Infrared Thermal-Imaging Method Applied To Muscle Behaviour Study of Sport Skill (The Roundhouse Kick of Martial Arts As An Example)

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Abstract

In the field of muscle behavior study of sport skills, it seems that there is no other advanced technology applied to the research of muscle behavior, except for electromyography. In this work, we employed an advanced and innovative technology to study systematically the muscle behavior of sport skills, with the roundhouse kick of martial arts as an example. The several main results are obtained as follows. (i) With kick based on either leg, the quadriceps femoris, biceps femoris and gastrocnemius muscles located at supporting leg are always more strenuous than these located at kicking leg. (ii) In contrast, the external oblique and gluteus maximus muscles located at kicking side are more strenuous than these muscles of supporting side. (iii) Further, it does not seem to be the key for the rectus abdominis and erector spinae muscles to affect the kicking motion. Moreover, this work suggests that athletes could enhance the exercise of thigh muscles, external oblique and gluteus maximus muscles in daily training, if they want to improve the leg-control technique of roundhouse kick. Overall, this work shows a new approach and some valuable results, which provides new perspective for the further muscle behavior study of sport skills.

Keywords — *Infrared thermal-imaging method, New approach, Muscle behavior study, Sport skills.*

I. INTRODUCTION

In terms of most martial arts including Taekwondo, Karate, Sanda and Muaythai, the roundhouse kick is the most basic and most practical motion [1, 2]. A large number of martial arts competitions show that the use of roundhouse kick technique receives main scores, especially for Taekwondo [3, 4]. Due to the importance and universality of roundhouse kick, roundhouse kick are studied widely [5, 6]. With the progress of scientific research equipment, people have made extensive research on the positions, posture, joint behavior and impact force of roundhouse kick [7-10]. To further improve athletes' kick level and understand the biological mechanism of roundhouse kick, the muscle behavior induced by roundhouse kick is worth to be investigated. However, a large amount of early studies on muscle behavior of roundhouse kick were based on statistical data, which was simple and vague. Hence, it is difficult and unrealistic for those studies to understand clearly muscle behavior and motion mechanism of roundhouse kick. Until recent years, the electromyography instrument is applied to sports science, which can study in depth the muscle behavior of roundhouse kick, causing a hot issue [11-14]. For instance, U. F. Ervilha *et al*. compared the taekwondo kick performing between elite and novice athletes by measuring the muscles activation of the lower back and the striking lower limb [14]. Nevertheless, the muscle information from electromyography is still not enough for the development of muscle science. Except for electromyography, it seems that the current reports have no else advanced technology applied to muscle research of kick. In this work, we show the innovative application of infrared thermal-imaging method in muscle research. The infrared thermal-imaging method is utilized to investigate the muscle behavior of roundhouse kick, which is convenient and effective. Our work proves that infrared thermal-imaging method can obtain more muscle information different from that of electromyography, which can be used as a new research approach to further study muscle behavior and sport skills.

II. EXPERIMENT AND METHOD

A. The principle of infrared thermal-imaging method applied to muscle behavior study

Any object can radiate infrared light, and the intensity of infrared light is related to the surface temperature of the object. Normally, the temperature of different parts of the body is not the same, and when a muscle of the body is exercised, the blood flow and metabolism in this part will increase, making the body temperature in this part higher than that before exercising. Fig. 1 simply shows the principle. Before and after the change of local muscle temperature, the infrared radiation of the muscle has different intensity and different wavelength. Therefore, these temperature changes can be investigated by advanced infrared thermal-imaging technology to analyze muscle behavior. For instance, Fig. 2 shows the practical application on gastrocnemius muscle. The surface temperature of gastrocnemius muscle before and after exercising is measured as shown at right in Fig. 2. The color difference of infrared thermography reflects the temperature change on muscle surface, and the infrared thermography (IR) temperature data can be read accurately by advanced analysis software. It can be seen from Fig. 2 that the IR temperature of gastrocnemius muscle (37.5 °C) after exercising is significantly higher than that (34.0 °C) before exercising, which proves the effectiveness of infrared thermal-imaging technology in the study of muscle behavior.

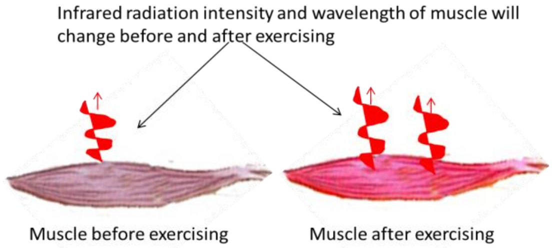


Fig. 1. The schematic infrared radiation difference of muscle before and after exercising

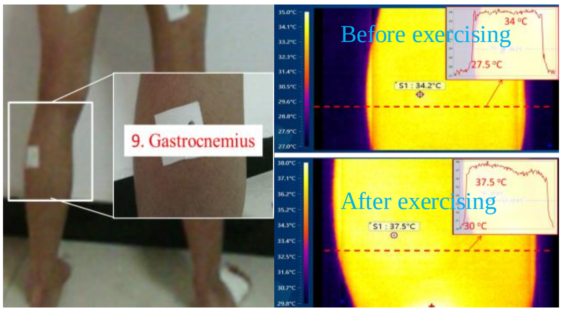


Fig. 2. A practical application show for the infrared thermography temperature of gastrocnemius muscle before and after exercising

B. Participants and experimental details

Participants are two young men and two young women, and they are professional taekwondo athletes. These athletes can show the roundhouse kick skillfully whichever leg they use. All participants are 14 years old with the 175 cm tall for two young men and 170 cm for two young women. Also, two male athletes with similar body proportions have the same weight of 60 kg, and two female athletes with similar body proportions have the same weight of 50 kg. The athletes' codes are respectively A and B (for two young men), C and D (for two women).

Because professional athletes were trained daily, all participants were required to rest for five days before the study to exclude the effects of daily training. Nine muscles of all participants were marked and shown in the schematic Fig. 3. Nine muscles are respectively ① rectus abdominis, ② external (abdomen) oblique, ③ rectus femoris, ④ vastus medialis, ⑤ vastus lateralis, ⑥ erector spinae, ⑦ gluteus maximus, ⑧ biceps femoris and ⑨ gastrocnemius. All tests were carried out indoors and the indoor temperature was kept at 26 °C. All participants used standard roundhouse kick with middle position, referring the standard pose as shown Fig. 4. Here, for convenience of analysis and description, we defined the supporting side where the supporting leg was located and defined the kicking side where kicking leg was located. Using infrared thermal-imaging instrument, the infrared thermography of every athlete was recorded before kicking, then they kick using right leg and left leg respectively for 20 times to make muscles active. Finally, they kept the completed roundhouse kick pose, and the infrared thermography of both the whole body and local muscles were recorded as shown in the schematic Fig. 5. Further, the IR temperature data were read from infrared thermography via the professional thermography analysis software, as shown in Table 1.

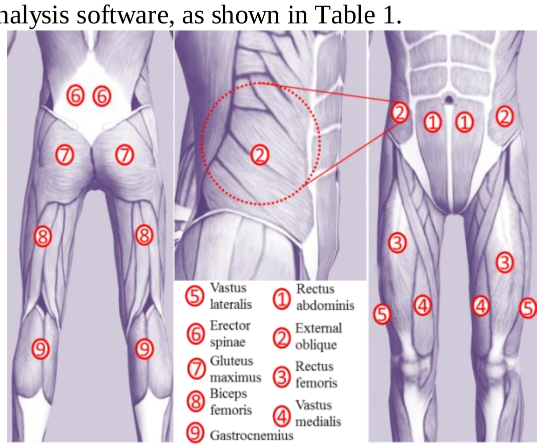


Fig. 3. The schematic nine muscle positions

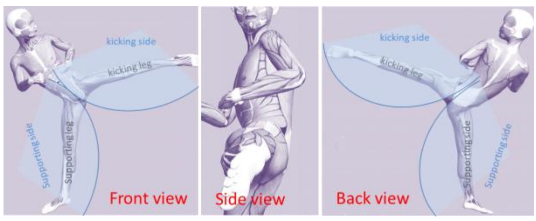
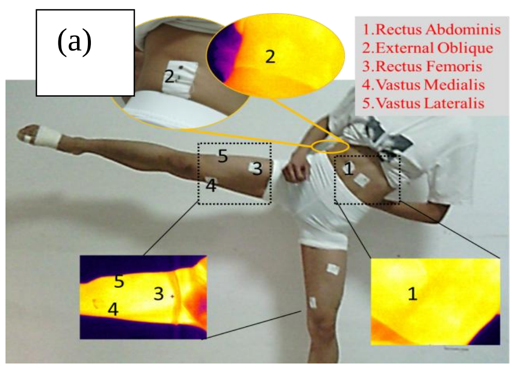


Fig. 4. The schematic for standard roundhouse kick with middle position



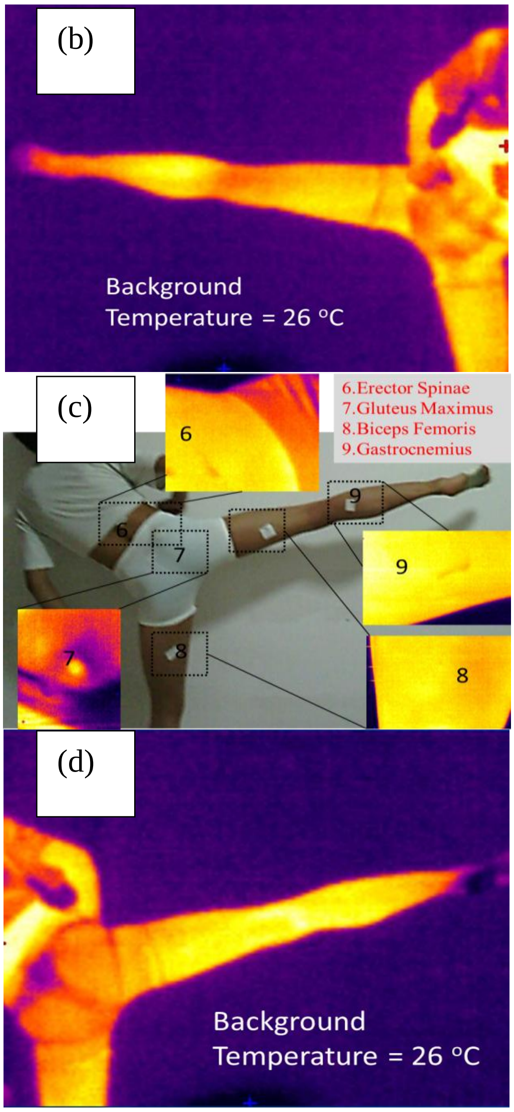


Fig. 5. The infrared thermography of both the whole body and local muscles for the completed roundhouse kick pose; (a) the local thermography in front view, (b) the whole thermography in front view, (c) the local thermography in back view, and (d) the whole thermography in front view

III. RESULTS

The investigated IR temperature data of nine muscles for all participants are shown in Table 1. The several important results in Table 1 capture our attention.

Firstly, comparing the data of kicking leg (K) and supporting leg (S) for quadriceps femoris (including rectus femoris, vastus medialis and vastus lateralis), biceps femoris and gastrocnemius muscles (see muscle positions No. 3-6 & No. 8-9 with blue tracking in Table 1), it can be seen for all participants that muscle temperature of supporting leg is always higher than that of kicking leg. To further see this result, athlete A' data are used as an example to be depicted in Fig. 6. With the kick based on either leg (left leg or right leg), IR temperatures of quadriceps femoris, biceps femoris and gastrocnemius muscles of supporting leg are higher as compared with that of kicking leg, suggesting these muscles of supporting leg are more strenuous than that of kicking leg.

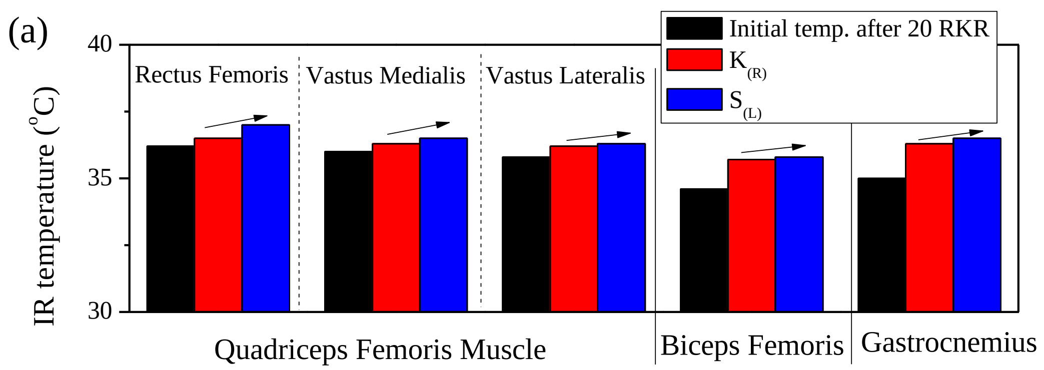
Secondly, comparing the data of kicking leg (K) and supporting leg (S) for external abdomen oblique and gluteus maximus muscles (see muscle positions No. 2 & No. 7 with violet tracking in Table 1), these two muscles located at supporting side have obviously the lower IR temperatures than them located at kicking side. Fig. 7 used the athlete A' data as an example is also depicted to reveal this result. With the kick based on either leg, the external abdomen oblique and gluteus maximus muscles of kicking leg are more strenuous than that of supporting leg, which is the contrast to the first result.

Moreover, although the IR temperatures between kicking leg and supporting leg are different for most muscles, such the differences between supporting side and kicking side is not found for rectus abdominis and erector spinae muscles with kick based on either leg. This result originates from the data of muscle positions No. 1 & No. 6 with gray tracking in Table 1 and is also as depicted in Fig. 8. It can be seen from Fig. 8 that the IR temperature of rectus abdominis and erector spinae muscles between right and left is obvious same regardless of which leg is used to kick.

Table 1. The IR temperature (temp.) data of nine muscles for all participants before and after kicking

Athlete coding	Muscle positions	Initial IR temp. (°C)	IR temp. after 20 RKR (°C)		IR temp. after 20 RKL (°C)	
			$K_{(R)}$	$S_{(L)}$	$K_{(L)}$	$S_{(R)}$
A	1.Rectus Abdominis	37.0	37.5	37.5	37.5	37.5
	2.External Oblique	36.5	36.9	36.5	37.2	36.8
	3.Rectus Femoris	36.2	36.7	37.0	36.4	37.4
	4.Vastus Medialis	36.0	36.3	36.5	36.1	36.9
	5.Vastus Lateralis	35.8	36.2	36.3	35.8	36.5
	6.Erector Spinae	35.5	36.1	36.1	36.4	36.4
	7.Gluteus Maximus	32.0	34.8	34.0	35.9	35.3
	8.Biceps Femoris	34.6	35.7	35.8	36.0	36.5
	9.Gastrocnemius	35.0	36.3	36.5	36.0	36.3
B	1.Rectus Abdominis	37.8	38.0	38.0	38.0	38.0
	2.External Oblique	37.5	38.3	38.1	38.5	38.0
	3.Rectus Femoris	36.5	37.0	37.6	37.5	37.8
	4.Vastus Medialis	36.1	36.3	36.6	36.5	36.6
	5.Vastus Lateralis	36.2	36.3	36.7	36.8	36.8
	6.Erector Spinae	37.0	37.7	37.7	37.3	37.3
	7.Gluteus Maximus	36.8	37.8	37.2	37.9	37.7
	8.Biceps Femoris	36.5	37.3	37.4	36.8	37.1
	9.Gastrocnemius	35.6	36.0	36.5	36.1	36.8
C	1.Rectus Abdominis	37.8	37.9	37.9	38.0	38.0
	2.External Oblique	37.2	37.5	37.2	37.7	37.3
	3.Rectus Femoris	37.1	37.4	37.5	37.4	37.5
	4.Vastus Medialis	37.0	37.1	37.1	37.1	37.2
	5.Vastus Lateralis	36.9	36.9	37.2	36.9	36.9
	6.Erector Spinae	37.8	38.0	38.0	38.1	38.1
	7.Gluteus Maximus	35.0	35.6	35.3	35.2	34.9
	8.Biceps Femoris	36.6	36.7	36.9	36.8	36.9
	9.Gastrocnemius	36.0	36.1	36.3	36.7	36.9
D	1.Rectus Abdominis	37.0	37.6	37.6	37.7	37.7
	2.External Oblique	36.1	36.6	36.3	36.8	36.5
	3.Rectus Femoris	37.0	37.3	37.5	37.6	37.9
	4.Vastus Medialis	36.9	37.0	37.2	37.1	37.2
	5.Vastus Lateralis	36.9	37.0	37.2	37.1	37.3
	6.Erector Spinae	37.4	38.0	38.0	38.0	38.0
	7.Gluteus Maximus	36.0	36.6	35.9	36.7	36.5
	8.Biceps Femoris	36.5	36.6	36.9	37.0	37.2
	9.Gastrocnemius	35.8	36.1	36.3	36.7	36.9

Notes. The "RKR" means roundhouse kick using right leg, and the "RKL" means roundhouse kick using left leg. The "$K_{(R)}$ and $K_{(L)}$" mean respectively the side of kicking (K) using right leg (R) and the side of kicking (K) using left leg (L). The "$S_{(R)}$ and $S_{(L)}$" mean respectively the side of supporting (S) using right leg (R) and the side of supporting (S) using left leg (L)



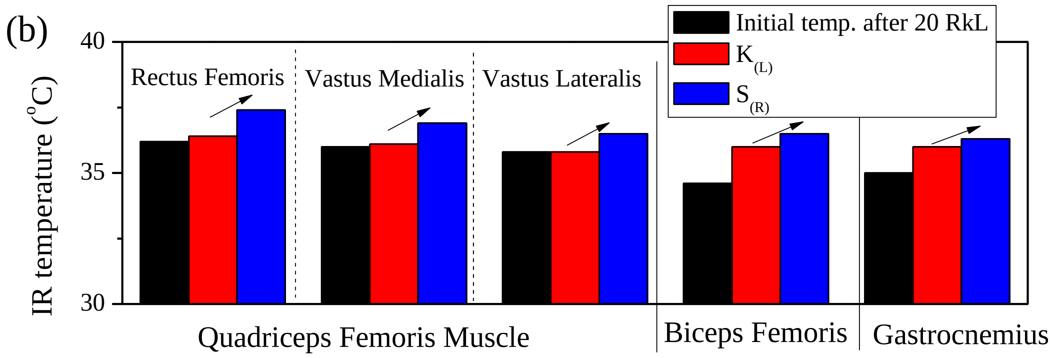


Fig. 6. The IR temperature comparison for quadriceps femoris, biceps femoris and gastrocnemius muscles located at supporting leg and kicking leg; (a) after 20 roundhouse kick using right leg, and (b) after 20 roundhouse kick using left leg

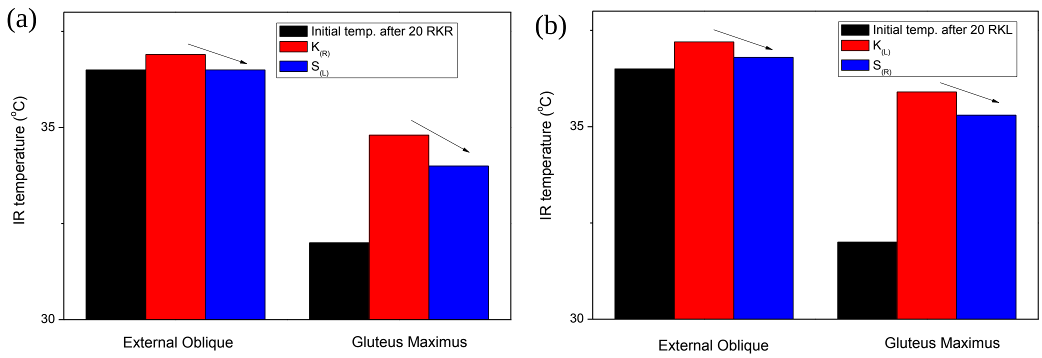


Fig. 7. The IR temperature comparison for external oblique and gluteus maximus muscles at supporting side and kicking side; (a) after 20 roundhouse kick using right leg, and (b) after 20 roundhouse kick using left leg

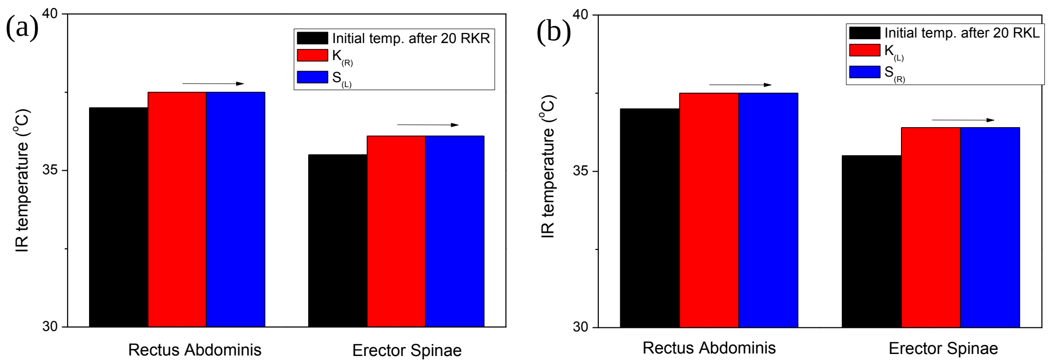


Fig. 8. The IR temperature comparison for rectus abdominis and erector spinae muscles at supporting side and kicking side; (a) after 20 roundhouse kick using right leg, and (b) after 20 roundhouse kick using left leg

IV. DISCUSSION

(Corresponding to above the first result) Fig. 9 shows the schematic muscle stress upon kicking. With the completed roundhouse kick, the only supporting leg supports the whole body and has to bear the weight of the whole body. By comparison, the kicking leg support only itself, thus the muscles stress of kicking leg is weaker than that of supporting leg. As a result, the IR temperature of supporting leg is higher than that of kicking leg in regard to quadriceps femoris, biceps femoris and gastrocnemius muscles. Meanwhile, it needs to be proposed that the main weight of kicking leg is carried by its thigh muscles (including quadriceps femoris and biceps femoris), instead of calf muscles (such as gastrocnemius). Since the knee joint can not be bent laterally, it is natural that the knee joint can hamper the drop of shank upon kicking, so that the calf muscles of kicking leg do not have to carry the weight of the kicking leg.

(Corresponding to above the second result) In contrast, for the external oblique and gluteus maximus muscles, their IR temperatures at supporting side are lower than that at kicking side. The reason can be due to the muscle behavior described in Fig. 10. As shown in Fig. 10, to further keep the kicking leg steady in position without falling, the external oblique and gluteus maximus muscles located at kicking side play a very important role. At kicking side, the athlete must consciously and actively apply force to these two muscles to cause them to contract, thereby pulling the thigh muscles and further stabilizing the kicking leg. At supporting side, however, these two muscles are only passively stretched or tensed and do not need to be deliberately controlled by the athlete. Evidently, comparing with passive muscle behavior, active muscle behavior requires more energy, which can speed up local blood flow and metabolism, resulting in higher local IR temperature.

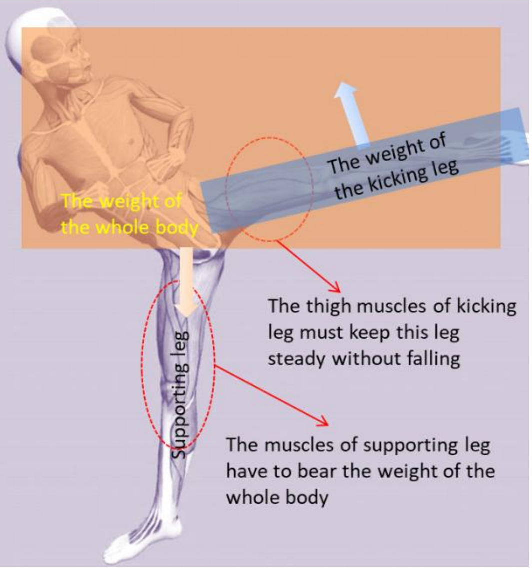


Fig. 9. the schematic muscle stress upon kicking

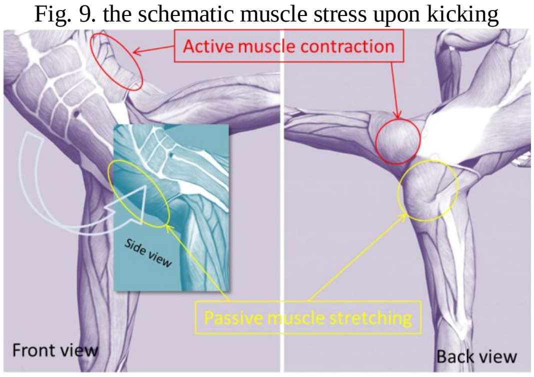


Fig. 10. The muscle behavior comparison for external oblique and gluteus maximus at supporting side and kicking side

Although the kicking motion also utilizes rectus abdominis and erector spinae muscles, their IR temperatures indicate that these two muscles receive the same intensity between supporting side and kicking side, further meaning that they do not play a decisive role in kicking motion compared to other muscles. Based on above analysis, one suggestion can be made --- if the athletes want to practice the leg-control technique of roundhouse kick, they are suggested to pay more attention to strengthening the exercise of thigh muscles (including quadriceps femoris and biceps femoris), external oblique of abdomen muscle and gluteus maximus muscles in daily training.

V. CONCLUSION

To study the muscles behavior of roundhouse kick, nine key muscles were investigated by employing infrared thermal-imaging method. The nine key muscles are respectively ① rectus abdominis, ② external abdomen oblique, ③-⑤ quadriceps femoris (including rectus femoris, vastus medialis and vastus lateralis), ⑥ erector spinae, ⑦ gluteus maximus, ⑧ biceps femoris and ⑨ gastrocnemius. Results show that the quadriceps femoris, biceps femoris and gastrocnemius muscles located at supporting leg are more strenuous than those located at kicking leg. The reason is attributed to that those muscles of kicking leg only support its own weight but those muscles of supporting leg have to bear the weight of whole body upon kicking. By contrast, the external oblique and gluteus maximus muscles located at kicking side are more strenuous than these muscles of supporting side, which is due to that their muscle behaviors are active at kicking side but passive at supporting side. Nevertheless, regardless of which leg is used to kick, both the rectus abdominis and erector spinae muscles show the same stress intensity, might suggest that these two muscles are not the decisive factor for kicking motion compared to other muscles. Furthermore, this work provides a guideline for improving the leg-control technique of roundhouse kick --- athletes are kindly recommended to enhance the exercise of thigh muscles (including quadriceps femoris and biceps femoris), external oblique muscle and gluteus maximus muscle in daily training. Summarily, this work shows a new approach and a new perspective for the further muscle behavior study of sport skills.

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REFERENCES

[1] Gavagan CJ, Sayers MGL, 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, 2017, 12, e0182645.
[2] Cimadoro G, Mahaffey R, Babault N, Acute neuromuscular responses to short and long roundhouse kick striking paces in professional Muay Thai fighters. Journal of Sports Medicine and Physical Fitness, 2019, 59, 204-209.
[3] Estevan I, Falco C, Mechanical analysis of the roundhouse kick according to height and distance in taekwondo. Biology of Sport, 2017, 30, 275-279.
[4] Fife GP, O'Sullivan D, Pieter W, Biomechanics of head injury in olympic taekwondo and boxing. Biology of Sport, 2013, 30, 263-268.
[5] Oliveira MP, Cochrane D, Drummond MDM, Albuquerque MR, Almeida PAS, Couto BP, No acute effect of whole-body vibration on Roundhouse kick and countermovement jump performance of competitive Taekwondo athletes.

Revista Brasileira de Cineantropometria & Desempenho Humano, 2018, 20, 576-584.

[6] Håkon SA, Erna VH, Roland VT, Effect of postactivation potentiation induced by elastic resistance on kinematics and performance in a roundhouse kick of trained martial arts practitioners. Journal of Strength and Conditioning Research, 2018, 32, 990-996.

[7] Isaac E, Julia FS, Daniel J, Coral F, Segment coupling and coordination variability analyses of the roundhouse kick in taekwondo relative to the initial stance position. Journal of sports sciences, 2016, 34, 1766-1773.

[8] Isaac E, Coral F, Julia FS, Daniel J, Comparison of Lower Limb Segments Kinematics in a Taekwondo Kick: An Approach to the Proximal to Distal Motion. Journal of Human Kinetics, 2015, 47, 41-49.

[9] Sant'Ana J, Franchini E, da Silva V, Diefenthaeler F, Effect of fatigue on reaction time, response time, performance time, and kick impact in taekwondo roundhouse kick. Sports Biomechanics, 2017, 16, 201-209.

[10] Coral F, Octavio A, Isabel C, Isaac E, Julio M, Fernando M, Antonio I, Influence of the distance in a roundhouse kick's execution time and impact force in Taekwondo. Journal of Biomechanics, 2009, 42, 242-248.

[11] Federico Q, Valentina C, Alberto DM, Francesco F, Paola S, Repeated Kicking Actions in Karate: Effect on Technical Execution in Elite Practitioners. International Journal of Sports Physiology and Performance, 2016, 11, 363-369.

[12] Tae-Whan K, Sang-Cheol L, Se-Kee K, Sung-Chul K, Young-Tae L, Ki-Tae K, Siddhartha BP, Kicking modality during erratic-dynamic and static condition effects the muscular co-activation of attacker. Journal of sports sciences, 2017, 35, 835-841.

[13] Jemili H, Mejri MA, Sioud R, Bouhlel E, Amri M, Changes in muscle activity during karate guiaku-zuki-punch and kiza-mawashi-guiri-kick after specific training in elite athletes. Science & Sports, 2017, 32, 73-81.

[14] Ulysses FE, Fernando de MF, Camila CS, Joseph H, Reaction time and muscle activation patterns in elite and novice athletes performing a taekwondo kick. Sports Biomechanics, 2018.