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Article

Effects of hurdle leg stretch and neuromuscular electrical stimulation intervention on front kick in martial arts: A kinematic analysis

Chao-Fu Chen[1], Xing-Xing Shen[2], Yi-Chen Chou[3,*], Hui-Ju Wu[4,*]

[1] Jimei University, Physical Education College, Xiamen 361021, China
[2] Physical Education College, Huaibei Normal University, Huaibei 235000, China
[3] Physical Education Office, National Tsing Hua University, Hsinchu 300044, Taiwan
[4] Xiamen Yixue Sports and Technology Co., Ltd, Xiamen 361021, China
*** Corresponding author:** Yi-Chen Chou, a0925701007@yahoo.com.tw; Hui-Ju Wu, s1234567898023@gmail.com

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Abstract: Exploring the effects of electrical stimulation intervention and hurdle leg stretching on forward kicking in martial arts. This study recruited 15 male students majoring in martial arts from normal universities as the experimental participants. The first test (T1) made the hurdle leg stretch the left and right legs on the yoga mat for 2 min. In the second test (T2), after three days of waiting, the electrotherapy device was utilized to perform NMES intervention on these three muscles for 30 minutes. Subsequently, wear the inertial motion capture system, and try the participant's best to complete the forward kick. At the instant of toe-off, the T2 of the thigh acceleration, hip joint angle, and thigh angular velocity performs better than T1, and presents a highly significant level. In the forward kicking technique of martial arts, the intervention effect of NMES was better than that of traditional stretching training. The thigh acceleration, thigh angular velocity, and hip joint angle at the instant of leaving the ground are the key techniques of forward kicking. Therefore, NMES technology can be employed as a crucial tool to improve both the flexibility and strength of leg muscles, as well as the quality of forward kicking movements.

Keywords: jumping front kick; tai chi; long fist; snap kick; southern fist

1. Introduction

Martial arts is a great traditional culture and a precious cultural heritage in China. The Martial Arts Management Center of the General Administration of Sports of China revised the rules of martial arts in 2003. Under the newly modified rules, the difficulty level and score evaluation system of martial arts movements will be more comprehensive. In this context, martial arts is proposed to be developed in the direction of "high, beautiful, difficult, and novel" [1]. Front kick can be said to be the basic skill of martial arts, so if you want to achieve the goal of difficult martial arts movements and enhance the quality of movements, you must first practice the basic skills of martial arts well to create a solid foundation for the goal you want to achieve. The essentials of forward kicking movements are chest out, waist straight, abdomen retracted, hips retracted, and keeping the soles of the foot in the dorsiflexion position during kicking [2]. In such a state, the knees of the supporting legs are also straightened to enhance the overall stability of the body and prevent them from accidentally shaking [3]. The movement quality of the front kick can indicate whether a person's basic martial arts skills are solid. However, traditional training methods such as leg ligament flexibility (muscle stretching) and enhancing leg strength could be employed to improve the quality of martial arts movements. These traditional training methods only enhance the quality of kicking in martial arts by changing the function of the muscles, but overlook the effect of the nervous system on the muscles [2,4,5].

Neuromuscular electrical stimulation (NMES) refers to the application of low-frequency stimulating current to muscle tissue, reestablishing nerve stimulation channels, and restoring or enhancing muscle contraction function by implementing the physiological variations induced by NMES [6].The combination of NMES and advanced motion capture technology is innovative, as it allows for precise tracking and analysis of neuromuscular activation and movement patterns, offering deeper insights into its effects on motor performance and rehabilitation. In recent years, NMES technology has received high attention in the field of sports and has been extensively developed. Since it could adjust the neuromuscular system function and enhance the body's exercise capacity, it stimulates the neuromuscular fibers. When the excitement is transmitted to the muscle, causing the contraction of the muscle fiber, that is, with less intensity of neuromuscular stimulation, NMES is also capable of growing the recruitment speed of the muscle fiber [4]. On the other hand, NMES also has a substantial influence on enhancing the maximum isometric contraction force of muscles and enlarging the volume of muscles, and the human body has no noticeable discomfort with NMES [7]. Therefore, NMES technology has become one of the more and more crucial tools of modern sports training and rehabilitation therapy. It is often employed in muscle atrophy, muscle function rehabilitation training for spinal cord injury patients, muscle strengthening training for athletes, and other training [8,9]. However, the inertial capture system records the movement of these joints employing inertial gyroscopes or accelerometers installed at some crucial joints of the human body. Compared with the optical capture system, it is highly portable, not easy to fall off, and easy to operate. In this state, there are many precise data to capture the action [10,11]. This experiment was completed with the assistance of an inertial motion capture system. Currently, there are not many studies on the influence of NMES on front kick movements, and no in-depth kinematic analysis has been conducted on this issue. Therefore, this study aims to employ the verification results of this experiment as a solid reference for those who will engage in martial arts in the near future.

2. Materials and methods

2.1. Participants

This study recruited 15 male students majoring in martial arts from normal universities as the experimental participants, with an average professional experience of 2.5 ± 0.5 years, an average height of 175.53 ± 4.98 cm, a weight of 66.87 ± 6.20 kg, an age of 22.00 ± 1.46 years, and the dimensions of the head, neck, upper body, pelvis, shoulders, upper arm, forearm, hand, thigh, calf, ankle, and foot were 22.3 ± 1.6 cm, 10.63 ± 1.47 cm, 58.25 ± 6.44 cm, 30.9 ± 2.1 cm, 36.47 ± 3.02 cm, 29.81 ± 2.06 cm, 24.72 ± 1.21 cm, 19.18 ± 1.01 cm, 42.6 ± 3.6 cm, 40.1 ± 2.0 cm, 9.1 ± 1.8 cm, and 28.3 ± 1.9 cm, respectively. Before the experiment, the participants were aware of the purpose, process, and precautions of the experiment and signed the informed consent. All the implementation processes of this study comply with the standards and norms of the Declaration of Helsinki in 1964 and were reviewed by the local University Academic Ethics Committee (No. 22040851).

2.2. Experimental instruments and materials

1) Inertial motion capture system (FOHEART·X, Beijing, China);
2) Motion analysis system (Motion Venus 3.1.0);
3) Electrotherapy device (ZN-566, Guangzhou City, Beijing, China);
4) Yoga mat 185 × 80 cm (CHUANGZHEN, China).

2.3. Study design and procedures

This study was conducted using an inertial motion capture system that was performed in a laboratory. Before preparing for the test, the dimensions of the participant’s head, neck, upper body, pelvis, shoulders, upper arm, forearm, hand, thigh, calf, ankle, and foot are measured with a ruler. After completing the measurement, log the data into the bone length of the motion analysis system, click on the program, and then compare the two forward kick tests. After the measurement was completed, these data were input into the motion analysis system, and then the comparison of two forward kicking tests was carried out.

The first test (T1) was to permit the experimental participants to fully warm up. Thereafter, make the hurdle leg stretch the left and right legs on the yoga mat for 2 min (**Figure 1**) [12]. Wear the FOHEART X clothing and install 17 sensors on the understudied participants’ head, left shoulder, right shoulder, sternum, left upper arm, right upper arm, left forearm, right forearm, left hand, right hand, pelvis, left thigh, right thigh, left calf, right calf, left foot, and right foot (**Figure 2**). After the device was completed, the sensor was subjected to three-dimensional calibration of Z-Pose (**Figure 3a**), I-Pose (**Figure 3b**), T-Pose (**Figure 3c**) and S-Pose (**Figure 3d**), and then the participant performed a forward kick as best as he could.

Figure 1. Schematic diagram of hurdle leg stretching.

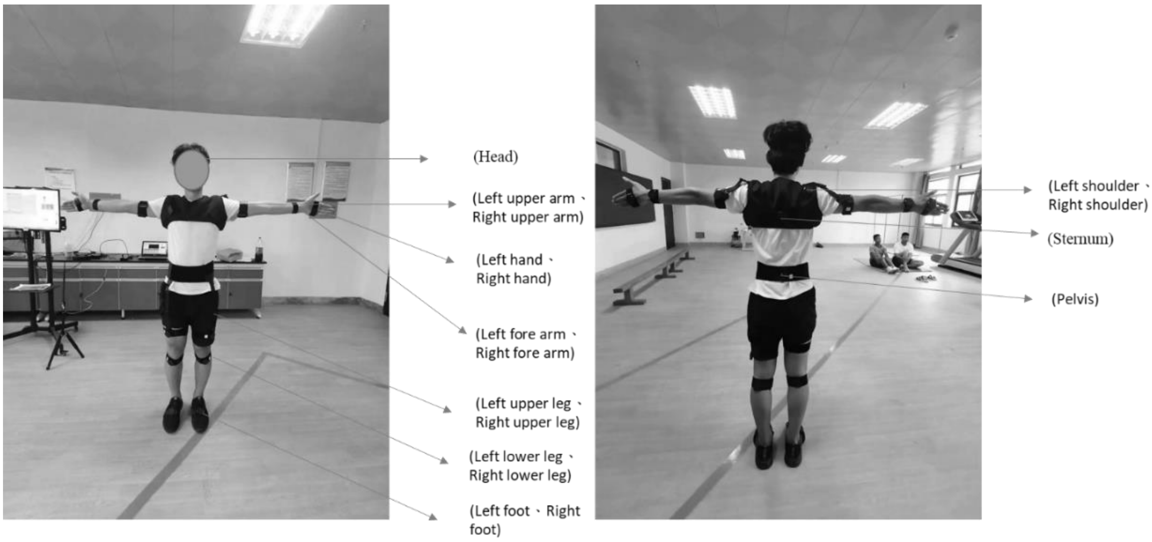

Figure 2. Inertial motion capture system 17 sensor device position.

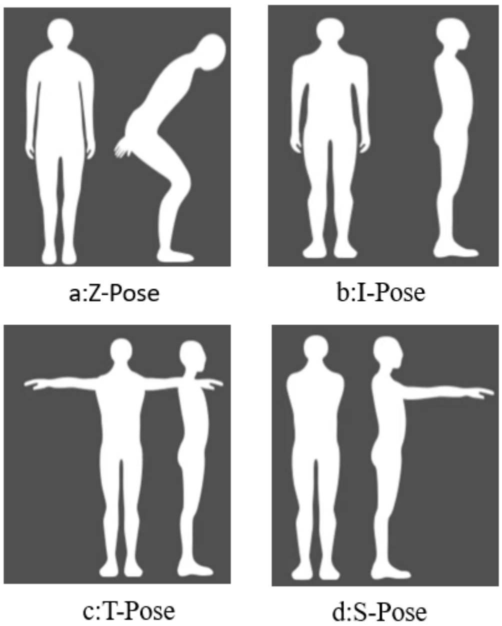

Figure 3. Schematic diagram of inertial motion capture correction.

In the second test (T2), after three days of waiting, the skin of the quadriceps femoris, biceps femoris, and gastrocnemius muscle of the participant's legs was first wiped with alcohol cotton pads to enhance the accuracy of electrical stimulation (**Figure 4**) [3,13]. Then the electrotherapy device was utilized to perform NMES intervention on these three muscles for 30 min [4,14,15]. The stimulation was initiated at a frequency of 1000 Hz, with the intensity set to the participant's maximum tolerance level. The average power output was 28.67 ± 1.86 VA. Subsequently, wear the inertial motion capture system, perform postural correction, and try the participant's best to complete the forward kick.

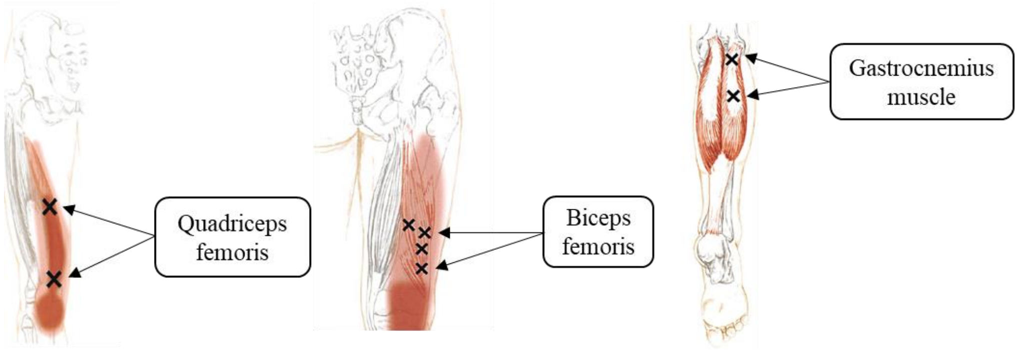

Figure 4. Schematic diagram of neuromuscular electrode placement [13].

2.4. Statistical analysis

In the present study, the experimental analysis of 15 male college students' hurdle leg stretching intervention (T1) and NMES technology intervention (T2) kinematic analysis of the impact in forward kicking that keeping the soles of the foot in the dorsiflexion position during kicking. The action stage was divided into: the instant of the toe-off and the highest point, as shown in the **Figure 5**. Define the *X*-axis as the left-right direction, the *Y*-axis as the front-rear direction, and the *Z*-axis as the vertical direction. First, extract the action moments that need to be analyzed (the instant of the toe-off and the highest point). The inertial motion capture system was used for analysis. The moment when the knee joint angle was at the minimum value was defined as the instant of the toe-off, and the instant when the hip joint angle was at the maximum value was defined as the instant of the highest point. The acceleration and angular velocity of the thigh, calf, and foot, the angles of the hip, knee, and ankle in the two instants were analyzed respectively [3,14–16].

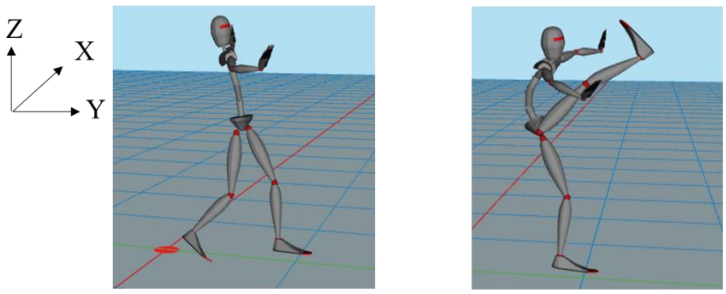

Figure 5. Schematic diagram of the instant of the toe-off and the highest point.

The kinematic parameter data compiled in this research experiment were statistically processed with SPSS 26 for Windows (SPSS, Inc., Chicago, IL, USA) statistical software, and the mean and standard deviation were calculated by descriptive statistics, and then expressed as the Mann-Whitney U test of parental statistics was used to test the differences between T1 and T2 kinematic parameters, and the significance level was set at $\alpha = 0.05$.

3. Results

The results of T1 and T2 kinematic parameters were shown in **Table 1**. The results show that at the instant of toe-off, the thigh acceleration T2 was greater than T1 and presents a highly significant level ($z = -0.284$, $p = 0.005$), the hip joint angle T2 was greater than T1 and presents a significant level ($z = -0.852$, $p = 0.023$), the thigh angular velocity T2 was faster than T1 and shows a significant level ($z = -2.272$, $p = 0.023$). At the instant of the highest point, there was no significant difference in the kinematic parameters ($p > 0.05$).

Table 1. Kinematic parameters of T1 and T2 instant of the toe-off and the highest point. $N = 15$.

	Forward kick after hurdle leg stretch (T1)	**Forward kick after NMES intervention (T2)**	***z*-value**	
The instant of the toe-off				
Thigh acceleration (m/s)	2.83 ± 0.56	3.82 ± 1.22	−0.284	**
Calf acceleration (m/s)	3.15 ± 0.77	3.63 ± 1.33	−1.533	
Foot acceleration (m/s)	5.82 ± 1.45	6.05 ± 1.35	−0.966	
Hip angle (Deg)	10.32 ± 6.80	12.19 ± 8.43	−0.852	*
Knee angle (Deg)	127.64 ± 9.17	124.22 ± 11.94	−2.272	
Ankle angle (Deg)	107.93 ± 11.06	105.34 ± 14.05	−0.511	
Thigh angular velocity (m/s)	324.60 ± 79.64	388.97 ± 115.98	−2.272	*
Calf angular velocity (m/s)	241.93 ± 92.93	293.30 ± 158.45	−0.966	
Foot angular velocity (m/s)	487.10 ± 167.43	485.67 ± 190.93	−0.057	
The instant of the highest point (when the hip joint angle was at its maximum value)				
Thigh acceleration (m/s)	2.29 ± 0.85	1.97 ± 1.97	−1.540	
Calf acceleration (m/s)	3.58 ± 0.95	3.37 ± 3.37	−1.193	
Foot acceleration (m/s)	6.81 ± 1.97	6.77 ± 6.77	−0.284	
Hip angle (Deg)	115.61 ± 18.15	121.59 ± 16.43	−0.909	
Knee angle (Deg)	159.88 ± 8.37	161.94 ± 9.94	−0.341	
Ankle angle (Deg)	100.20 ± 10.23	105.72 ± 16.99	−1.988	
Thigh angular velocity (m/s)	114.68 ± 52.33	169.02 ± 184.14	−0.398	
Calf angular velocity (m/s)	117.08 ± 71.42	103.20 ± 92.50	−0.909	
Foot angular velocity (m/s)	131.78 ± 82.04	140.87 ± 98.65	−0.220	

Notes: $*p < 0.05$; $**p < 0.01$.

4. Discussion

In the preceding explorations, it has been found that the application of NMES enhances both trained and untrained muscle strength as well as leg performance in the lower extremities [14,15,17]. In martial arts forward kicking technique, the balance ability should be based on the muscle strength of the body, so it is necessary to strengthen the muscle strength of the legs and upper limbs and coordinate the developing upper and lower limb muscle strength, which is the key to doing martial arts movements well. Flexibility is a prerequisite for performing leg swings [1,2,18]. To examine human movement from a muscular point of view, you should consider how muscle power is generated and how various muscle groups work together [12,19–22]. The combination of NMES and advanced motion capture technology is innovative, as it enables precise tracking of neuromuscular activation and movement patterns, providing deeper insights into the coordination of muscle groups and their contribution to martial arts technique.

The results of the present study reveal that thigh acceleration, thigh angular velocity, and hip joint angle at T2 were better than at T1 at the instant of toe-off, indicating a linkage between leg flexibility and hip joint flexibility (i.e., range of motion). These findings align with previous studies suggesting that improved hip flexibility contributes to enhanced kicking performance [3,18]. Moreover, the results demonstrate that the intervention effect of NMES was superior to that of traditional stretching training, consistent with research highlighting the benefits of NMES in improving muscle function and flexibility [10,14,15]. During kicking, utilizing the flexibility of the posterior ligaments of the thigh and calf is essential for optimizing movement execution, further emphasizing the importance of enhancing hip joint flexibility, which is primarily influenced by the surrounding ligaments. Integrating these findings with existing literature strengthens the argument that NMES can be an effective alternative or complement to traditional flexibility training.

Only through effective training can the flexibility of the surrounding ligaments be increased, the flexibility of the hip joint be improved, and the height of the forward kick be increased, resulting in enhancing the quality of the forward kick [18]. The intervention of NMES technology not only improves the flexibility of leg muscles to a certain extent but also magnifies the acceleration and angular velocity of the legs. The improvement of leg speed was inseparable from the strength of leg muscles. Therefore, NMES technology can be employed as a crucial tool to improve both the flexibility and strength of leg muscles, as well as the quality of forward kicking movements. NMES technology intervention will be an innovative training approach [4,6–9,14,15].

5. Conclusion

In the martial arts forward kicking technique, the intervention effect of NMES was more effective than that of traditional stretching training. Thigh acceleration, angular velocity, and hip joint angle at the toe-off phase were among the crucial prerequisites for optimal kicking performance. This study was limited to male subjects, and each participant underwent only a short NMES intervention period. Future research could include female subjects to enhance generalizability and examine the effects of NMES over a longer intervention period. Additionally, further studies could explore the long-term impact of NMES on martial arts performance and its application in other movement techniques or sports disciplines. Such investigations would provide valuable insights into optimizing NMES intervention training and serve as a solid reference for trainers seeking to enhance athletic performances.

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HJW; data curation, CFC; writing—original draft preparation, CFC, YCC, XXS and HJW; writing—review and editing, CFC, YCC, XXS and HJW; supervision, CFC, YCC and HJW; project administration, CFC, YCC and HJW. All authors have read and agreed to the published version of the manuscript.

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Ethical approval: The implementation processes of this study comply with the standards and norms of the Declaration of Helsinki in 1964 and were reviewed by the local University Academic Ethics Committee (No. 22040851).

Conflict of interest: The authors declare no conflict of interest.

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