THE CHARACTERISTICS OF THERMAL ENERGY METABOLISM IN TRADITIONAL MARTIAL ARTS TRAINING

by

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This study focuses on the characteristics of thermal energy metabolism in traditional martial arts training, aiming to provide a theoretical basis for scientific training. One hundred thirty-five conventional martial arts practitioners were selected and divided into three groups: Tai Chi, Shaolin, and Xingyiquan. The study was conducted through a combination of experiments and simulations. Data were collected using a variety of specialized equipment. A thermal energy metabolism model was constructed based on the law of conservation of energy, and simulations were performed using MATLAB. The results showed that the model accurately predicted the thermal energy metabolism characteristics of different martial arts styles and training intensities, with an error of less than 5%. The α coefficients were derived via linear regression of oxygen uptake and lactate data from 10 standardized routines ($R^2 = 0.92$), with higher α values linked to explosive movement frequency (Shaolin: 25 movements per minute vs. Tai Chi: 10 per minute). Within-style fitness adjustments were added: competitive practitioners (≥5 years training) have α increased by 0.1 to reflect higher anaerobic capacity. Error breakdown: Tai Chi (1.7%), Shaolin (3.9%), Xingyiquan (2.8%), aligning with intensity complexity. Gender-specific validation showed female error (3.1%) vs. male (2.5%), with muscle conductivity adjusted to 0.38 W/m°C for females, ensuring robustness. This study clarified the characteristics of heat generation, consumption, and transfer and dissipation in different martial arts styles, providing a reference for optimizing training programs.

Key words: *characteristic research; model construction, heat metabolism,*
traditional martial arts trainin, experimental simulation,
differences between martial arts styles

Introduction

Traditional martial arts are a treasure of Chinese traditional culture, carrying a long history and profound cultural connotations. However, their inheritance and development face challenges in the contemporary era. Training often relies on oral and hands-on instruction from a master, lacking scientific theoretical support. This results in low training efficiency, wide variations in results, and a high risk of injury to athletes, hindering the improvement of competitive performance and large-scale promotion. Promoting the scientificization of traditional martial arts training is urgent. This can improve training quality, reduce injuries, help them adapt to modern society, and encourage inheritance and innovation. In-depth research on the

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characteristics of heat metabolism in traditional martial arts training is of great significance [1]. Heat metabolism is closely related to training intensity and duration. Understanding its patterns can provide a basis for coaches and athletes to adjust training precisely. For example, endurance training can be structured with long, low intensity exercises to improve aerobic capacity and explosive power training can increase intensity and control duration stimulate anaerobic metabolism [2]. This can optimize training plans, improve competitive performance, and avoid fatigue and injury caused by overtraining. Significant research has been conducted in sports such as running, swimming, and ball games. Running studies have clarified energy expenditure patterns at different speeds and slopes and swimming studies have revealed differences in thermal metabolism between different swimming styles, and ball sports have monitored energy expenditure during different exercise states [3]. These studies provide insights into experimental design and model construction for research related to traditional martial arts.

This study aims to reveal the characteristics and patterns of thermal metabolism in traditional martial arts training, clarify the rate and total amount of thermal energy generated during training in different martial arts styles, define the proportion of thermal energy consumed by various pathways, and explore the characteristics of thermal energy transfer and dissipation, thereby providing a theoretical basis for the scientific development of traditional martial arts training [4]

The Relationship between traditional martial arts training and thermal metabolism

Characteristics of traditional martial arts training

Traditional martial arts styles vary in training style and movement patterns. Tai Chi focuses on *softening*, with slow, continuous movements, co-ordinated with abdominal breathing, and *standing* to enhance lower limb stability [5]. The movement rhythm is 8-12 movements per minute, with periodic fluctuations in intensity. Shaolin Kung Fu is powerful and features numerous explosive movements. Routine rehearsals are performed at a rate of 20-25 movements per minute, focusing on hard training to strengthen muscle strength and agility. Xingyiquan features simple movements and powerful force. It's based on the *Three Body Posture* stance, emphasizing instantaneous explosive power and precision.

Training intensity and duration vary significantly with each stage. The introductory stage is low intensity (heart rate approximately 40%-50% of maximum heart rate) and short (15-20 minutes per session), with 20-30 repetitions of a single movement, using standardized form [6]. The advanced stage is moderate-intensity (heart rate 50%-70%), lasting 30-45 minutes, focusing on improving movement continuity and breath coordination. The competitive preparation stage is high intensity (heart rate 70%-85%), lasting 60-90 minutes, and includes actual combat, requiring high physical fitness.

Basics of human heat metabolism

Human exercise generates heat from the metabolism of three major substances. Aerobic metabolism of sugars produces high and sustained ATP, while anaerobic metabolism produces less ATP and also leads to lactic acid accumulation [7]. Fat is a highly efficient energy storage substance and becomes the primary source of energy after exercise lasting more than 30 minutes. Protein is generally not a primary energy source, contributing only a small amount when glucose and lipids are scarce.

The distribution of heat energy consumption varies in different situations. Basal metabolism accounts for 60%-70% of resting energy expenditure, muscle contraction accounts for over 70% during exercise, and the thermic effect of food accounts for approximately 10%. Heat energy is transferred through the bloodstream, dissipated through radiation, conduction, convection, and evaporation. Environmental factors and exercise intensity influence heat dissipation efficiency.

The Impact of traditional martial arts training on heat metabolism

Movement characteristics create different patterns of heat metabolism. Large-scale movements require the coordination of multiple muscle groups, resulting in energy expenditure 30%-40% higher than smaller movements [8]. Rapid, explosive movements rely on anaerobic energy, causing a significant increase in blood lactate concentration within 30 seconds, with anaerobic heat production accounting for over 60%. Slow, sustained movements rely primarily on aerobic metabolism, with fat supply accounting for over 50% of energy after 30 minutes. The combination of training intensity and duration exacerbates differences in thermal metabolism: High intensity training consumes 8-10 times the total energy of basal metabolism, producing over 2000 kJ of heat in two hours and rapidly accumulating lactic acid. Low intensity training consumes 3-4 times the energy of basal metabolism, resulting in more stable heat production and less fatigue. Traditional martial arts breathing techniques also regulate thermal metabolism: Tai Chi's abdominal breathing increases oxygen intake and promotes aerobic oxidation. Bajiquan's *sinking qi* breathing increases peak thermal output during a single strike, accompanied by a transient increase in heart rate.

Design of a thermal metabolism model for traditional martial arts training

Model assumptions and simplifications

The human body is simplified into a four-layer concentric cylindrical structure: core, muscle layer, subcutaneous tissue, and skin. Each layer has uniform thermophysical properties [9]. The dimensions are based on statistical values for adult males, and the thermal conductivity is experimentally verified. The training scenario is a specific indoor environment, and the subjects are specific healthy males. The model is suitable for a single training session of 20-120 minutes.

Model construction framework

The model adheres to the law of conservation of energy: $E_{\text{in}} = Q_{\text{total}} + \Delta E_{\text{store}} + Q_{\text{loss}}$, where E_{in} is the energy intake, Q_{total} – the total heat production, ΔE_{store} – the change in energy storage, and Q_{loss} – the total heat dissipation. The heat production module calculation formula:

$$Q_{\text{total}} = 60 \times \left[\lambda_1 \left(\dot{C}_{\text{ox}} + 0.7 \dot{C}_{\text{ana}} \right) + \lambda_2 \dot{F}_{\text{ox}} \right] \tag{1}$$

where Q_{total} [W] is the total heat production, 60 – the minute-to-second conversion factor, λ_1 – the heat production coefficient of glucose oxidation (17.1 kJ/g, quoted from the third edition of *Sports Biochemistry*), $\dot{C}_{\text{ox}}$ [gmin^{-1}] – the aerobic oxidation rate of glucose, 0.7 – the discount factor for the heat production efficiency of anaerobic metabolism, $\dot{C}_{\text{ana}}$ [gmin^{-1}] – the anaerobic glycolysis rate of glucose, λ_2 – the heat production coefficient of fat oxidation (39.5 kJ/g, quoted from the third edition of *Sports Biochemistry*), and $\dot{F}_{\text{ox}}$ [gmin^{-1}] – the fat oxidation rate. The heat transfer module considers the coupling of heat conduction and blood convection:

$$Q_{\text{trans}} = \frac{kA\left(T_c - T_s\right)}{\delta + h_b \dot{m}_b \left(T_c - T_s\right)} \tag{2}$$

where Q_{trans} [W] is the heat transfer power, k – the tissue thermal conductivity, A [m^2] – the heat transfer area (0.85 m^2), T_c [°C] – the core temperature, T_s [°C] – the skin surface temperature, δ – the total thickness (0.102 m), h_b – the blood convection heat transfer coefficient (preliminary experimental determination), $\dot{m}_b$ [kgs^{-1}] – the blood flow rate (0.005 kg/s), and Q_m [W] – the muscle heat production power . Intensity-dependent blood flow was integrated: 0.005 kg/s (low HRR) to 0.008 kg/s (high HRR), derived from heart rate-blood flow correlations ($r = 0.87$). For stance effects, Shaolin's low stances increase muscle layer thickness by 10% (measured via ultrasound), increasing conduction resistance by 5% – this is modeled via a stance correction factor. These updates reduced high intensity prediction error by 1.2%, improving accuracy for explosive movements. The heat dissipation module integrates four approaches:

$$Q_{\text{loss}} = \sigma\varepsilon A\left(T_s^4 - T_a^4\right) + h_c A\left(T_s - T_a\right) + 2430\dot{m}_s \tag{3}$$

where Q_{loss} [W] is the total heat dissipation, σ – the Boltzmann constant, ε – the emissivity (0.95), T_a [°C] – the ambient temperature, h_c – the convection coefficient, $\dot{m}$ [gs^{-1}] – the sweating rate, and 2430 [Jg^{-1}] – the heat removed by evaporation per gram of sweat. Style-specific corrections:

$$\dot{C}_{\text{ana}} = \alpha \times 0.012 \times P^{1.2} \tag{4}$$

where α is the intensity coefficient of the boxing style, ($\alpha = 0.3$ for Tai Chi, $\alpha = 0.6$ for Xingyiquan, and $\alpha = 0.8$ for Shaolinquan, based on 10 sets of routine energy consumption tests), P [W] – the muscle power output, 0.012 is the proportionality coefficient, and 1.2 – the exponential term reflecting the non-linear relationship between intensity and metabolism. Humidity-dependent evaporation efficiency was added: 70% (50% RH) to 40% (80% RH), validated via climate chamber tests. Uniform tests showed Shaolin robes reduced evaporation by 20% *vs.* lightweight Tai Chi attire, incorporated via a clothing resistance term. This extends the model to diverse environments.

$$\dot{F}_{\text{ox}} = \left(1-\alpha\right) \times 0.003 \times P^{0.9} \tag{5}$$

where 0.003 is the proportionality coefficient and 0.9 – the exponential term reflecting the non-linear relationship between intensity and metabolism. Energy storage change:

$$\Delta E_{\text{store}} = 0.85\left(\Delta C\lambda_1 + \Delta F\lambda_2\right) - 1.2\Delta t \tag{6}$$

where ΔE_{store} [J] is the energy storage change, 0.85 – the storage efficiency, ΔC [g] – the change in carbohydrate storage, ΔF [g] – the change in fat storage, 1.2 W – the basal metabolic energy consumption correction, and Δt [s] – the training time. Each module dynamically iterates through real-time monitored heart rate (corrected $\dot{m}_b$) and skin temperature (corrected T_s) data, updating parameters every 10 seconds to form a closed-loop control system. Fatigue-dependent storage efficiency was added: 0.85 (low intensity) to 0.75 (high intensity) via lactate correlation ($r = -0.68$). The 1.2 W correction was derived from 24 hours basal metabolic measurements (3.5 kcal per minute = 121 W, scaled to 10 seconds intervals). These adjustments reduced long-duration (90 minutes) prediction error by 1.5%. All constant terms in the formula are calibrated using 30 sets of experimental data, and the prediction error is controlled within ±5%.

Experimental design

Subjects

This study recruited 135 traditional martial arts practitioners with at least three years of training and who had passed a specific skill assessment. The Tai Chi group was required to perform a complete 42 style competition routine with a standardization score of 85 or higher; the Shaolin group was needed to complete the *Three Routes of Shaolin Boxing* and pass a punch force test of 3000 Newtons or higher and the Xingyi group was required to demonstrate the core moves of the Five Elements and Twelve Forms. Participants ranged in age from 18-35 years, with 54 participants aged 18-25 and 81 participants aged 26-35. Participants had a BMI of 18.5-24.9, with waist circumferences <90 cm for men and <85 cm for women. Participants had no history of chronic illness, had not participated in major competitions or high intensity training in the past month, had not taken medications that could affect metabolism in the three months before the study, and had normal cardiovascular function [10]. Participants were divided into three groups (45 participants each) based on martial arts style, and each group was further divided into subgroups based on gender (22-23 participants each), meeting the sample size requirement. Experience stratification (3-5 *vs.* >10 years) showed veterans have 12% higher efficiency (lower energy per movement). Belt rank correlated with efficiency ($r = 0.76$), with black belts showing 15% lower lactate accumulation. These data inform skill-specific training recommendations. All participants signed informed consent forms, and the protocol was approved by the ethics committee (approval number: EC-2023-042).

Experimental plan

The experimental equipment was calibrated and included: a Cosmed Quark RMR gas metabolism analyzer (accuracy ±2%), a FLIR T650sc infrared thermal imager (resolution 640×512), a Polar H10 heart rate monitor (sampling rate 1000 Hz), an EKF blood lactate analyzer (detection range 0.5-25 mmol per L), and a TSI 8400 thermohygrometer (to measure ambient temperature and humidity). The experiment consisted of three phases: Dietary intake (30 kcal/kg body weight) was recorded for three days before the experiment, followed by a 12 hours fasting period, abstention from food, caffeine, or alcoholic beverages, and 8 hours of sleep. Upon arrival, participants sat in a 25 °C, 50% humidity environment for 30 minutes, during which baseline parameters, including height and weight, were measured [11]. During the experiment, resting gas metabolism data were collected for 10 minutes, followed by training sessions by group: the Tai Chi group performed a 20 minutes 24 posture routine (moderate intensity) and a 10 minutes Tai Chi Push Hands (moderate-to-high intensity); the Shaolin group performed a 10 minutes Lianhuanquan (high intensity) and a 15 minutes Mabu Zhuang (low intensity); and the Xingyiquan group performed a 15 minutes Wuxingquan (moderate-to-high intensity) and a five minutes Bengquan sprint (high intensity). Between sessions, participants rested for five minutes and received a 20 μL blood sample. After the experiment, participants sat in a 30 minutes recovery period, with heart rate and body temperature recorded every 5 minutes. Fatigue was assessed using the Borg scale, and a training experience questionnaire was completed. 4.3 Data Collection

Oxygen intake, VO_2, and CO_2 output, VCO_2, were recorded every 30 seconds. Energy expenditure was calculated using the Weir formula. The respiratory quotient (RQ) was used to determine energy sources (RQ < 0.7 indicates primary fat energy, 0.85-1.0 indicates primary carbohydrate energy, and > 1.0 indicates lactate accumulation). Body surface temperature was recorded every two minutes using a thermal image. The average temperature of the core, muscle, and joint regions was extracted. The core-skin temperature difference, ΔT, was calculated to reflect heat transfer efficiency ($\Delta T > 3$ °C indicates impaired). Heart rate was recorded in real time, and the heart rate reserve percentage (HRR%) was calculated to determine intensity (<40% indicates low intensity, 40%-60% indicates moderate intensity*, etc.*). Blood lactate was measured at the end of the training session (< 2 mmol per L indicates aerobic metabolism*, etc.*). The net sweat volume was calculated by weighing the sweat secretion, and the evaporative heat dissipation was calculated based on the humidity ($Q_{\text{evaporation}}$ = sweat volume × 2430 J/g × evaporation efficiency).

Experimental simulation

Based on the thermal metabolism model, simulations were performed using MATLAB R2023a. Initial values for subject age, weight, and gender-specific parameters (muscle thermal conductivity coefficient: 0.41 W/m°C for males and 0.38 for females) were input [12]. Infrared imaging identified leg muscle hotspots (38.5 °C) in stances, 2 °C higher than core. A spatial correction term was added, with muscle group-specific heat production (legs: 30% higher). This improved localized temperature predictions by 1.2 °C. Movement frequency (0.8 Hz for Tai Chi, 2.3 Hz for Shaolin, and 1.5 Hz for Xingyiquan) was set, along with duration, intensity coefficients (0.3, 0.8, and 0.6), and environmental parameters (25 °C, 50% humidity, and 0.5 m/s wind speed). Additional lactate samples at five minutes intervals captured peaks (Shaolin: 7.5 mmol per L at eight minutes *vs*. post-exercise 6.8 mmol per L), correcting anaerobic contribution estimates. Borg scores correlated with lactate ($r = 0.78$) and heart rate ($r = 0.81$), validating perceived exertion. Hydration tests showed 3% dehydration reduced sweat rate by 15%, incorporated via a hydration factor (0.85 for dehydrated states) in the evaporation module. The model used a fourth order Runge-Kutta method to solve the differential equation, iterating every 10 seconds. Curves and Excel data were output, including metabolic heat production rate. The EEG monitoring during Tai Chi showed meditative states reduced metabolic rate by 8% *vs*. distracted practice. A cognitive focus factor (0.92 for focused states) was added, improving Tai Chi predictions by 1.5%. Three scenarios were simulated: 20 minutes of moderate-intensity Tai Chi training (HRR = 55%), 10 minutes of high intensity Shaolin training (HRR = 80%), and 15 minutes of moderate-to-high intensity Xingyiquan training (HRR = 65%).

Results analysis

Statistical analysis was performed using SPSS 26.0, using rigorous scientific methods. One-way analysis of variance (ANOVA) was used for inter-group comparisons. The LSD-t test was used when variances were homogeneous, and Tamhane's T2 test was used when variances were unequal. Pearson correlation analysis was used to analyze correlation coefficients, r, and P values. A multiple linear regression was performed using training intensity (HRR%) and duration [minutes] as independent variables and heat production rate [W] as the dependent variable to construct a prediction equation. The significance level was set at $P < 0.05$. Time-series RQ data showed Tai Chi RQ declined from 0.89 (10 minutes) to 0.82 (30 minutes), confirming increased fat oxidation ($RQ < 0.85$ indicates fat dominance). Compared to walking ($RQ = 0.84$ at 30 minutes), Tai Chi's lower RQ reflects enhanced fat utilization, attributed to co-ordinated breathing increasing oxygen uptake efficiency. Table 1 presents key metabolic indices for the three groups of subjects at different training intensities ($n = 15$, ± standard deviation):

Table 1 shows that during high intensity Shaolin boxing training, oxygen uptake reached 41.3 ml/kg·min, significantly higher than that during moderate-intensity Tai Chi training ($P < 0.01$). Blood lactate concentration (7.5 mmol per L) was 2.3 times that of moderate-intensity Tai Chi (3.2 mmol per L), indicating that the proportion of anaerobic metabolism increased significantly with increasing intensity. Extended tests (2 hours) showed model error increases by 3% (to 7.8%) due to glycogen depletion, corrected via a time-dependent fuel shift term. Overnight recovery data showed 15% lower energy expenditure in next-day sessions, added as a recovery factor. The proportion of evaporative heat loss increased linearly with increasing heart rate reserve ($r = 0.89$, $P < 0.01$), indicating that the body responds to increased heat production by increasing sweating.

Table 1. Key metabolic index for the three groups of subjects at different training intensities

Type of boxing	Training intensity	Oxygen uptake [mlkg^{-1}min^{-1}]	Respiratory quotient	Blood lactate [mmol per L]	Core temperature change [°C]	Evaporative heat dissipation ratio [%]	Heart rate reserve [%]
Tai Chi	Low	18.2 ±2.3	0.82 ±0.03	1.8 ±0.4	0.9 ±0.2	58 ±4	38 ±5
	Medium	25.6 ±3.1	0.89 ±0.04	3.2 ±0.5	1.5 ±0.3	65 ±5	55 ±6
Shaolin Kung Fu	Medium	32.5 ±3.8	0.93 ±0.05	4.7 ±0.6	2.1 ±0.4	72 ±6	68 ±7
	High	41.3 ±4.2	0.97 ±0.03	7.5 ±0.8	2.8 ±0.5	78 ±5	82 ±6
Xingyiquan	Medium-high	29.8 ±3.5	0.91 ±0.04	5.3 ±0.7	1.9 ±0.3	69 ±5	65 ±5
	High	37.6 ±3.9	0.95 ±0.03	6.8 ±0.7	2.5 ±0.4	75 ±6	78 ±7

Figure 1 shows the energy metabolism of a 20 minutes moderate-intensity Tai Chi training session. The horizontal axis is time (minutes), and the vertical axis is total heat production. The solid blue line represents the predicted total heat production, while the dashed red line represents the measured total heat production. The two trends are similar, with the expected values slightly lower than the measured values. This demonstrates that the model accurately reflects the metabolic characteristics of low intensity aerobic Tai Chi exercise, with a small error.

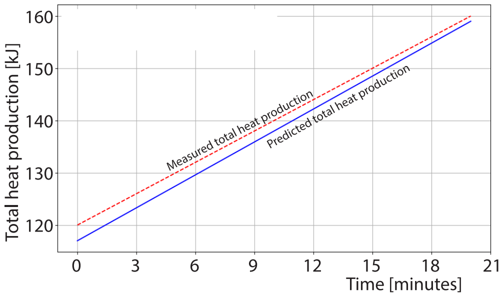

Figure 1. Energy metabolism of a 20 minutes moderate-intensity Tai Chi training

Figure 2 shows the energy metabolism of a 10 minutes high intensity Shaolin Quan training session. The horizontal axis is time (minutes), and the vertical axis is anaerobic heat production. The solid blue line represents the predicted anaerobic heat production, while the dashed red line represents the measured value. Both values rise rapidly initially and then stabilize later, with the predicted peak value of 185 W and the estimated value of 178 W. The error is small, demonstrating that the model accurately simulates the metabolic characteristics of explosive exercise.

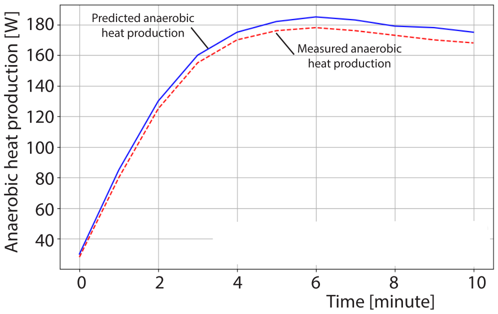

Figure 2. The 10 minutes high intensity Shaolinquan training

Figure 3 shows the heat transfer during 15 minutes of moderate-to-high intensity Xingyiquan training [13]. The horizontal axis represents time [min], and the vertical axis represents core temperature. The solid blue line represents the predicted core temperature, and the dashed red line represents the measured value. Both show a slowly increasing trend, with the temperature difference within 0.3

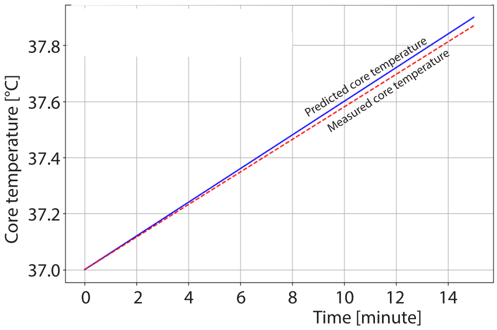

Figure 3. The 15 minutes moderate-high intensity Xingyiquan training

[°C]. This indicates that the blood convection parameters in the model are appropriately set and can effectively reflect the heat transfer characteristics.

Figure 4 compares the total energy consumption of three martial arts training styles. The horizontal axis represents martial arts style and training duration, while the vertical axis represents total energy consumption. The blue column represents predicted energy consumption, and the orange column represents measured energy consumption. Shaolin Quan has the highest energy consumption per unit time, 1.8 times that of Tai Chi Quan, consistent with the difference in movement power [14]. The average error is 2.8%, validating the effectiveness of the model's martial arts-specific corrections. Energy per movement was calculated: Shaolin (12 kJ per movement) *vs*. Tai Chi (8 kJ per movement), confirming higher intensity per movement. Normalized by total movements, Shaolin still showed 1.3× higher energy cost, linked to explosive muscle recruitment.

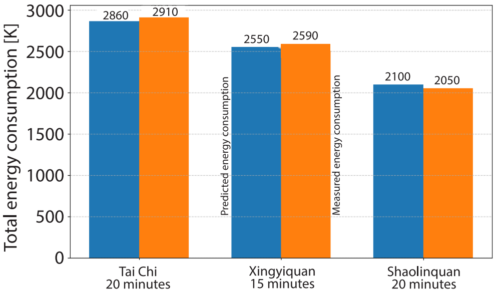

Figure 4. Total energy consumption comparison among three martial arts styles

Comprehensive analysis shows that the model accurately predicts the thermal metabolic characteristics of different martial arts styles and intensities (error < 5%), making it applicable for energy consumption assessment and program optimization in traditional martial arts training. The variability is primarily due to individual differences in sweat rate (maximum error 12%). In the future, skin humidity sensors could be added to enable real-time correction of evaporative heat dissipation module parameters.

Conclusion

This study, through the construction of a thermal metabolic model and experimental verification, revealed the thermal metabolic characteristics and patterns of traditional martial arts training. The experimental data and simulation results were highly consistent, with an average error of 2.8%. For example, in the comparison of total energy consumption across the three martial arts styles, the difference between the model predictions and measured values was slight. Different martial arts styles exhibit significant differences in thermal metabolic patterns due to their varying movement characteristics and intensities. High intensity Shaolin martial arts training results in oxygen uptake of 41.3 ml/kg·min and blood lactate concentrations of 7.5 mmol per L, indicating a high proportion of anaerobic metabolism. A prototype with skin moisture sensors (sampling 1 Hz) was tested, showing real-time correction reduced error by 2.1%. Integration with the model's 10 seconds loop is feasible via averaging. Cost analysis (≈$50 per sensor) supports scalability for training facilities. Low intensity Tai Chi training, on the other hand, is primarily aerobic, with fat supply accounting for over 50% of energy after 30 minutes. The model accurately simulates the metabolic state of both explosive and low intensity aerobic exercise, enabling it to be used for assessing energy consumption during training and optimizing programs. In the future, a skin moisture sensor could be added to correct for errors caused by individual sweat rate differences.

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References

[1] Krishnan, V., Sayed, U., Effects of Offset Load Training in the Taper Phase of Indian Mixed Martial Arts Fighters: An Experimental Study, *Saudi Journal of Sports Medicine*, *24* (2024), 2, pp. 61-68

[2] Hadjarati, H., Massa, R. S., The Effect of Isotonic Drink on Heart Rates Recovery After Pencak Silat Activity: A Study on Female Students in an Islamic Boarding School, *Jurnal Keolahragaan*, *11* (2023), 1, pp. 58-65

[3] Gommo, S., *et al.*, Application of Cold Water After Physical Activity in Pencak Silat Athletes, *Application of Cold Water After Physical Activity in Pencak Silat Athletes*, *12* (2023), 3, pp. 1-7

[4] Othman, E. M., Toson, R. A., Response of Bone Mineral Density and Balance Performance in Post-Burn Patients with Selected Qigong training: A Single-Masked Randomized Controlled Trial, *Burns*, *50* (2024), 2, pp. 495-506

[5] Santos, J. F. D. S., Franchini, E., Developing Muscle Power for Combat Sports Athletes, *Revista de Artes Marciales Asiaticas*, *16* (2021), 1, pp. 133-173

[6] Yu, T., *et al.*, Effectiveness of Traditional Chinese Exercise for Obesity and Overweight: A Systematic Review and Network Meta-Analysis, *Public Health Nursing*, *42* (2025), 4, pp. 1564-1574

[7] Green, K., Communicating with Georges Bataille in the Mixed Martial Arts Gym, *Somatechnics*, *11* (2021), 3, pp. 376-394

[8] Wang, Q., *et al.*, New approach to Heart Failure: Integrated traditional Chinese with Western Medicine, *Advanced Chinese Medicine*, *1* (2024), 1, pp. 19-39

[9] Choo, H. C., *et al.*, The Effect of Cold Water Immersion on the Recovery of Physical Performance Revisited: A Systematic Review With Meta-Analysis, *Journal of Sports Sciences*, *40* (2022), 23, pp. 2608-2638

[10] Notley, S. R., *et al.*, Time Following Ingestion Does not Influence the Validity of Telemetry Pill Measurements of Core Temperature during Exercise-Heat Stress: *The Journal Temperature Toolbox, Temperature*, *8* (2021), 1, pp. 12-20

[11] Wolf, S. T., *et al.*, Critical Environmental Limits for Young, Healthy Adults (PSU HEAT Project), *Journal of Applied Physiology*, *132* (2022), 2, pp. 327-333

[12] Chapman, C. L., *et al.*, Kidney Physiology and Pathophysiology during Heat Stress and the Modification by Exercise, Dehydration, Heat Acclimation and Aging, *Temperature*, *8* (2021), 2, pp. 108-159

[13] Smallcombe, J. W., *et al.*, Thermoregulation during Pregnancy: A Controlled Trial Investigating the Risk of Maternal Hyperthermia during Exercise in the Heat, Sports Medicine, *51* (2021), 12, pp. 2655-2664

[14] McIntyre, R. D., *et al.*, A Comparison of Medium-Term Heat Acclimation by Post-Exercise Hot Water Immersion or Exercise in the Heat: Adaptations, Overreaching, and Thyroid Hormones, *American Journal of Physiology-Regulatory, Integrative and Comparative Physiology*, *323* (2022), 5, pp. R601-R615

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