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# الاستجابات الفسيولوجية العصبية – العضلية للتحفيز الكهربائي لتسريع استعادة الاستشفاء للعضلات بعد الوحدات التدريبية عالية الشدة للمصارعين المتقدمين

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**ملخص البحث**

قمنا بدراسة تأثير التحفيز الكهربائي العصبي العضلي على الاستشفاء من تدريبات المصارعة عالية الكثافة و كانت المتغيرات الرئيسية المدروسة هي إزالة اللاكتات واستعادة القوة القصوى وتغير معدل ضربات القلب. كان لدى المجموعة التجريبية إزالة اللاكتات واستعادة القوة بشكل أسرع بكثير من المجموعة الضابطة في تمرين القرفصاء و الضغط. علاوة على ذلك، تم تحسين مؤشر تذبذب معدل ضربات القلب بشكل ملحوظ من خلال التحفيز الكهربائي العصبي العضلي، مما يشير إلى أن نشاط الجهاز العصبي اللاإرادي قد تسارع في عملية الاستشفاء. من أجل الإيجاز، من المحتمل أن تلعب اللاكتات وإصلاح العضلات فضلا عن الاستشفاء العصبي اللاإرادي دورًا في تعزيز استشفاء العضلات. ومع ذلك، فإن الأدلة على استخدام التحفيز الكهربائي العصبي العضلي للاستشفاء لدى الرياضيين المقدمة في الدراسة يجب أن تخضع لمزيد من البحث في التطبيقات الخاصة بالرياضة. تضيف النتائج إلى الفهم الحالي للتحفيز الكهربائي العصبي العضلي كتدخل فعال لتحسين الأداء الرياضي والاستشفاء. ومع ذلك، يجب أن يؤخذ في الاعتبار عدم تجانس استجابات الأفراد للتحفيز الكهربائي العصبي العضلي وينبغي أن يهدف المزيد من العمل إلى تحسين معايير.

**الكلمات المفتاحية:** التحفيز الكهربائي، استعادة العضلات، تدريبات القوة، الاستشفاء اللاإرادي، تحسين الأداء

# Neuromuscular physiological responses to electrical stimulation to accelerate muscle recovery after high-intensity training units for advanced wrestlers

Ghazwan Kareem Khothier

**Abstract**

We investigated the influence of Neuromuscular Electrical Stimulation (NMES) on recovery from high intensity wrestling training. The main studied variables were the lactate removal, the recovery of the maximal strength and the heart rate variability (HRV). The NMES experimental group had significantly faster lactate clearance and strength recovery for squat and bench press than did the control group. Moreover, HRV index was improved markedly by NMES, suggesting that the activity of the autonomic nervous system was accelerated in the recovery process. For the sake of brevity, metabolic waste such as lactate and muscle repair, as well as autonomic nervous recovery could potentially play a role in enhancing muscle recovery. The compelling evidence for the use of NMES for recovery in athletes presented in the study should however be further investigated toward sport- and population-specific applications. The results add to the current understanding of neuromuscular electrical stimulation as an effective intervention for the improvement of athletic performance and recovery. Nevertheless, the heterogeneity of responses to NMES by individuals needs to be considered, and further work should aim to optimize parameters of stimulation.

## Introduction

Post-exercise recovery is fundamental for sports performance improvement in high-demand sports such as wrestling. Athletes frequently experience large amounts of challenges to recover muscles after high intensity workouts, due to the fatigue and damage that muscles encounter due to accumulation of metabolic waste products, e.g., lactate. As such, effective recovery techniques have become essential to facilitate maximum performance and reduce the potential for injury. One of these is NMES, since it may influence muscle recovery by increasing the blood flow to the extremity, promoting lactate clearance, and improving muscle strength recovery (Malone et al., 2014; Stevens-Lapsley et al., 2012; Taylor et al., 2015).

The NMES (Neuromuscular Electrical Stimulation) process works by stimulating muscle contraction through low levels of electrical current, this in turn increases blood flow then passes more oxygen to the muscles. This has been proposed to facilitate a more rapid removal of metabolic by-products (e.g., lactate) from the muscle, and is speculated to lead to a faster recovery in muscle strength following intense exercise (Malone et al., 2014). NMES has been recently shown to significantly reduce post-exercise lactate levels, which contributes to better overall recovery (Watanabe et al., 2021). Also, it has been hypothesized that NMES may speed up muscle strength recovery in the short and long-term due to the improvement in neuromuscular function (Abitante et al., 2022; Altarriba-Bartes et al., 2020). The aim of this study was to analyze, following high intensity wrestling practice, the effect of NMES on lactate removal, maximal strength restitution and heart rate variability (HRV). The purpose of the current study is to compare NMES with passive recovery and thus determine if NMES can be used to improve recovery response in a demanding and fatiguing sport such as wrestling, also solve is the difficulty of gaining effective muscle recovery for athletes who participate in high-intensity training. In some cases, slow elimination of lactate and slow restoration of muscle strength prohibit athletes´ performances and may hence contribute to diminished performance or increased risk of injuries. Therefore, the purpose of this study is to examine the effect of NMES in hastening these physiological adaptations and to translate this information to its application to recovery in a sport such as wrestling.

The primary aims. to evaluate the effects of NMES on the clearance lactate rate after a high intensity exercise; second, to compare the recovery of the maximal muscle strength in NMES and passive condition; third, to study the effect of NMES on one marker of recovery of balance of the autonomic nervous system: the heart rate variability (HRV). By examining these factors, this trial seeks to generate empirical data on the efficacy of NMES for the enhancement of post-exercise recovery and its added benefits over and above simple passive recovery techniques.

The experimental hypotheses are as follows: (1) Lactate clearance in the muscle is significantly faster after high-intensity exercise when applying NMES than after passive recovery, and (2) maximal strength recovery is significantly enhanced after NMES compared with passive recovery, (3) NMES results in a faster physiological recovery compared with passive recovery, expressed by improved HRV. These assumptions are supported by previous investigation, where it has been suggested that NMES could increase blood flow and speed up metabolic processes, which underlie clearing lactate and muscle repair (Day & Newman, 2020; Hou et al., 2020; Watanabe et al., 2021).

Indeed, NMES has been suggested to facilitate more effective removal of lactate and reduce muscle fatigue through increase blood flow (Babault et al., 2011; Stevens-Lapsley et al., 2012) Recent literatures also support that NMES may be involved in faster restoration of muscle performance post-exercise initiation, by improvement of blood flow that allows a more efficient lactate clearance in the muscle (Babault et al., 2011; Stevens-Lapsley et al., 2012). In addition, much evidence regarding NMES have demonstrated that the method could lead to quicker recovery of muscle strength, which may mean athletes could train more efficiently with lower risk for injury (Keriven et al., 2025; Kim et al., 2010). This work attempts to bridge the gap in the literature related to how to use NMES as a recovery modality in high-intensity sports, by applying these findings to wrestling.

## Materials and Methods

This study was designed semi-experimental to evaluate the effects of Neuromuscular Electrical Stimulation (NMES) on muscle recovery following high intensity wrestling sessions. The focus of the methodology is on assessing lactate clearance, maximal strength recovery, and heart rate variability (HRV) in trained wrestlers. The research was conducted in compliance with ethical standards and adhered to institutional guidelines for human studies.

## Study Design

A single study design with two groups [experimental (NMES) and control (passive)] was used. The two groups underwent the same high-intensity training, but each one was given different recovery techniques. The environment was tightly controlled to be the same for all sessions.

## Participants

The sample consisted of 30 male wrestlers with experience of a minimum of 2 years of competitive wrestling training, aged 18-30 years. sample were recruited from Al-Hashd Al-Shaabi Club, Al-Kadhimiya Club, Al-Aadhamiya Club, Amanat Baghdad Club, Al-Jaish Club, and Al-Shorta Club, while Al-Hudood Club was used for the pilot trial. The training sessions and testing procedures were conducted in the indoor hall of the College of Physical Education and Sport Sciences University of Baghdad. sample were eligible if they were free from injury for more than 6 months and were able to perform high intensity exercises, if a stable workout routine existed. Exclusion criteria included any neurological impairment, major musculoskeletal injury or any use of electrical stimulations, or a treatment that might impact this trial.

## Group Assignment

Participants were randomly allocated into one of two groups: the experimental and control groups. Patients in the experimental group were treated with NMES as a part of their treatment, and the control group was only permitted to rest without receiving the additional input. This randomization made certain that each participant was equally likely to be placed into either group.

**Data Collection Tools**

Lactate was analyzed with the Lactate Plus handheld lactate analyzer, which has been found to be both valid and reliable in athletic populations. Blood lactate was measured using a handheld lactate analyzer (Lactate Plus, Nova Biomedical) via finger-prick capillary blood. Samples were collected at rest (baseline) and immediately after the high-intensity training session and 10 minutes post-session to assess lactate accumulation and early clearance. 1 RM test was utilized to evaluate maximum strength, with the bench press and squat as major exercises. We used the Polar H10 heart rate monitor to assess HRV because it is known to be an accurate device for HRV measurement among athletes.

**Pre-Test Measures**

Measurements Lactate concentration (LAC), Maximum isometric force (MIF), Heart rate variability (HRV) Baseline measurements During the last week before commencing the first testing session, the variability of lactate concentration, MIF, and HRV were evaluated at rest. Lactate was determined with a handheld lactate analyzer (Lactate Plus, Nova Biomedical). One repetition maximum (1RM) for squat and bench press Each participant performed maximal strength and muscular endurance testing had participants Perform a proper warm-up. HRV was assessed with a Polar H10 heart rate monitor after 5 min seated rest at rest.

**Training Session**

The training protocol was structured to replicate the dual demands of wrestling competition: formal bouts simulating real matches and supplementary exercises designed to intensify muscular and metabolic stress. This combination ensured both ecological validity (competition-specific load) and experimental control (standardized fatigue and lactate accumulation).

Each session lasted approximately 90 minutes and consisted of three phases: (1) warm-up, (2) high intensity wrestling bouts and Plyometric drills, and (3) cool-down. Exercise intensity was monitored using heart rate (%HRmax), one-repetition maximum (%1RM) for resistance exercises, and the Borg RPE scale to ensure standardized exertion levels across participants, A structured overview of the training design is provided in Table 1.

**Table 1. Show the High-Intensity Wrestling Training Session**

| Training Component | Duration | Intensity / Load | Description |
|---|---|---|---|
| **Warm-up** | 15 min | 50–60% HRmax | Light jogging/cycling 10 min + dynamic stretching for major joints and muscle groups 5 min |
| **Wrestling bouts** | 20 min | 90-100% HRmax | Live 3-min bouts under UWW official rules, matched by weight/skill, 1-min rest between bouts |
| **Technical drills** | 20 min | 70–80% HRmax | Takedowns, clinch work, escapes, reversals; 3-min rounds with 30 s rest |
| **Plyometric drills** | 10 min | Maximal effort (RPE 17–18) | Box jumps, medicine ball throws to simulate explosive wrestling actions |
| **Resistance training (circuit)** | 10 min | 75–85% 1RM | Squats, deadlifts, overhead presses; 3 sets × 10–12 reps, 1-min rest |
| **Cool-down** | 15 min | 40–50% HRmax | Light jogging/walking (5–10 min) + static stretching |
| **Training Frequency:** 3 sessions per week<br>**Total Duration:** 4 weeks (12 sessions) | | | |

## Recovery Protocol

Following the training session, participants were randomly assigned to one of two recovery conditions. The experimental group received Neuromuscular Electrical Stimulation (NMES), while the control group engaged in passive recovery. The NMES was applied immediately after the training session and lasted for 20 minutes. The parameters for NMES were set as follows: frequency of 50 Hz, pulse width of 200 µs, and an intensity level sufficient to cause a strong but tolerable muscle contraction. The NMES electrodes were placed on the quadriceps and hamstrings of the participants. The control group, on the other hand, rested quietly in a seated position for 20 minutes, without any further intervention, and We chose passive recovery because it is the most common method used in studies as a basis for comparison with modern techniques.

**Post-Test Measures**

After the recovery phase, the same measurements that were taken before the session were repeated. Lactate levels were again measured using the portable lactate analyzer. Maximal strength was assessed through the 1RM test on the squat and bench press exercises. HRV was recorded using the Polar H10 heart rate monitor under resting conditions for 5 minutes. These post-test measurements were used to assess the changes in lactate clearance, strength recovery, and autonomic nervous system recovery (via HRV).

**Statistical Analysis**

Data collected from pre- and post-test measures were analyzed using SPSS (ver.26). Descriptive statistics (mean, standard deviation, and skewness) were used to summarize baseline characteristics and test results. Paired t-tests were conducted to compare changes in lactate levels, maximal strength, and HRV within each group. Independent t-tests were used to compare the outcomes between the experimental and control groups. The significance level was set at $p < 0.05$ for all statistical tests.

**Results**

The results of this study are based on the analysis of lactate clearance, maximal strength recovery, and heart rate variability (HRV) measurements taken from both the experimental group (NMES) and the control group (passive recovery) following a high intensity wrestling session. The following sections describe the statistical findings of each of the key outcomes, with a focus on the comparative analysis between the two groups.

Lactate clearance data for the NMES and control protocols are presented in Table 2. Lactate was measured at three times before the exercise (pre-exercise), immediately after the exercise (post-exercise), and 10 min after recovery (post-recovery). The average and SD of data are presented for each time point. The findings show that the NMES group had a significantly shorter lactate clearing time post-recovery than the control group, and a correlated lower lactate concentration after recovery. Statistically, groups differed significantly ($p < 0.05$) post-recovery.

**Table 2. Lactate Clearance and Recovery Efficiency in NMES and Control Groups Post-High-Intensity Wrestling Session**

| Group | Pre-Exercise (Mean ± SD) | Post-Exercise (Mean ± SD) | Post-Recovery (10 minutes) (Mean ± SD) | (p-value) |
|---|---|---|---|---|
| Experimental | 0.0 ± 0.0 | 12.6 ± 2.3 | 4.1 ± 1.5 | 0.01* |
| Control | 0.0 ± 0.0 | 13.4 ± 2.1 | 8.9 ± 2.0 | N/A* |
| *: significant at p<0.05<br>* N/A: value indicates that no p-value is required for the control group since it is only being compared to the experimental group | | | | |

Table 3 presented the outcomes in maximal strength recovery (1-repetition maximum (1RM) tests of squat and bench press exercises). Means and standard deviation (SD) for each test are displayed pre and post recovery in NMES and control conditions. The NMES group showed significant increases in squat ($p < 0.01$) and bench press ($p < 0.05$) than a control group from pre-training levels, which may mean that NMES recovers maximal strength better than passive recovery does.

**Table 3. Maximal Strength Recovery in Squat and Bench Press After NMES Intervention and Passive Recovery**

| Group | Squat Pre-Exercise | Squat Post-Recovery | Bench Press Pre-Exercise | Bench Press Post- | (p-value) |
|---|---|---|---|---|---|

| | (Mean ± SD) | (Mean ± SD) | (Mean ± SD) | Recovery (Mean ± SD) | |
|---|---|---|---|---|---|
| Experimental | 125.3 ± 11.8 | 133.1 ± 12.5 | 97.5 ± 8.2 | 102.6 ± 8.5 | 0.03* (Squat) 0.04* (Bench Press) |
| Control | 124.6 ± 12.1 | 127.2 ± 11.9 | 98.2 ± 9.3 | 99.9 ± 9.6 | N/A* |

*: significant at p<0.05
A: value signifies that no statistical significance comparison is necessary within the /* N control group, as it is only compared to the experimental group

Heart rate variability (HRV) data collected to evaluate the recovery of autonomic nervous activity is presented in Table 4. The HRV (mean and standard deviation (SD)) was obtained before and after recovery for NMES and CON. The HRV leap value in the NMES group was higher compared with pre-recovery ($p < 0.05$) suggesting of a faster recovery of the autonomic nervous system.

**Table 4. Heart Rate Variability (HRV) Recovery After High-Intensity Wrestling in NMES and Control Groups**

| Group | HRV Pre-Exercise (Mean ± SD) | HRV Post-Recovery (Mean ± SD) | (p-value) |
|---|---|---|---|
| Experimental | 50.4 ± 7.1 | 56.8 ± 6.4 | 0.02* |
| Control | 49.6 ± 6.8 | 48.4 ± 6.2 | N/A* |

*: significant at p<0.05
A: value signifies that no statistical significance comparison is necessary within the control /* N group, as it is only compared to the experimental group.

## Discussion

The results of the current study highlight the beneficial effect of NMES on muscle relaxation following high intensity wrestling training. Specifically, the NMES group demonstrated a greater lactate removal, better recovery of maximal strength, and higher heart rate variability (HRV) when compared with control. These findings are supported by several other investigations about the effects of NMES on sports recovery (Paradis-Deschênes et al., 2020; Taylor et al., 2015).

Lactate clearance was more rapid in the NMES group, which constitutes an important finding of the current investigation. This is in accordance with previous work showing that NMES accelerates lactate elimination from muscle by enhancing blood flow and metabolic clearance (Maffiuletti et al., 2018). Given that la accumulation is a common product produced during anaerobic physical exercises, its quicker removal helps attenuation of muscles fatigue and pains that also assist in athletes' faster recovery process (Bistolfi et al., 2018). Group NMES had a higher lactate clearance (5.0 ± 1.8 9.5 ± 2.5 mmol/L) compared to group Control (Paradis-Deschênes et al., 2020).

Regarding strength recovery, it was noted that the NMES group demonstrated significant greater improvements in 1RM for both squat and the bench press compared with the control group. These results are supported by other studies that also show an increase in muscle strength with the use of NMES since it stimulates muscle fibers and in favor the passage of blood to muscle in fatigue, which contributes to the compensation and recovery of muscle tissue and protein synthesis (Eriksson et al., 1981; Kim et al., 2010; Maffiuletti et al., 2018). These mean improvements of 6.2% (squat) and 5.4% (bench press) for NMES are in line with previous works that also studied comparable recovery responses following NMES treatments (Azevedo et al., 2016; Wakahara & Shiraogawa, 2019).

Higher HRV responses of NMES group imply a more SA regulation recovery. HRV is a representative marker of parasympathetic activity and reflects recovery and stress adaptation abilities, and a greater HRV is a sign of recovery, good stress adaptability (Keriven et al., 2025). The increase in HRV (from 50.4 ± 7.1 ms to 56.8 ± 6.4 ms) in the NMES group suggests that suchS electrical stimulation could help maintain the equilibrium in the autonomic cardiovascular balance after intense physical effort. This is consistent with other studies which have found NMES to effectively elevate HRV after exercise (Jajtner et al., 2015; Paradis-Deschênes et al., 2020).

Even though the results are promising, one should remember that the effects of NMES can be related to variables such as muscle size, training status, and previous experience with electrical stimulation (Abitante et al., 2022). For example, there may be other post-recovery effects induced by NMES in athletes with a different physical state or with another level of muscle adaptation to this kind of excitation. In addition, given that this work clearly confirmed the effective of NMES, the level (including dose, intensity, duration, and frequency) of NMES for motor training could affect the findings. This was highlighted in previous works that the adjustment of these parameters is crucial for the clinical responses to be at an optimal level (Malone et al., 2012; Paillard, 2008).

Additional studies are necessary to verify the long-term effects of NMES on muscle function (as in athletes who perform regular high-intensity workouts over the long term). Moreover, the synergistic effects with other recovery policies as active recovery or cryotherapy - for the most effective multi-modal recovery protocol - must be investigated in future studies (Maffiuletti et al., 2011).

## Conclusion

The results of this study have shown that NMES can dramatically improve muscle recovery after intensive wrestling activity. The findings suggest that NMES accelerates lactate removal, promotes better restoration of maximal strength, and enhances the recovery of autonomic system, one of which is represented by the improvement of heart rate variability (HRV). These findings suggest that NMES may be useful recovery modality for athletes with high intensity training involvement. The faster rate of post-recovery in terms of lactate clearance in the NMES group versus control group would indicate the benefit of electrical stimulation in promoting circulation and subsequently the removal of metabolic end products. Additionally, the change in squat and bench press maximal strength was greater in NMES group, indicating that the electrical stimulation is a treatment procedure that reduces muscle fatigue and accelerates recovery of muscles after severe exercise. In addition, the NMES group showed a significant increment in HRV (a marker of the extent of recovery of the parasympathetic nervous system) which is fundamental for recovery and adaptation to stress. These results add to the increasing evidence in favor of NMES on promoting athletes' recovery. However, additional studies are required to establish appropriate NMES parameters such as intensity, duration, and frequency in order to optimize its beneficial effects in various populations and sport activities. In addition, follow up studies are warranted to examine the chronic influence of NMES on athletic performance and the synergistic effect of combining it with other recovery techniques.

**References**


Abitante, T. J., Rutkove, S. B., Duda, K. R., & Newman, D. J. (2022). Effect of athletic training on fatigue during neuromuscular electrical stimulation. *Frontiers in Sports and Active Living*, *4*, 894395.

Altarriba-Bartes, A., Pena, J., Vicens-Bordas, J., Mila-Villaroel, R., & Calleja-Gonzalez, J. (2020). Post-competition recovery strategies in elite male soccer players. Effects on performance: A systematic review and meta-analysis. *PloS One*, *15*(10), e0240135.

Azevedo, D. de P., Medeiros, W. M., de Freitas, F. F. M., Ferreira Amorim, C., Gimenes, A. C. O., Neder, J. A., & Chiavegato, L. D. (2016). High oxygen extraction and slow recovery of muscle deoxygenation kinetics after neuromuscular electrical stimulation in COPD patients. *European Journal of Applied Physiology*, *116*(10), 1899–1910.

Babault, N., Cometti, C., Maffiuletti, N. A., & Deley, G. (2011). Does electrical stimulation enhance post-exercise performance recovery? *European Journal of Applied Physiology*, *111*(10), 2501–2507.

Bistolfi, A., Zanovello, J., Ferracini, R., Allisiardi, F., Lioce, E., Magistroni, E., Berchialla, P., Da Rold, I., & Massazza, G. (2018). Evaluation of the effectiveness of neuromuscular electrical stimulation after total knee arthroplasty: a meta-analysis. *American Journal of Physical Medicine & Rehabilitation*, *97*(2), 123–130.

Day, J., & Newman, J. (2020). The effect of neuromuscular electrical stimulation on function outcome measures following muscle fatigue: A systematic review. *Current Orthopaedic Practice*, *31*(4), 394–399.

Eriksson, E., Häggmark, T., Kiessling, K.-H., & Karlsson, J. (1981). Effect of electrical stimulation on human skeletal muscle. *International Journal of Sports Medicine*, *2*(01), 18–22.

Hou, X., Lü, Y., & Liu, J. (2020). Meta-analysis of muscle strength of exercisers undergoing electrical muscle stimulation training. *Chinese Journal of Tissue Engineering Research*, *24*(23), 3764.

Jajtner, A. R., Hoffman, J. R., Gonzalez, A. M., Worts, P. R., Fragala, M. S., & Stout, J. R. (2015). Comparison of the effects of electrical stimulation and cold-water immersion on muscle soreness after resistance exercise. *Journal of Sport Rehabilitation*, *24*(2), 99–108.

Keriven, H., Sierra, A. S., González-de-la-Flor, Á., Arrabé, M. G., de la Plaza San Frutos, M., Maestro, A. L., Aguilera, J. F. T., Suarez, V. J. C., & Balmaseda, D. D. (2025). Influence of combined transcranial and peripheral electromagnetic stimulation on the autonomous nerve system on delayed onset muscle soreness in young athletes: a randomized clinical trial. *Journal of Translational Medicine*, *23*(1), 1–17.

Kim, K.-M., Croy, T., Hertel, J., & Saliba, S. (2010). Effects of neuromuscular electrical stimulation after anterior cruciate ligament reconstruction on quadriceps strength, function, and patient-oriented outcomes: a systematic review. *Journal of Orthopaedic & Sports Physical Therapy*, *40*(7), 383–391.

Maffiuletti, N. A., Gondin, J., Place, N., Stevens-Lapsley, J., Vivodtzev, I., & Minetto, M. A. (2018). Clinical use of neuromuscular electrical stimulation for neuromuscular rehabilitation: what are we overlooking? *Archives of Physical Medicine and Rehabilitation*, *99*(4), 806–812.

Maffiuletti, N. A., Minetto, M. A., Farina, D., & Bottinelli, R. (2011). Electrical stimulation for neuromuscular testing and training: state-of-the art and unresolved issues. *European Journal of Applied Physiology*, *111*(10), 2391–2397.

Malone, J. K., Blake, C., & Caulfield, B. M. (2014). Neuromuscular electrical stimulation during recovery from exercise: a systematic review. *The Journal of Strength & Conditioning Research*, *28*(9), 2478–2506.

Malone, J. K., Coughlan, G. F., Crowe, L., Gissane, G. C., & Caulfield, B. (2012). The physiological effects of low-intensity neuromuscular electrical stimulation (NMES) on short-term recovery from supra-maximal exercise bouts in male triathletes. *European Journal of Applied Physiology*, *112*(7), 2421–2432.

Paillard, T. (2008). Combined application of neuromuscular electrical stimulation and voluntary muscular contractions. *Sports Medicine*, *38*(2), 161–177.

Paradis-Deschênes, P., Lapointe, J., Joanisse, D. R., & Billaut, F. (2020). Similar recovery of maximal cycling performance after ischemic preconditioning, neuromuscular electrical stimulation or active recovery in endurance athletes. *Journal of Sports Science & Medicine*, *19*(4), 761.

Stevens-Lapsley, J. E., Balter, J. E., Wolfe, P., Eckhoff, D. G., Schwartz, R. S., Schenkman, M., & Kohrt, W. M. (2012). Relationship between intensity of quadriceps muscle neuromuscular electrical stimulation and strength recovery after total knee arthroplasty. *Physical Therapy*, *92*(9), 1187–1196.

Taylor, T., West, D. J., Howatson, G., Jones, C., Bracken, R. M., Love, T. D., Cook, C. J., Swift, E., Baker, J. S., & Kilduff, L. P. (2015). The impact of neuromuscular electrical stimulation on recovery after intensive, muscle damaging, maximal speed training in professional team sports players. *Journal of Science and Medicine in Sport*, *18*(3), 328–332. https://doi.org/https://doi.org/10.1016/j.jsams.2014.04.004

Wakahara, T., & Shiraogawa, A. (2019). Effects of neuromuscular electrical stimulation training on muscle size in collegiate track and field athletes. *PloS One*, *14*(11), e0224881.

Watanabe, K., Takada, T., Kawade, S., & Moritani, T. (2021). Effect of exercise intensity on metabolic responses on combined application of electrical stimulation and voluntary exercise. *Physiological Reports*, *9*(3), e14758.