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METABOLIC AND NEUROMUSCULAR RESPONSES TO HIGH-INTENSITY TRAINING WITH AND WITHOUT TAOPATCH® NANOTECHNOLOGY: A PILOT RANDOMIZED CONTROL STUDY

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Abstract High-intensity training (HIT), such as CrossFit® training, causes metabolic and neuromuscular stress. Wearable devices, such as Taopatch®, which combine photobiomodulation and proprioceptive stimulation, have been proposed to enhance metabolic responses during HIT. Our pilot study investigated the acute effects of Taopatch® on metabolic (blood lactate and glycemia) and neuromuscular (handgrip strength and push-up performance) markers in six trained female CrossFit® athletes. Participants were assigned to either experimental group (TAO), who received the Taopatch® device, or the control group (CC), who received the Taopatch® placebo device. Each athletes completed a 15-minute CrossFit® training session. Lactate and glycemia levels were measured at baseline before device application (T0). The Taopatch®, active or placebo, was then applied, and post-training measurements were collected 45 minutes after the end of training (T1), and 90 minutes after the end of training (T2). Strength tests were performed before and after the application of Taopatch®. The results showed no statistically significant differences between groups. However, TAO group showed a stable glycaemic profile and a less marked lactate peak than CC group after the workout, suggesting a potential effect of Taopatch® on metabolic regulation. In neuromuscular parameters, there were no relevant changes between the groups. A small improvement in left-hand grip strength test was observed in TAO group, suggesting that Taopatch® can improve the non-dominant limb. However, the absence of evident effects on neuromuscular parameters could be related to the small sample size and short duration of the study. These preliminary findings suggest a potential modulatory effect on metabolic response that warrants verification in larger, fully-powered trials.

Key words: Taopatch®, AMRAP, High-intensity training, CrossFit®, blood lactate levels, blood glucose, handgrip, push-up, physiological response, motor performance

Introduction

In recent years, high-intensity training (HIT) has gained increasing attention as an effective method for enhancing physical performance and positively influencing many health factors, such as cardiovascular, metabolic and cognitive health. CrossFit®, in particular, is based on the principles of HIT (Ben-Zeev & Okun, 2021) by combining high-intensity resistance exercises with functional movements to improve muscle strength and aerobic capacity while reducing body fat (Ficarra et al., 2022; Escobar et al., 2017). Among the most commonly used programs in CrossFit® is AMRAP (As Many Rounds/Repetitions As Possible), which involves performing as many repetitions or rounds of predefined exercises as possible within a set time frame, usually between 10 and 20 minutes (Barba-Ruíz et al., 2024). From a metabolic perspective, CrossFit® workouts produce important physiological responses, particularly with regard to blood lactate and glucose levels. The HIT and short recovery times, characteristic of this program, promote a rapid shift towards anaerobic energy pathways. Consequently, substantial increases in blood lactate concentrations are evident, reflecting the significant metabolic demand and glycolytic activity during exercise (De-Oliveira et al., 2021; Toledo et al., 2021). Additionally, acute CrossFit® sessions can lead to transient glycemia variations, with levels often rising during exercise due to increased hepatic glucose production. This is followed by a post-exercise decrease as glucose uptake by skeletal muscles increases (Camacho et al., 2005; Rose & Richter, 2005). In this context, innovative technologies are designed to enhance physical performance and physiological efficiency during HIT. One such technology is the Taopatch®

a wearable nanotechnology-based device that combines photonic stimulation with proprioceptive input to influence neuromuscular function (Campoli et al., 2025; Messina et al., 2022). Preliminary evidence suggests that Taopatch® may modulate biological responses by enhancing postural control and muscle coordination, as well as potentially improving metabolic efficiency during physical activity (Amato et al., 2021; Lomeo et al., 2019). However, there are limited data available regarding its acute effects during HIT, such as CrossFit® workout. The pilot study aims to evaluate the metabolic and neuromuscular responses following a CrossFit® training, with Taopatch® and a placebo device. By examining the metabolic effects, this research aims to fill a gap in the literature by exploring if Taopatch® can improve performance and recovery in HIT reducing metabolic stress. These findings are expected to advance scientific knowledge of the metabolic and neuromuscular effects.

Materials and Methods

Study Design

This study was designed as a pilot study aimed at evaluate protocol feasibility and preliminary variability of physiological response. Therefore, no a priori power calculation was performed. We aimed to focus on acute physiological markers, specifically lactate and glycemia levels, handgrip strength and muscular endurance by push-up performance. These markers are well established in capturing key neuromuscular and metabolic adaptations during high-intensity functional exercise. These parameters are directly involved in anaerobic energy metabolism, neuromuscular activation and short-term performance output, all of which are critical in CrossFit® training (Scoubeau et al., 2023). Specifically, blood lactate concentration provides insight into anaerobic glycolysis and the metabolic load imposed by intense effort (Jacob et al., 2023), while glycemia reflects acute fluctuations in carbohydrate metabolism and endocrine regulation under physical stress. Both are key indicators of the body's ability to mobilize and utilize energy during HIT (Jacob et al., 2022; Peter Adams, 2013). The handgrip strength test is a reliable indicator of isometric muscular force and neuromuscular efficiency and is associated with overall upper body strength in athletes (Vaidya & Nariya, 2021). Finally, the push-up performance test provides a functional assessment of muscular endurance and coordination under fatigue (Nasrulloh et al., 2022). Together, these outcome measures provide insight into how neuromuscular performance and metabolic responses can be modulated acutely by non-invasive technologies such as Taopatch®, paving the way for future applications in optimising training and recovery strategies for high-intensity modalities.

Participants

Six female advanced athletes were enrolled in our study. The anthropometric characteristics of the participants are shown in Table 1. The inclusion criteria were as follows: absence of musculoskeletal injuries, chronic illnesses, or any condition that could compromise either safety or performance during the study, aged between 21 and 49, right dominant limb and at least two years' experience of performing CrossFit®. Exclusion criteria included recent pharmacological treatments affecting metabolism or muscle performance, and pregnancy. The participants were randomly assigned to two groups: the experimental group (TAO) with Taopatch® (n = 3) and the control group (CC) with placebo Taopatch® (n = 3). This was done randomly via "wheel of names" software. All participants were fully informed about the study protocols before its commencement and provided written informed consent for all tests. The study was conducted following the Declaration of Helsinki and approved by the Ethics Committee of Palermo 1

(Approval No. 240/2024), Department of Psychological, Educational and Movement Sciences, University of Palermo. Upon enrolment, participants completed a questionnaire to gather anthropometric and training habit data.

Table 1. Means and standard deviations (SD) of the participants' anthropometric characteristics.

Characteristics	Control Group (CC)	Experimental Group (TAO)
	Mean ±SD	Mean ±SD
Age (years)	30.3 ±16.2	39 ±14.8
Body mass (kg)	60.3 ±2.5	60 ±7
Body height (cm)	165 ±5	160.7 ±5.5
BMI ($kg \cdot m^{-2}$)	22.2 ±1.9	23.2 ±1.5

BMI = body mass index.

Assessments

Participants of both groups performed a hand grip test and push-up test before and after the application of Taopatch®. In addition, lactate and glucose levels were evaluated in all participants at baseline (T0), 45 minutes after the Crossfit® training (T1) and 90 minutes after the end of training program (T2), with a passive recovery, during which no stretching, eating, or excessive hydration was allowed. Blood samples were placed on test strips for quantification of glucose and lactate (Accutrend® Plus Glucose and Accutrend® Plus BM-Lactate, Roche). Handgrip test (KERN MAP Version 1.2 08/2012, Hand Grip Dynamometer) was used to assess the strength of the flexor muscles through maximum isometric grip (MIG), an important indicator of musculoskeletal function. Participants performed three trials per hand with their elbow flexed at 90°. The mean value obtained from the three trials for each hand was used for data analysis. A push-up test was conducted based on the maximum number of repetitions that each participant could perform in one minute. Participants performed push-ups from a prone position with their legs fully extended and their hands placed directly under their shoulders. Each repetition required them to touch their chest to the floor and then return to the starting position with their arms fully extended. They had to maintain a straight body line throughout, without bending at the hips or knees.

Intervention

Before starting the Crossfit® training, two Taopatch® devices, containing a mixture of nanotechnology with nanocrystals called "quantum dots," were applied one below the vertebrae C7 posteriorly and one on the xiphoid process anteriorly (Amato et al., 2021; Carbonari et al., 2021). The experimental group (n = 3) used the active devices. The control group (n = 3) used a placebo device, that is identical in appearance and texture to the active one, but without photobiomodulatory activity. It was applied to the same area of the body, in the same way as the active Taopatch® to ensure that no subjects could distinguish between the active treatment and the placebo.

2.5 Crossfit® Program

The AMRAP (As Many Rounds As Possible) session was structured as a single HIT based on a 15-minute of Crossfit® training protocol, aimed at enhancing muscular endurance, strength, and cardiorespiratory fitness. The study was carried out under the supervision of a kinesiologist to ensure the appropriate technique of the exercises and belaying. Immediately before the Crossfit® training, all participants performed an identical warm-up. The purpose of the warm-up was to prepare the muscles and joints for heavy effort, while minimizing fatigue during it, so as not to reduce the size of the weight lifted in the maximum repetition (Durkalec-Michalski et al., 2022).

The session was organized to allow two participants to begin at a time, with a staggered start every 5 minutes to ensure optimal space utilization and individualized supervision. The circuit included the exercises shown in Table 2.

Table 2. CrossFit® protocol

CrossFit®	Characteristics	Aim	Total duration
10 Shuttle runs	Covering 7 meters out and 7 meters back per repetition	To assess aerobic fitness and to stimulate agility and cardiovascular effort (Ambroży et al., 2022; Cataldi et al., 2021; Cruz-León et al., 2025)	15 min
Ladder +2	For each round completed, participants increased the number of repetitions of each exercise by 2	Promoting progressive overload and muscular endurance.	
6 down & up	A simplified burpee variation without the push-up phase	Developing full-body coordination and anaerobic capacity	
2 dumbbell thrusters	Combining a front squat and an overhead press using dumbbells	To targeting both lower and upper body strength	

Participants were instructed to complete as many rounds as possible within the 15-minute time limit, maintaining proper form and safety throughout. The Crossfit® training was chosen for its ability to individualize intensity based on each participant's fitness level, while ensuring a consistent workload for comparison across subjects.

Statistical Analysis

Statistical analysis was performed with "Jamovi" software version "2.6.26.0". Data in descriptive statistical analysis were expressed as means and standard deviations. The Shapiro-Wilk test was used to check for normal distribution, showing that all variables were normally distributed ($p > 0.05$), supporting the use of parametric tests. Repeated measures ANOVA was used to assess the effects of time (T0, T1, T2), group (CC vs. TAO), and their interaction on glycemia, lactate, handgrip and push-up test. Post-hoc test Bonferroni was used to compare these differences in the two groups. A 5% probability level was considered significant. Due to the preliminary nature of the pilot and the very small sample size, statistical analyses are exploratory.

Results

Metabolic parameters, as glycemia (mg/dL) and lactate (mmol/L) levels, were assessed at three times: at baseline (T0), 45 minutes after the Crossfit® training (T1) and 90 minutes after the end of training (T2), to observe the response of HIT in the control group (CC) and experimental group (TAO) with the application of Taopatch® (Table 3). Results showed that glycemia levels increased more markedly in the CC group than in the TAO group. In particular, in CC group, glycemia increased from T0 (88.3 ±21.1 mg/dL) to T1 (126.7 ±60.1 mg/dL), while in TAO group, glycemia levels increased from 73.7 ±16.8 mg/dL to 86.0 ±42.1 mg/dL. Regarding lactate levels, both groups showed an increase after the training program; nevertheless, in CC group, the lactate level rose to 9.9 ±2.7 mmol/L, whilst in TAO group lactate increased up to 7.9 ±3.8 mmol/L at T1 time point.

Table 3. Metabolic parameters (mean ±SD) in experimental (TAO) and control group (CC) at baseline (T0), 45 minutes after the Crossfit® training program with the application of Taopatch® device (T1) and 90 minutes after the training (T2).

Parameters	Group	T0 Mean ±SD	T1 Mean ±SD	T2 Mean ±SD
Glycemia (Mg/dL)	TAO	73.7 ±16.8	86.0 ±42.1	59.7 ±17.1
	CC	88.3 ±21.1	126.7 ±60.1	79.0 ±7.8
Lactate (Mmol/L)	TAO	1.1 ±0.5	7.9 ±3.8	3.4 ±2.4
	CC	1.2 ±0.6	9.9 ±2.7	2.6 ±1.6

In addition, to determine whether Taopatch® had an immediate impact on strength, neuromuscular parameters were assessed before and after the Taopatch® application through isometric strength (handgrip) and a muscle endurance test (Table 4). In the right handgrip test, CC group showed a slight increase from 29.7 ±5.7 kg to 31.6 ±6.2 kg, while it didn't change in TAO group (27.6 ±2.0 kg *vs* 27.8 ±2.6 kg). An opposite situation was highlighted for the left hand in which there was an increase just in TAO group from 25.4 ±3.3 kg to 27.1 ±3.2 kg. As concerns the push-up test, TAO group showed a slight improvement in performance before (21.7 ±6.7) and after (23.3 ±7.0), while in CC group, the performance remained almost unchanged.

Table 4. Neuromuscular parameters (mean ±SD) in experimental (TAO) and control group (CC) before and after the application of Taopatch®.

Parameters	Group	Before Mean ±SD	After Mean ±SD
Handgrip R (kg)	TAO	27.6 ±2.0	27.8 ±2.6
	CC	29.7 ±5.7	31.6 ±6.2
Handgrip L (kg)	TAO	25.4 ±3.3	27.1 ±3.2
	CC	27.6 ±4.8	28.4 ±5.1
Push-Up (n° Reps)	TAO	21.7 ±6.7	23.3 ±7.0
	CC	34.0 ±6.1	35.3 ±1.5

Discussion

This pilot study investigated the acute effects of Taopatch® on the metabolic and neuromuscular responses of trained female athletes to high-intensity CrossFit® training. The physiological responses to Crossfit® training are well documented in the literature (Hafidz et al., 2022; Wibowo et al., 2022). HIT is known to increase metabolic stress, influence muscular endurance, and briefly alter blood parameters such as lactate and glycemia. In our pilot study, both groups, TAO and CC, performed a 15-minute Crossfit® workout, aiming to investigate whether the combination of Taopatch® with physical activity could enhance functional and physiological responses in healthy subjects, reducing the metabolic stress. The results suggest a potentially favourable impact of the device on the metabolic responses to intense exercise. As expected, following the Crossfit® training, glycemia levels increased in both groups, suggesting an initial increase linked to metabolic response to exercise, with subsequent redistribution and possible utilisation of glucose in muscle tissue during the recovery phase. This tendency can be attributed to the body's physiological response to high-intensity exercise that involves an increase in catecholamines (adrenaline and noradrenaline), which stimulate glycogenolysis and gluconeogenesis, and inhibit the action of hypoglycaemic hormones, resulting in a temporary increase in blood glucose levels. During exercise, glucose uptake by skeletal muscle increases; this is mediated by an increase in insulin-sensitive GLUT4 transporters, with a consequent reduction in plasma glucose level. In high-intensity training, a glycaemic threshold can be identified that indicates the relationship between effort intensity, muscle glucose utilisation and reduced hepatic availability (Mota et al., 2021). TAO group showed a more stable glycemia profile compared to CC group. In particular, glycemia levels in TAO group increased moderately from T0 to T1, without showing a marked peak compared to CC group (CC 88.3 ±21.1 *vs* 126.7 ±60.1; TAO 73.7 ±16.8 *vs* 86.0 ±42.1). This suggests that the device may modulate the glycaemic response to HIT and, consequently, promoting a more efficient exercise metabolic response. Therefore, as expected, in response to HIT, both groups showed a marked increase in lactate levels at T1; however, CC group reached a higher lactate peak than TAO group, suggesting a greater activation of the anaerobic pathway and metabolic stress induction. This may reflect a more balanced metabolic recovery and a better metabolic tolerance, in which lactate reuse is more efficient in TAO group than in CC group (Meier et al., 2021; Eroglu et al., 2023). It is possible that Taopatch® could influence pathways related to AMPK/PGC- 1α activation and GLUT4 expression, contributing to better glycemia control and efficient muscle glycogen synthesis (Chen et al., 2025). These results suggest that Taopatch® may modulate the metabolic response to HIT, thereby reducing excessive lactate accumulation. As muscle fatigue can influence neuromuscular performance, particularly in strength-based tasks, it was important to evaluate changes in upper limb function. In the strength test, the TAO group showed no significant change on the right side, while on the left side, it showed a greater improvement compared to CC group (TAO 27.1 ±3.2 vs CC 28.4 ±5.1). This could be a power-up of the non-dominant limb, for a better adaptation and improvement. Regarding muscular endurance, the push-up test didn't show any marked change between the groups. These results, while not statistically significant, suggest that the use of Taopatch® in combination with HIT may enhance short-term metabolic responses. However further studies are needed to confirm these assumptions.

Conclusions

The pilot study aimed to investigate the acute metabolic and functional effects of a 15-minute Crossfit® workout in trained subjects, with and without the use of Taopatch® technologies, to understand if there should be a synergistic effect able to reduce metabolic stress with better glycaemic control, lactate management, and upper body performance. However, either the results didn't show a significant statistical change, or they laid a starting point for future investigation to better define the potential role of Taopatch® in improving the metabolic response to HIT. The results obtained in TAO group suggest that Taopatch® may have contributed to modulating the metabolic response to exercise, reducing excessive lactate accumulation and promoting more efficient post-workout glycaemic regulation. This pilot study could open new setups on improving performance by improving the metabolic response to HIT. The main limitations of the study are the small sample size (n = 6) and short duration of the intervention, which prevents any firm statistical conclusions and may have limited the detection of more subtle changes, particularly those associated with neuromuscular function and performance relating to the use of the device. Further studies into long-term integration of Taopatch® into structured training programmes could provide more insights into its impact on metabolic and neuromuscular parameters, such as strength, endurance and motor control. This pilot study should therefore be interpreted as a feasibility investigation, providing preliminary insights and generating hypotheses for future to more definitive assessments of the effects of Taopatch® on metabolic and neuromuscular responses.

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