36)	0.43
Rear ankle: plantarflexion	117	(49)	0.42
Right elbow: extension	119	(43)	0.36
Right shoulder: flex	123	(43)	0.35
Left shoulder: flexion	125	(41)	0.33
Left elbow: extension	136	(32)	0.24

#To judge the degree of dispersion in the consistency among the eight test subjects, a smaller coefficient of variation indicates higher consistency of the data.

Table 6. The sequence of muscle activation initiations during a fajin action.

Sequence of occurrences	Statistical result	
Right leg: tibialis anterior	Significance (p-value)	<.001
Left leg: tibialis anterior		
Anterior deltoid		
Left leg: rectus femoris		
Triceps brachii		
Left leg: biceps femoris		
Rectus abdominis		
Pectoralis major		
Left leg: gastrocnemius	Kendall coefficient (W)	0.582
Latissimus dorsi		
Middle trapezius		
Erector spinae		
Right leg: rectus femoris		
Front foot: minimum ground reaction force		
Right leg: biceps femoris		
Right leg: gastrocnemius		
Recipient begins to move		
Front foot: maximum ground reaction force		
Right elbow: maximum extension		

A p-value less than 0.05 is considered significant. Kendall's coefficient of concordance (W) ranged from 0.5 to 0.7, which indicates a moderate correlation.

Table 7. Time points of the initiation of muscle activation in various parts of the body; 0%-100% refers to the period required for a "fajin" action.

Muscle	Percent of fajin time period		
	Mean	Standard deviation	Coefficient of variation#
Anterior deltoid	-263	(270)	1.03
Right leg: tibialis anterior	-233	(216)	0.93
Triceps brachii	-214	(233)	1.09
Left leg: tibialis anterior	-150	(84)	0.56
Left leg: biceps femoris	-107	(82)	0.77
Left leg: rectus femoris	-149	(128)	0.86
Pectoralis Major	-131	(221)	1.69
Erector spinae	-106	(231)	2.17
Rectus abdominis	-96	(109)	1.14
Left leg: gastrocnemius	-62	(56)	0.90
Right leg: biceps femoris	-58	(238)	4.12
Latissimus dorsi	-42	(64)	1.55
Right leg: rectus femoris	-31	(97)	3.09
Middle trapezius	-30	(92)	3.09
Right leg: gastrocnemius	14	(45)	3.22

#To judge the degree of dispersion in the consistency among the eight test subjects, a smaller coefficient of variation indicates higher consistency of the data.

More specifically, the following order was observed for the occurrence of maximum angles in the examined joints. Maximum angles were first attained by the right knee, left hip, and right ankle. At this point, the fajin recipient started moving backwards. Subsequently, maximum angles were attained by the right wrist, left wrist, right hip, waist, and left knee. The ground reaction force on the front foot then reached its maximum value, followed by the occurrence of the maximum angles of the left ankle, right elbow, right shoulder, left shoulder, and left elbow. The timing of the left elbow's maximum angle of extension (136%) exhibited a small degree of dispersion across the eight subjects (a coefficient of variation less than 0.3). Most muscle activations were initiated prior to reaching the minimum ground reaction force on the front foot. In particular, the following order of muscle activation initiations was observed. Initiation of muscle activation first occurred in the right tibialis anterior, left tibialis anterior, anterior deltoid, left rectus femoris, triceps, left biceps femoris, rectus abdominis, pectoralis major, left gastrocnemius muscle, latissimus dorsi, trapezius muscle, erector spinae, and right rectus femoris. At this point, the minimum ground reaction force was reached on the front foot. Subsequently, the initial activation of the right biceps femoris and the right gastrocnemius occurred. The fajin recipient then started moving backwards, and the maximum ground reaction force was generated on the front foot. The right elbow extended, reaching its maximum muscle activation signal, after the minimum ground reaction force was reached on the forward foot. Peak muscle activation occurred in the following order. First, peak muscle activation was attained by the left gastrocnemius, left rectus femoris, left tibialis anterior, and left biceps femoris. At this point, the fajin recipient started to move. Subsequently, peak muscle activation was attained by the anterior deltoid, right rectus femoris, pectoralis major, rectus abdominis, triceps brachii, middle trapezius, right tibialis anterior, latissimus dorsi, and right gastrocnemius. Then, the maximum ground reaction force was reached on the front foot, followed by the peak activation of the erector spinae and right biceps femoris. Finally, the right elbow achieved maximum extension. The timing of the peak activation of the right gastrocnemius (93%) and the right biceps femoris (115%) exhibited small degrees of dispersion across the eight subjects (Tables 6-9).

Table 8. The sequence of the peak muscle activations during a fajin action.

Sequence of occurrences	Statistical result	
Front foot: minimum ground reaction force	p-value	<.001v
Left leg: gastrocnemius		
Left leg: rectus femoris		
Left leg: tibialis anterior		
Left leg: biceps femoris		
The target moved		
Anterior deltoid		
Right leg: rectus femoris		
Pectoralis Major		
Rectus abdominis	Kendall's W	.447
Triceps brachii		
Middle trapezius		
Right leg: tibialis anterior		
Latissimus dorsi		
Right leg: gastrocnemius		
Front foot: maximum ground reaction force		
Erector spinae		
Right leg: biceps femoris		
Right elbow: maximum extension		

A p-value less than 0.05 is considered significant. Kendall's coefficient of concordance (W) ranged from 0.5 to 0.7, which indicates a moderate correlation.

Table 10 displays the degree of dispersion for the activation duration of various muscles; this value was particularly low for the left tibialis anterior.

Table 9. Time points of the peak activation of muscles in various parts of the body; 0%-100% refers to the complete period required for a "fajin" action.

Muscle	Percent of fajin time period		
	Mean	Standard deviation	Coefficient of variation#
Left leg: tibialis anterior	21	(64)	3.06
Left leg: biceps femoris	43	(65)	1.54
Left leg: gastrocnemius	45	(45)	1.00
Rectus abdominis	55	(68)	1.23
Right leg: rectus femoris	55	(53)	0.96
Left leg: gastrocnemius	55	(26)	0.47
Anterior deltoid	62	(22)	0.35
Pectoralis Major	72	(43)	0.60
Latissimus dorsi	76	(85)	1.12
Triceps brachii	81	(37)	0.46
Right leg: tibialis anterior	84	(73)	0.87
Middle trapezius	85	(44)	0.52
Right leg: gastrocnemius	93	(24)	0.26
Erector spinae	109	(53)	0.49
Right leg: biceps femoris	115	(27)	0.23

#To judge the degree of dispersion in the consistency among the eight test subjects, a smaller coefficient of variation indicates higher consistency of the data.

Table 10. The duration of the activation of each muscle; 100% refers to the complete period required for a "fajin" action.

Muscle	Percent of fajin time period		
	Mean	Standard deviation	Coefficient of variation#
Right leg: gastrocnemius	215	(150)	0.70
Right leg: rectus femoris	266	(136)	0.51
Latissimus dorsi	318	(216)	0.68
Left leg: gastrocnemius	323	(269)	0.83
Erector spinae	334	(290)	0.87
Left leg: biceps femoris	338	(169)	0.50
Rectus abdominis	341	(177)	0.52
Right leg: biceps femoris	343	(279)	0.81
Pectoralis Major	343	(236)	0.69
Left leg: tibialis anterior	350	(83)	0.24
Middle trapezius	356	(213)	0.60
Triceps brachii	396	(276)	0.70
Left leg: rectus femoris	408	(179)	0.44
Right leg: tibialis anterior	481	(255)	0.53
Anterior deltoid	525	(290)	0.55

#To judge the degree of dispersion in the consistency among the eight test subjects, a smaller coefficient of variation indicates higher consistency of the data.

Discussion

The fajin technique explored in this study mainly involves action in the forward and backward directions, like Push Hand in Tai Chi Chuan [9]. More specifically, the fajin practitioner first moves his centre of gravity as far back as possible and then quickly shifts it forward through the extension of his rear foot and the flexion of his front foot. Thus, in this investigation, joint motions are only discussed in the sagittal plane. The study results revealed that the maximum ground reaction force (produced by a push of the left leg) occurred during the early stages of fajin, prior to the maximum joint angular velocity, maximum joint angle, and movements of the fajin recipient. This finding verifies that fajin is launched by pushing against the ground with the rear foot [10-12]. After this push, the extension velocities of the left knee, waist, left ankle, and left hip sequentially increased to their maximum levels, and the centre of gravity quickly shifted forward. The fajin recipient started moving when his waist reached its maximum extension velocity, which occurred approximately halfway into the fajin period. Although the right wrist's maximum extension velocity occurred prior to the waist's maximum stretch speed and the left wrist's maximum extension velocity occurred prior to the left hip's maximum extension velocity, the maximum angular velocities of all of the other joints in the upper limbs occurred after the maximum angular velocities of the joints in the lower limbs. Similar experimental results were obtained with respect to the sequence of the maximum joint angles, supporting the model of a kinetic chain that transmits power from the lower limbs to the upper limbs [3]. Although the wrist is located at the end of an upper limb, studies suggest that it must quickly extend and lock when the rear foot pushes against the ground and the fajin practitioner's centre of gravity shifts forward because the heel of the palm is the main contact point with the fajin recipient. This wrist motion allows the forward force to be sent to the opponent through the heel of the hand. If the wrist does not immediately extend when the practitioner's centre of gravity shifts, contact with the fajin recipient will cause flexion in the wrist. This movement wastes a portion of the forward impetus. Because the upper body is slightly twisted in these experiments, the extension and locking action will be slightly slower in the left wrist than in the right wrist.

Fajin constitutes a reasonable and efficient way to transmit power from a human body. The order of muscle activation during fajin helps elucidate how this power is transferred. This study found that the activation of all examined muscles (except for the right biceps femoris and the right gastrocnemius) occurred prior to the fajin. It may be speculated that this activation reflected the maintenance of a stable preparatory status before the fajin. However, the peak muscle activation occurred after the fajin was initiated. In particular, the following order was observed for this peak activation. First, the peak activation of the left gastrocnemius, left rectus femoris, left tibialis anterior, and left biceps femoris was observed. Subsequently, the sequential peak activation of the anterior deltoid, pectoralis major, rectus abdominis, triceps, middle trapezius, latissimus dorsi, and erector spinae occurred in the upper body. This sequence of peak activations is identical to the order determined by Nien for all of the examined muscles (except for the triceps) [1]. The integrated muscle use involves pushing by the rear foot, extension of the rear leg to maintain stability, and continued force exertion through the upper limbs. The force in the upper limbs prevents the reaction force (generated by contact with the fajin recipient) from bending the upper limb and mitigates the forward thrust of the fajin motion. The muscle groups in the torso are responsible for maintaining the upper body's postural stability to avoid a loss of balance. The muscle groups in the right supporting leg reach their peak activation during the late stages of fajin, providing stability as the center of gravity shifts forward into a lunge. This movement helps complete the power transfer process.

Because the study participants practiced various types of martial arts, they learned fajin through different processes. Thus, it is unsurprising to find considerable individual differences in muscle utilization. This variability produced inconsistencies in the time of peak angular velocities, maximum joint angles, muscle activation initiation, and peak muscle activation, as well as in the muscle activation durations. These inconsistencies persisted after standardizing the data against the duration of fajin movements. Therefore, the time points of any particular joint or muscle activity cannot be presented. Moreover, the specific activation duration of each muscle cannot be accurately calculated. However, the subjects showed consistency in terms of the order of various occurrences. In particular, the sequence of maximum joint angles was highly consistent. Thus, while the exact time points and the muscle activation durations varied across individuals, the movement and positioning of their body segments occurred in a consistent order. This fixed order allows each limb segment to contribute to the fajin action in an integrated, synergistic manner.

Conclusions

This study demonstrated that the fajin movement pattern involves the initiation of a ground reaction force (a push by the rear foot), a forward shift of the centre of gravity, and the transference of force from the lower limbs to the upper limbs. The timing of the joint operations and muscle activations occurred in the same order in all of the subjects. Because traditional martial arts training uses descriptive language in the teaching process, muscle utilization differences can readily arise between individual martial artists. However, the body segments moved in a fixed order in all of the subjects, indicating that various martial arts approaches converge towards the achievement of the same objectives during a fajin. Future studies should specifically examine a number of top martial artists and/or individuals who practice the same martial arts discipline. These examinations may elucidate the extent to which martial arts practices can be quantified and can contribute to identification of the optimal language and methodology for martial arts instruction.

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Competing interests

The authors declare that they have no competing interests.

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