Physiological responses on Muay Thai skill learning for Matthayomsueksa students of Buriram province

Respuesta fisiológica al aprendizaje de habilidades de Muay Thai en estudiantes de educación secundaria de la provincia de Buriram

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Abstract

Introduction: Muay Thai is a whole-body martial art requiring coordinated strength, balance, and motor control, yet evidence on muscle activation patterns and training effects in schools remains limited.
Objective: This study investigated muscle electrical activity (electromyography) during the Wai Khru ritual, 15 Mae Mai techniques, and 15 Luk Mai techniques, and compared physiological responses between secondary school students in Buriram Province who received Muay Thai instruction and those who did not.
Methodology: The study used two phases: Phase 1 recorded electromyography in 15 trained students to develop lesson content. Phase 2 implemented the program in 50 students assigned to a control group (conventional sport-skill instruction) or an experimental group (Muay Thai instruction), 25 students per group, taught one 50-minute class each week for 12 weeks. Cognitive performance (computer-based test battery) and physical fitness were assessed before and after the intervention, and between-group differences were analyzed.
Results: The Wai Khru primarily activated the Vastus Lateralis, Medial Deltoid, Triceps Brachii, Flexor Carpi Ulnaris, Biceps Femoris, and Latissimus Dorsi, while fundamental and advanced techniques predominantly engaged the Biceps Brachii, Vastus Lateralis, Medial Deltoid, Biceps Femoris, Flexor Carpi Ulnaris, and Latissimus Dorsi. After 12 weeks, the experimental group showed greater improvements in balance, muscular strength, core muscular endurance, cardiorespiratory endurance, executive functions, and creativity than the control group.
Discussion: Electromyography showed whole-body engagement during Wai Khru Mae Mai and Luk Mai 12-week Muay Thai improved fitness and executive functions.
Conclusions: Muay Thai skills instruction improves integrated physiological and cognitive development in secondary school students.

Keywords

Electromyography; physical fitness; muay thai; cognitive performance; Physical Education.

Resumen

Introducción: El muay thai es un arte marcial de cuerpo entero que requiere fuerza, equilibrio y control motor; sin embargo, la evidencia escolar sobre activación muscular y efectos del entrenamiento es limitada.
Objetivo: Analizar la actividad eléctrica muscular (electromiografía) durante el Wai Khru, 15 técnicas Mae Mai y 15 técnicas Luk Mai, y comparar respuestas fisiológicas entre estudiantes de secundaria de Buriram con y sin instrucción de muay thai.
Metodología: Estudio en dos fases. Fase 1: electromiografía en 15 estudiantes entrenados para elaborar el contenido. Fase 2, 50 estudiantes en grupo control (instrucción convencional) o experimental (muay thai), 25 por grupo, una clase semanal de 50 minutos durante 12 semanas. Se evaluaron rendimiento cognitivo (batería informatizada) y condición física antes y después; se analizaron diferencias entre grupos.
Resultados: El Wai Khru activó principalmente el vasto lateral, el deltoides medio, el tríceps braquial, el flexor cubital del carpo, el bíceps femoral y el dorsal ancho; las técnicas Mae Mai y Luk Mai involucraron predominantemente el bíceps braquial además de esos músculos. Tras 12 semanas, el grupo experimental mostró mayores mejoras en equilibrio, fuerza muscular, resistencia del core, resistencia cardiorrespiratoria, funciones ejecutivas y creatividad que el grupo control.
Discusión: La electromiografía indicó una participación corporal integral durante Wai Khru, Mae Mai y Luk Mai, y la instrucción de muay thai se asoció con mayores mejoras físicas y ejecutivas.
Conclusiones: La instrucción de habilidades de muay thai mejora el desarrollo fisiológico y cognitivo integrado en estudiantes de secundaria.

Palabras clave

Electromiografía; condición física; muay thai; rendimiento cognitivo; Educación Física.

Introduction

Muay Thai is a traditional Thai sport that requires learners to integrate physical fitness with technical skills. The physical fitness components involved play a crucial role in determining the level of performance and proficiency in movement execution, thereby enhancing the effectiveness of sport participation. However, in the school context, the specific physiological response to Muay Thai skill learning remains insufficiently studied. In particular, there is limited evidence regarding specific muscle activation patterns during Muay Thai techniques, the physical fitness adaptations including cardiorespiratory related outcomes, and the cognitive impact associated with the neuromuscular coordination demands of skill learning. Clarifying these aspects is necessary to guide the reader more clearly toward the study objectives and to support curriculum based Muay Thai instruction. At the same time, health-related fitness developed through Muay Thai training includes muscular strength, muscular endurance, flexibility, cardiorespiratory endurance, speed, muscular power, agility, balance, reaction time, and neuromuscular coordination. In addition, Muay Thai can be applied as a means of self-defense in situations involving potential threats (Rapkiewicz et al., 2018).

However, Muay Thai training, when considered in terms of physiological adaptation, should encompass more than changes in the muscular and cardiovascular systems. The process of learning Muay Thai skills involves complex motor activities that require continuous perception of external stimuli, rapid decision-making, and precise motor control. As such, this form of training is inherently linked to the functioning of the nervous system and the brain, particularly within the domain of cognitive functions, which can be regarded as an essential component of physiological adaptation. In the present study, the term "physiological" is used in an integrative sense to refer to measurable responses and adaptations across three interrelated systems that support Muay Thai skill learning: (i) the muscular system, reflected by muscle activation patterns; (ii) the cardiovascular system, reflected by health related fitness outcomes including cardiorespiratory endurance; and (iii) the nervous system, reflected by cognitive and executive function performance relevant to information processing and motor control. Accordingly, executive functions and related cognitive processes are considered indicators of nervous system level physiological adaptation within the framework of this study, rather than being treated as a separate non physiological domain (Alvarado et al., 2025; Laha & Phanpheng, 2025). Training in complex, multi-component skills tends to stimulate adaptations in the central nervous system and information-processing mechanisms, manifested through improvements in several cognitive domains. These include attention, which supports the selection of relevant stimuli and sustained focus during skill execution; memory, especially the encoding and retrieval of movement sequences and previously learned skills for practical performance; and executive functions that regulate goal-directed behavior and movement. Executive functions involve inhibitory control to suppress inappropriate responses, working memory for the temporary storage and manipulation of information such as rules, instructions, or movement timing, and cognitive flexibility that enables the adjustment of movement plans and response strategies in accordance with situational demands. In addition, Muay Thai training is associated with information-processing ability, reflecting the speed and accuracy of perception, interpretation, decision-making, and motor command execution, as well as spatial ability related to the perception of body position, distance, direction, and spatial relationships during movement. Collectively, these cognitive and perceptual processes reflect physiological responses and adaptations of the nervous system, which plays a central role in controlling and coordinating movement in interaction with the muscular system throughout the motor skill learning process (Diamond, 2013; Hillman et al., 2008). In this study, electromyographic analysis is not used solely to describe the physical demands of Muay Thai techniques. Instead, EMG is used to provide physiological evidence of neuromuscular coordination and motor control strategies during skill learning, by indicating how learners recruit and coordinate specific muscle groups when executing technique sequences under instructional practice. When interpreted together with cognitive and executive function outcomes, the EMG findings help to explain motor learning processes in terms of perception, decision making, and movement regulation, rather than only reporting which muscles are activated.

Previous studies examining the effects of Muay Thai skill training have generally reported positive outcomes on overall physical fitness (MOHAMAD et al., 2017) however, clear physiological evidence remains limited. There is a lack of detailed information regarding the specific muscle groups engaged during Muay Thai training and the distinct types of physical fitness adaptations that result from such training. At the same time, Muay Thai has gained increasing recognition among the general population, including international practitioners, and is now widely accepted as a legitimate discipline. As a traditional Thai martial art with historical roots dating back to the Ayutthaya period and continuing to the present day, Muay Thai represents an important cultural and physical practice. Considering these gaps, the present study aims to investigate the physiological responses elicited by Muay Thai skill training delivered as part of a formal Muay Thai course among secondary school students. Furthermore, this study seeks to contribute empirical evidence to support curriculum development by providing clearer insights into the physiological adaptations associated with Muay Thai instruction. Such evidence may enhance both teachers' and students' understanding of the physiological effects of Muay Thai learning and support its pedagogical application by integrating the cultural heritage of traditional martial arts with the physiological benefits of sports training.

Method

Design and Participants

The study was conducted in two phases. Phase 1 examined electromyographic (EMG) responses elicited during the performance of the Muay Thai Wai Khru ritual, 15 Mae Mai techniques, and 15 Luk Mai techniques as part of a formal Muay Thai course, whereas Phase 2 focused on examining and developing Muay Thai skill instruction within secondary-school physical education classes. In Phase 1, participants were recruited from three secondary schools in Buriram Province that offered sports classroom programs were Ban Kruat Witthayakarn School, Tachong Phitthayasans School, and Nong Ki Phitthayakhom School. Cluster sampling was first performed using schools as the sampling units, resulting in the selection of Nong Ki Phitthayakhom School. A second-stage cluster sampling procedure was then conducted using classrooms as the sampling units at the lower secondary level within the selected school, where Muay Thai instruction was provided. The required sample size was determined using G*Power 3.1 with a significance level of .05, statistical power of .80, and an effect size of .70, yielding 15 secondary-school students. Inclusion criteria were completion of Muay Thai skill training to proficiency and voluntary consent to participate. Participants had at least 2 years of Muay Thai training experience. Exclusion criteria included injury or illness that prevented testing and withdrawal from the study at any time.

In Phase 2, participants were secondary school students enrolled in the Muay Thai unit within physical education classes at Tachong Phitthayasans School. The sample was selected using purposive sampling. Sample size was determined using G*Power 3.1 with a significance level of .05, statistical power of .80, and an effect size of .84 (Faul et al., 2009) yielding two groups: an experimental group (n = 25) and a control group (n = 25), for a total of 50 participants. Inclusion criteria were (1) being a secondary school student enrolled in physical education and (2) willingness to participate. Exclusion criteria were (1) injury or illness preventing participation in practical skill learning and (2) withdrawal from the study at any time. The experimental group received Muay Thai instruction, whereas the control group received general sport-skill instruction according to the curriculum. Both groups attended one 50-minute class per week for a total of *12* weeks.

Procedure

The researcher conducted electromyographic (EMG) testing with the participants throughout the performance of the Muay Thai Wai Khru ritual, 15 Mae Mai techniques, and 15 Luk Mai techniques, as presented in Table 1. The data were then analyzed and summarized to identify the muscle groups exerting force during correct execution of each movement. These findings were used to develop instructional content for students receiving physical education instruction in Muay Thai, with an emphasis on muscle exertion during the performance of each technique. In Study 2, the experimental group of secondary school students received Muay Thai instruction based on the developed training model for 12 weeks, once per week for 50 minutes per session, using a demonstration teaching approach, consistent with the instructor's usual practice. During instruction, the teacher observed student performance and provided explanations and corrective feedback to students who had not yet performed the skills correctly, in order to improve movement efficiency. After 12 weeks, cognitive performance and physical fitness test results were analyzed and compared between the control group, which received general sport-skill instruction according to the curriculum, and the experimental group, which received Muay Thai skill instruction.

Table 1. Muay Thai Wai Khru ritual, 15 Mae Mai techniques, and 15 Luk Mai techniques.

Type of Activities	Type of Movements
Muay Thai Wai Khru ritual	1. Thaksinawat (clockwise circling, 3 laps) 2. Boek Thang (alternate-nostril breathing, left–right) 3. Krap Benjangkapradit (five-point prostration, 3 times) 4. Kop Phra Mae Thorani (sweeping arms out, then hands together in front) 5. Thawai Bangkhom (hands at chest, sweep back–forward, bow forward 3 times) 6. Pan Khanun (alternate hand-molding, up–down3 times) 7. Sao Noi Pra Paeng (kneeling mirror-and-grooming gestures) 8. Hanuman Song Mek (hand to forehead, lean left and right) 9. Hanuman Waek Mek (hand at face level, sweep across left to right and right to left) 10. Mek Khala Lo Kaeo (hand at forehead level, lure gesture left to right and right to left) 11. Lap Hok Mokkhassak (sharpen spear twice, then forward lean with rear leg lift and blade sweep twice) 12. Sot Soi Mala (alternating hand-threading at face level for 3 rounds) 13. Khun Phaen Poet Man (kneeling hands together push forward, then open hands outward) 14. Ambai Boek Fa (hand at head level, flick left and right) 15. Phra Mae Thorani Bip Muai Phom (hair-wringing motion for 3 rounds, then pull down and sweep arm out level with the floor) 16. Hong Hoen (hands at chest, extend arms like wings to the left, right, and center) 17. Yang Sung (raise right knee with right hand, then raise left knee with left hand) 18. Chang Sabat Nguang (right arm extends forward and swings up and down to the left, center, and right) 19. Phra Ram Phlaeng Son (draw and aim, release with backward lean and stomp, then arm sweep to the forehead with rocking) 20. Tat Mai Khom Nam (stomp and extend the arm, then stomp left, right, and center) 21. Krai Thuan Paet Thit (alternate foot taps marking eight points around the body) 22. Du Thep Thotsakan (left hand on head, right hand at waist, nod) 23. Klap Hua Sanam (inverting the ring)
15 Mae Mai techniques	1. Salap Fan Pla (outer-range attack) 2. Paksa Waek Rang (inner-range attack) 3. Chawa Sat Hok (elbow to the ribs) 4. Ihena Thaeng Krit (elbow to the chest) 5. Yo Khao Phra Sumen (dip then punch) 6. Ta Thera Kham Fak (brace then punch to the chin) 7. Mon Yan Lak (push kick to the chest) 8. Pak Luk Thoi (double elbow to the thigh) 9. Jorakhe Fhat Hang (spinning back attack to the neck) 10. Hak Nguang Aiyara (elbow to the thigh) 11. Naka Bit Hang (knee strike then twist the leg) 12. Wirun Hok Klap (left-right push kicks) 13. Dap Chawala (punch to the face) 14. Khun Yak Chap Ling (defend punch, kick, and elbow) 15. Hak Kho Erawan (pull down the neck then knee strike)
15 Luk Mai techniques	1. Erawan Soei Nga (punching attack) 2. Bathan Lup Phak (foot strike to the face) 3. Khun Yak Phan Nang (lifting the opponent) 4. Phra Ram Nao Son (dip then punch) 5. Kraisorn Kham Huai (dip then push kick) 6. Kwang Liao Lang (back kick) 7. Hiran Muan Phaen Din (spinning back elbow) 8. Naka Mut Badan (duck then push kick) 9. Hanuman Thawai Waen (double-punch attack) 10. Yuan Thot Hae (parry the leg then kick) 11. Tha Yae Kham Sao (intercepting push kick) 12. Hong Pik Hak (cutting elbow) 13. Sak Phuang Malai (elbow to the chest) 14. Thera Kwuat Lan (low cutting kick) 15. Fan Luk Buap (diagonal elbow)

Instrument

Research instruments and testing protocols for the two-phase study were as follows. Phase 1 focused on analyzing muscle activation using electromyography (EMG) during the performance of the Wai Khru Muay Thai sequence, 15 Mae Mai Muay Thai techniques, and 15 Luk Mai Muay Thai techniques. Muscle activity was recorded using the Wireless Bipolar Cometa Wave Plus EMG system. Electrode placement and orientation followed a standardized surface EMG procedure. Electrodes were placed over the muscle belly and aligned parallel to the presumed direction of the muscle fibers using anatomical landmarks and recommended placement sites (Konrad, 2005). Skin preparation was performed prior to electrode placement to reduce impedance and improve signal quality. EMG electrode pads were placed on upper-body muscles including flexor carpi ulnaris, extensor carpi ulnaris, biceps brachii, triceps brachii, medial deltoid, pectoralis major, latissimus dorsi, and rectus abdominis (Lenetsky et al., 2020; Tsai et al., 2014), and on lower-body muscles including vastus lateralis, rectus femoris, biceps femoris, gluteus maximus, and gastrocnemius (Camomilla et al., 2009). These measurements were used to determine maximal voluntary isometric contraction (MVC) and maximum EMG intensity for each technique performed. For EMG signal normalization, maximal voluntary isometric contraction (MVC) was obtained by instructing participants to perform maximal isometric contractions in standardized MVC testing postures for each target muscle, as specified in the MVIC table. For erector spinae, participants lay prone and performed isolated back extension. For rectus abdominis, participants performed a trunk curl up movement while the tester controlled motion at the sternum region. For iliopsoas, participants flexed the hip to approximately 90 degrees and exerted maximal force against resistance applied at the distal thigh. For gluteus maximus, participants performed hip extension while posture was controlled to maintain approximately 20 degrees of hyperextension. For knee extensors, single leg knee extension efforts were performed with controlled knee angles, including vastus lateralis at approximately 90 degrees, vastus medialis at approximately 160 degrees, and rectus femoris at approximately 100 to 110 degrees. For knee flexors, knee flexion efforts were performed from approximately 20 to 30 degrees of knee flexion, with resistance applied while holding the foot at the lateral malleolus for biceps femoris and at the medial malleolus for semitendinosus. For gastrocnemius, participants performed plantar flexion at a 90 degree ankle position against resistance. For tibialis anterior, participants performed dorsiflexion in standing with stabilization using an external load placed at the knee region. The MVC reference value for each muscle was determined from the maximum EMG amplitude recorded during the maximal isometric effort (Konrad, 2005).

Phase 2 examined the effects of training the Wai Khru Muay Thai sequence, 15 Mae Mai Muay Thai techniques, and 15 Luk Mai Muay Thai techniques using two testing components. Component 1 (physical fitness) comprised: (1) muscle strength and endurance, assessed by the 60 second sit-ups (times), 30 second modified push-ups (times), and handgrip strength (kg); (2) cardiovascular and leg muscle endurance, assessed by the 3 minutes step up-and-down test (times); and (3) flexibility, assessed by the sit-and-reach test (cm) (Department of Physical Education of Thailand, 2019). The instruments used to assess physical fitness correspond to tests widely employed in the school context; nevertheless, they were selected because they are the standard school based physical fitness tests recommended and routinely implemented by the Department of Physical Education of Thailand. Accordingly, these tests provide an appropriate and practical framework for evaluating physical fitness outcomes in relation to Muay Thai skill instruction and the objectives of the study within Thai secondary school settings. In addition, (4) static balance was assessed using the stork stand test (Fahrosi et al., 2024). (5) Peak heart rate during Muay Thai skill performance and average heart rate during Krabi–Krabong skill performance (bpm) were measured using the Polar Team H10 system. Component 2 (cognitive performance) was assessed using a Computerized Cognitive Test Battery developed based on the Department of Physical Education (Thailand, 2024). The cognitive assessment battery comprised the Simple reaction time test (SRT) and the Choice reaction time test (CRT), which assess processing speed. The Trail making test (TMT) assesses attention, executive functions, cognitive flexibility, and working memory. The Flanker test (FT) assesses executive function and attention. The Design fluency test (DFT) assesses executive function and cognitive flexibility. The Mental rotation test (MRT) assesses spatial ability.

Data analysis

Quantitative data were assessed for normality using the Shapiro–Wilk test for maximal voluntary isometric contraction (MVC), maximum EMG intensity, cognitive performance, and physical fitness outcomes. When the data violated the assumption of normality, between-group differences were examined using the Mann–Whitney U test, whereas within-group comparisons across the 13 muscle groups were analyzed using the Friedman test. The level of statistical significance was set at $p < .05$. All analyses were conducted using IBM SPSS Statistics for Windows, Version 23.0 (IBM Corp., Armonk, NY).

Results

The study on physiological responses to learning Muay Thai skills among secondary school students in Buriram Province employed a quasi-experimental research design. Phase 1 results present electromyographic (EMG) responses recorded during the performance of the Muay Thai Wai Khru ritual, 15 Mae Mai techniques, and 15 Luk Mai techniques. The findings can be summarized in sequence as follows. First, the mean and standard deviation of the participants' baseline physiological characteristics in are presented in Table 2.

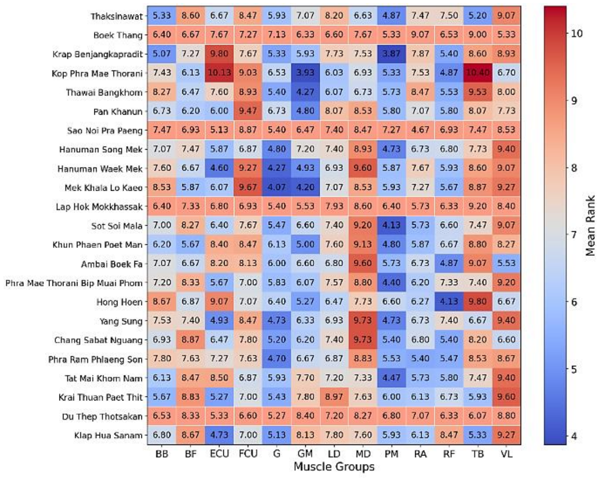
Table 2. Characteristics of secondary-school students in phase 1 (n = 15).

Parameter	Mean ± SD
Age (year)	15.35 ± 0.48
Height (cm)	161.48 ± 7.83
Body weight (kg)	54.49 ± 10.05
BMI (kg/cm²)	20.80 ± 2.85
HRmax (beat/min⁻¹)	204.65 ± 0.48
HRavg (beat/min⁻¹)	132.90 ± 8.21
HRpeak (beat/min⁻¹)	163.08 ± 5.28

Note. BMI: Body Mass Index; HRmax: Maximum Heart Rate; HRavg: Average Heart Rate; HRpeak: Peak Heart Rate.

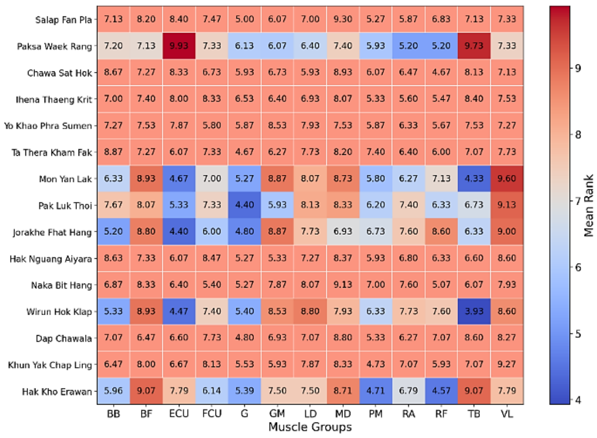
Second, the analysis of differences in the ratio of EMG maximum intensity during movement to maximal voluntary isometric contraction (MVC) during the performance of the Wai Khru Muay Thai sequence (23 techniques), 15 Mae Mai Muay Thai techniques, and 15 Luk Mai Muay Thai techniques showed the following results. For the 23 Wai Khru techniques, Friedman tests were conducted to compare across the 13 muscle groups within each technique. Muscle use did not differ significantly in Boek Thang (χ^2 = 15.921, *p* = .195), Sao Noi Pra Paeng (χ^2 = 20.211, *p* = .063), Lap Hok Mokkhassak (χ^2 = 17.670, *p* = .126), and Du Thep Thotsakan (χ^2 = 15.965, *p* = .193), whereas significant differences were observed in the remaining techniques ($p < .05$). (Figure 1). The 15 Mae Mai techniques, Friedman tests were conducted to compare across the 13 muscle groups within each technique. Muscle use did not differ significantly in Salap Fan Pla (χ^2 = 18.045, *p* = .114), Chawa Sat Hok (χ^2 = 18.479, *p* = .102), Ihena Thaeng Krit (χ^2 = 13.837, *p* = .311), Yo Khao Phra Sumen (χ^2 = 11.077, *p* = .522), Ta Thera Kham Fak (χ^2 = 14.400, *p* = .276), Hak Nguang Aiyara (χ^2 = 17.671, *p* = .126), Naka Bit Hang (χ^2 = 19.780, *p* = .071), Dap Chawala (χ^2 = 16.378, *p* = .175), and Khun Yak Chap Ling (χ^2 = 19.701, *p* = .073), whereas significant differences were observed in the remaining techniques (p < .05) (Figure 2). For the 15 Luk Mai techniques, muscle use across the 13 muscle groups within each technique. Muscle use did not differ significantly in Erawan Soei Nga (χ^2 = 20.343, p = .061), Hiran Muan Phaen Din (χ^2 = 20.062, p = .066), Hanuman Thawai Waen (χ^2 = 18.804, p = .093), Hong Pik Hak (χ^2 = 18.532, p = .100), and Sak Phuang Malai (χ^2 = 12.193, p = .430). However, the remaining techniques showed significant within technique differences at the .05 level (p < .05) (Figure 3). Overall, results should be interpreted together with the mean rank patterns shown in the heatmap. When a technique is not significant, it indicates that ratio of EMG maximum intensity during movement to maximal voluntary isometric contraction is distributed relatively evenly across the 13 muscle groups from the beginning to the end of that technique, reflecting a balanced contribution of the measured muscles during the whole movement sequence. In contrast, when a technique shows a significant result, it indicates a differentiated muscle recruitment pattern during the movement, where some muscle groups present clearly higher ranks than others. This pattern can be visually identified in the figures by mean rank values approaching 10 and by darker red tones, which represent higher relative activation levels compared with the other muscles within the same technique. The figures therefore provide not only statistical evidence regarding the presence or absence of significant differences but also an interpretable activation profile for each technique, which facilitates interpretation of whether the movement requires balanced whole body engagement or a more selective emphasis on specific muscle groups.

Figures 1. The EMG Maximum Intensity to Maximal Voluntary Isometric Contraction ratio in Muay Thai Wai Khru ritual was shown as mean rank**.**



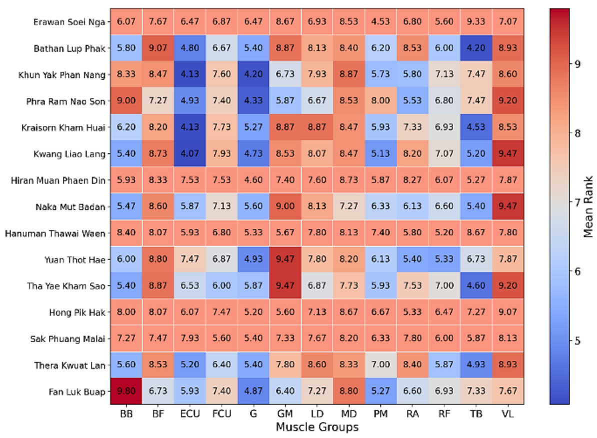
Note. BB: Bicep Brachii; BF: Biceps Femoris; FCU: Flexor Carpi Ulnalis; G: Gastrocnemius; LD: Latissimus Dorsi; MD: Medial Deltoid; PM: Pectoralis Major; RA: Rectus Abdominis; RF: Rectus Femoris; TB: Triceps Brachii; VL: Vastus Lateralis

Figures 2. The EMG Maximum Intensity to Maximal Voluntary Isometric Contraction ratio in 15 Mae Mai techniques was shown as mean rank.



Note. BB: Bicep Brachii; BF: Biceps Femoris; FCU: Flexor Carpi Ulnalis; G: Gastrocnemius; LD: Latissimus Dorsi; MD: Medial Deltoid; PM: Pectoralis Major; RA: Rectus Abdominis; RF: Rectus Femoris; TB: Triceps Brachii; VL: Vastus Lateralis

Figures 3. The EMG Maximum Intensity to Maximal Voluntary Isometric Contraction ratio in 15 Luk Mai techniques was shown as mean rank**.**



Note. BB: Bicep Brachii; BF: Biceps Femoris; FCU: Flexor Carpi Ulnalis; G: Gastrocnemius; LD: Latissimus Dorsi; MD: Medial Deltoid; PM: Pectoralis Major; RA: Rectus Abdominis; RF: Rectus Femoris; TB: Triceps Brachii; VL: Vastus Lateralis

The Phase 2 results report physical fitness outcomes following the 12 week instructional period, and the findings are presented from Table 3 onward.

Table 3. Characteristics of secondary-school students in phase 2

Parameter	Experimental Group (n=25) Mean ± SD	Control Group (n=25) Mean ± SD
Age (year)	15.35 ± 0.46	15.35 ± 0.41
Height (cm)	160.95 ± 8.09	162.00 ± 7.73
Body weight (kg)	54.15 ± 10.54	54.83 ± 9.80
BMI (kg/cm^2)	20.84 ± 3.24	20.76 ± 2.48
HRmax (beat/min^{-1})	204.65 ± 0.49	204.65 ± 0.47
HRavg (beat/min^{-1})	132.45 ± 7.47	133.35 ± 9.06
HRpeak (beat/min^{-1})	167.00 ± 3.52	159.15 ± 3.53

Note. BMI: Body Mass Index; HRmax: Maximum Heart Rate; HRavg: Average Heart Rate; HRpeak: Peak Heart Rate.

Physical fitness results

After 12 weeks, the experimental group demonstrated significantly better performance than the control group in selected physical fitness outcomes related to Muay Thai skill practice across the 23 Wai Khru techniques, 15 Mae Mai techniques, and 15 Luk Mai techniques. Significant between-group differences at the .05 level were found in the stork stand test, the 60-second sit-up test, and the 3-minute step up-and-down test (Table 4).

Table 4. Between-group comparisons of physical fitness outcomes at pre-test and post-test in Phase 2.

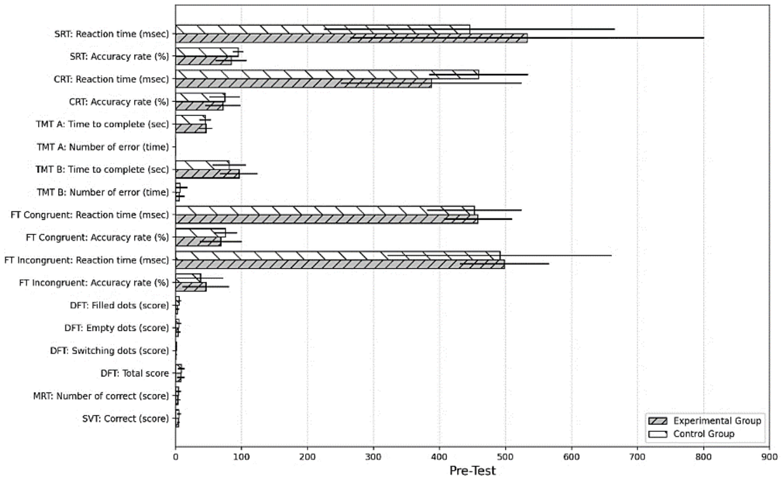
Parameter	Experimental Group (n=25) Mean ± SD	Control Group (n=25) Mean ± SD	U	t	p-value
Pre-test					
Sit and Reach (cm.)	7.65 ± 10.07	6.70 ± 6.11	148.50	-	0.165
Modified 30-second push-up test (Time)	18.70 ± 9.49	14.40 ± 4.50	150.50	-	0.183
Sit-up 60-second (Time)	24.55 ± 11.69	29.45 ± 5.36	-	1.704	0.097
3-minute step test (Time)	131.50 ± 40.54	134.50 ± 15.58	-	0.309	0.759
Handgrip strength (kg.)	30.59 ± 9.26	34.05 ± 6.28	-	1.379	0.176
Stoke stand test (Second)	13.08 ± 11.92	9.90 ± 5.36	198.00	-	0.968
Post-test					
Sit and Reach (cm.)	11.35 ± 5.88	8.40 ± 5.46	150.50	-	0.180
Modified 30-second push-up test (Time)	17.30 ± 10.81	12.45 ± 5.86	143.50	-	0.126
Sit-up 60-second (Time)	33.10 ± 7.83	20.85 ± 13.14	-	3.551	0.001*
3-minute step test (Time)	171.05 ± 17.32	152.95 ± 25.88	-	2.726	0.010*
Handgrip strength (kg.)	32.60 ± 10.44	29.30 ± 8.69	-	1.085	0.285
Stoke stand test (Second)	28.45 ± 16.87	7.43 ± 5.08	18.00	-	0.001*

Note. U: Mann-Whitney U test; t: Independent t-test; * Significant with $p \le 0.05$.

Cognitive performance results

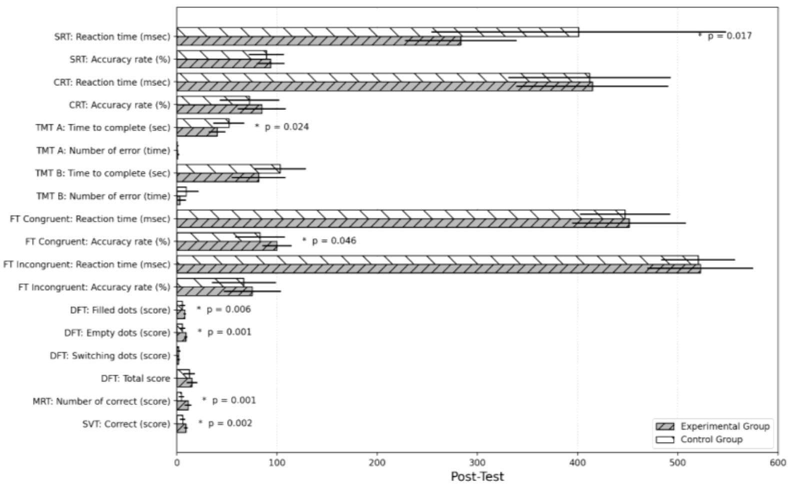
The cognitive results summarize performance on the computerized cognitive test battery and are presented after the physical fitness outcomes. After 12 weeks of Muay Thai skill learning, the experimental group showed significantly greater improvements than the control group at the .05 level in processing speed, as indicated by the Simple reaction time test (SRT) reaction time (msec) (U = 55.00, p = .017). Significant between group differences were also observed in attention and executive functions, as indicated by the Trail making test (TMT) Part A time to complete (sec) (U = 58.00, p = .024) and the Flanker test (FT) Congruent accuracy rate (percent) (U = 66.50, p = .046). In addition, significant improvements were found in executive function and cognitive flexibility, as indicated by the Design fluency test (DFT) black dots (score) (U = 47.00, p = .006) and white dots (score) (U = 33.00, p = .001), and in spatial ability, as indicated by the Mental rotation test (MRT) number of correct (score) (U = 14.00, p = .001) (Figure 4 and 5).

Figure 4. Baseline cognitive test performance in secondary school students between group comparison prior to Muay Thai learning.



Note: SRT: Simple reaction time test; CRT: Choice reaction time test; TMT: Trail making test; FT: Flanker test; DFT: Design fluency test; MRT: Mental rotation test; SVT: Spatial visualization test.

Figure 5. Cognitive test performance in secondary school students after 12 weeks of Muay Thai learning.



Note: SRT: Simple reaction time test; CRT: Choice reaction time test; TMT: Trail making test; FT: Flanker test; DFT: Design fluency test; MRT: Mental rotation test; SVT: Spatial visualization test; * Significant with p ≤ 0.05.

Discussion

EMG profile helps clarify the neuromuscular demands of Muay Thai skill learning across three instructional components, namely the Wai Khru sequence, the Mae Mai techniques, and the Luk Mai techniques. Rather than representing isolated muscular actions, the overall activation patterns are consistent with coordinated kinetic chain behaviour, in which lower limb stabilization and force production interact with trunk control and upper limb positioning to preserve movement quality. This integrative requirement is also consistent with evidence from Muay Thai striking tasks showing substantial acute neuromuscular demand during repeated kicking actions performed at full intensity (Cimadoro et al., 2019). Within this framework, the Wai Khru sequence can be interpreted as a structured coordination task that emphasizes rhythm, postural discipline, and continuous weight transfer. The movement characteristics of Wai Khru typically involve sustained ceremonial tempo, repeated changes of level, and coordinated arm pathways that must be executed while maintaining a stable centre of mass. From a physiological perspective, such a motor task plausibly encourages distributed activation that supports balance related control, because learners must stabilize the base of support while simultaneously regulating trunk alignment and coordinated upper limb gestures. Importantly, this interpretation focuses on the functional meaning of the EMG profile, rather than reiterating technique by technique statistical outputs. In contrast, Mae Mai and Luk Mai techniques impose more task specific mechanical constraints, including rapid transitions between guard and strike, directional changes, and coordinated proximal to distal sequencing for punching, elbowing, kicking, or combined defensive offensive patterns. These characteristics provide a plausible explanation for more differentiated recruitment patterns, because effective striking requires a stable lower limb platform, efficient trunk rotation and bracing, and precise upper limb control to maintain alignment at the shoulder, elbow, and wrist during impact oriented actions. This distinction is also educationally meaningful, as it supports a progression in lesson design. Teachers may use Wai Khru as a preparatory phase to establish rhythm, posture, and intermuscular coordination, then transition to Mae Mai and Luk Mai to increase task specificity and intensify neuromuscular loading while maintaining movement quality.

The EMG profile further provides a coherent physiological rationale for interpreting the functional outcomes reported in Phase 2. The continuous postural regulation and repeated weight transfer inherent to Wai Khru offer a plausible basis for balance improvements, while recurring trunk stabilization demands across the instructional content may support gains in core endurance. This interpretation is consistent with broader evidence that core training improves balance related outcomes and performance variables that rely on proximal stability and efficient force transfer (Rodriguez-Perea et al., 2023). In addition, Muay Thai instruction contains inherently cognitively engaging features such as rule based sequencing, timing, and rapid movement selection, which align with evidence that cognitively engaging physical activity interventions can improve executive function in children and adolescents (Mao et al., 2024). Finally, findings from school based martial arts programs suggest potential benefits for self regulation compared with traditional physical education contexts, reinforcing the educational relevance of structured martial arts content in school settings (Lakes & Hoyt, 2004). Importantly, the EMG-derived activation profile offers a direct physiological bridge to the functional improvements observed in balance, core endurance, and cardiorespiratory capacity. The consistent involvement of lower-limb stabilizers during stance regulation and weight transfer supports the ability to maintain knee and hip control under a changing base of support, which is central to single-leg balance performance. At the same time, the recurring demand for trunk bracing and segmental control across Wai Khru, Mae Mai, and Luk Mai provides a plausible basis for improved core endurance, as the trunk must sustain alignment while coordinating force transmission between the lower and upper extremities. In addition, the repeated execution of continuous rhythmic sequences likely accumulates a moderate aerobic workload across sessions, which can support adaptations in cardiorespiratory capacity. Taken together, the EMG profile and the movement characteristics of the training content help close the physiological rationale of the study by linking the observed muscle activation patterns to concurrent functional gains in balance, core endurance, and cardiorespiratory fitness.

After the intervention, the pattern of improvement suggests that Muay Thai based instruction may enhance balance, core muscular endurance, and cardiorespiratory endurance, which is physiologically plausible given the continuous rhythmic sequencing and repeated postural transitions embedded in the practice content. These results suggest positive physiological adaptations in balance, core muscular strength and endurance, and cardiovascular endurance. The Wai Khru emphasizes continuous postural regulation through repeated level changes and rhythmic weight transfer, which may enhance balance by improving trunk stabilization and reducing postural sway during single-leg support (Jouira et al., 2024; Salsabila et al., 2023). In addition, consistent stepping, lifting, and placing of the feet in rhythm may enhance proprioceptive awareness, reduce trunk sway, and allow students to maintain single-leg balance for a longer duration. These demands may also promote core endurance by repeatedly challenging abdominal and hip-flexor function during flexion–extension control and rotational transitions within the sequence (Juan et al., 2024; Park et al., 2024). Because the practice is performed as a continuous rhythmic sequence, it likely provides a moderate aerobic stimulus that can support cardiorespiratory adaptation. From the EMG perspective, the pattern is consistent with integrated lower-limb support and trunk stabilization combined with upper-limb positioning demands, reflecting whole-body coordination rather than isolated muscle action. Repeated activation of the lower-limb and core muscle groups throughout the sequence can therefore enhance muscular endurance in the involved muscles, while synchronizing breathing rhythm with sustained muscular force during held postures may reduce heart-rate fluctuation and support longer continuous performance (Juan et al., 2024; Price et al., 2024). Additionally, the gradual progression of movement sequencing may help reduce shear forces at the joints while maintaining an adequate cardiovascular challenge, making the program appropriate for school-aged learners. Taken together, these mechanisms provide a plausible explanation for concurrent improvements in balance, core function, and aerobic capacity observed following Muay Thai training (Cibinello et al., 2023; Mijalković et al., 2022).

In contrast, the 15 Mae Mai and 15 Luk Mai techniques place more task-specific demands on stance control and whole-body coordination through repeated defensive–offensive transitions, intermittent single-leg support, and multi-directional weight transfer, which may further support balance-related adaptation. In addition, performing consecutive sequences that transition from defensive to offensive actions and intermittently require single-leg stance places sustained demands on the core musculature, which alternates between static bracing and continuous dynamic activation to stabilize the trunk, thereby enhancing postural control and trunk balance (Fong et al., 2022; Gong et al., 2024). Rhythmic foot placement may also help minimize trunk sway during balance tasks. Because these continuous techniques typically impose moderate exercise intensity, they may also improve cardiovascular and circulatory endurance (Thonglong et al., 2025). At the muscle-specific level, coordinated activation of the vastus lateralis and biceps femoris supports knee extension–flexion and balance maintenance, the latissimus dorsi contributes to trunk rotation, the medial deltoid and biceps brachii assist in arm elevation and shoulder alignment, and the flexor carpi ulnaris helps maintain proper wrist positioning, enabling smoother arm swings with reduced effort. Collectively, these neuromuscular and physiological demands may explain concurrent improvements in balance, core muscular endurance, and cardiovascular endurance (Asouzu et al., 2024; Dong et al., 2024; Price et al., 2024).

Following the intervention, the cognitive outcomes suggest that Muay Thai based instruction may support improvements in executive functioning and visuospatial processing. These findings indicate that practicing the Wai Khru Muay Thai sequence (23 techniques), 15 Mae Mai Muay Thai techniques, and 15 Luk Mai Muay Thai techniques may enhance prefrontal executive functioning, particularly cognitive flexibility, inhibitory control, and selective attention, as well as creativity. This may be explained by the training characteristics, which combine slow-to-moderate rhythmic movement phases in the dance-like sequence with periods of increased tempo during offensive and defensive actions. Consequently, learners are required to selectively attend to task-relevant cues such as rhythm and hand–foot positioning while inhibiting premature, excessive, or mistimed responses. Moreover, continuous sequencing and frequent transitions from defense to attack require ongoing updating of movement rules and motor patterns, thereby promoting cognitive flexibility. The need to mentally simulate movement sequences and generate situation-appropriate responses may also support creative thinking. In addition, maintaining core control and weight transfer across techniques helps sustain concentration and postural steadiness, which may facilitate timely and systematic decision-making and directional changes. Taken together, these mechanisms provide a plausible explanation for the observed improvements in executive functions and key cognitive processes following Muay Thai training in school-aged students (Cigarroa et al., 2024; Harwood-Gross et al., 2021; Martín et al., 2025; Wang et al., 2024).

Limitations

Several considerations should be noted when interpreting the findings. The intervention was implemented within the standard structure of Thai physical education classes and was delivered once per week for 50 minutes per session over a 12-week period. In addition, group assignment was conducted at the classroom level using simple randomization, consistent with routine school-based implementation. Finally, as the program is grounded in Muay Thai with cultural and pedagogical specificity, the applicability of the findings to other settings may depend on appropriate contextual adaptation.

Conclusions

This study showed that Muay Thai practice consisting of the Wai Khru sequence, Mae Mai, and Luk Mai techniques provided an evidence-based profile of muscle activation demands derived from EMG analysis. This muscle-use information contributed practical value for researchers, physical education teachers, and sport scientists by supporting the development and refinement of Muay Thai–based physical education lessons and exercise programs that targeted specific muscle groups and training objectives. The findings also showed that, after 12 weeks, the experimental group demonstrated greater improvements than the control group in physical fitness, particularly balance, core muscular endurance, and cardiovascular endurance. Finally, cognitive performance outcomes improved after training, as indicated by better performance in measures related to executive functions, including selective attention, inhibitory control, cognitive flexibility, and visuospatial processing. Overall, the work advanced understanding of Muay Thai as an integrative school-based training modality and suggested future applications in physical education curricula as well as further studies that examined longer training periods, varied training doses, and broader functional and educational outcomes.

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Human research ethics

The Human Research Ethics Committee of Buriram Rajabhat University (BRU: 026/2568) approved this research.

Conflict of interest

The author declares that there are no interests.

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