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The Relationship Between Submaximal Exercise, Oxidative Stress, and Malondialdehyde (MDA) Levels as Indicators of Health and Physiological Adaptation in Athletes : A Litera-ture Review

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Abstract: Physical training is a crucial component in enhancing athletic performance, with sub-maximal exercise being widely utilized. While submaximal exercise contributes to im-proved physiological capacity and bodily adaptation, it can also trigger oxidative stress, characterized by increased production of free radicals. One of the primary biomarkers of oxidative stress is malondialdehyde (MDA), a by-product of lipid peroxidation, commonly used to assess cellular damage. This study aims to examine the relationship between submaximal exercise, oxidative stress, and MDA levels, and their implications for athlete health and physiological adaptation through a literature review approach. A systematic search of relevant literature was conducted across databases such as PubMed, ScienceDi-rect, and Google Scholar, covering publications from 2018 to 2025. From 221 initial arti-cles, 11 were selected based on inclusion criteria. The findings indicate that High-Intensity Interval Training (HIIT) and functional training can enhance the body's antioxidant status and reduce MDA levels. Additionally, nutritional interventions, such as the administra-tion of octacosanol and herbal drinks, also contributed to lowering oxidative stress and improving athlete health profiles. These findings suggest that a combination of appropri-ate physical training and nutritional support is effective in managing oxidative stress and enhancing performance. However, further research with robust longitudinal designs and more diverse populations is needed to validate these findings and develop more compre-hensive intervention guidelines. A deeper understanding of oxidative stress mechanisms is essential for designing optimal training programs that support both athletic perfor-mance and long-term health.

Keywords: Submaximal exercise; Oxidative stress; Malondialdehyde; Physiological adaptation

1. Introduction

Physical training is an important component in the development of athlete performance [1], [2], [3], [4]. Submaximal exercise, defined as exercise with an intensity below the maximal threshold, has been shown to have a significant impact on the health and physiological adaptation of athletes [5], [6], [7]. However, it can also trigger oxidative stress, which can disrupt the redox balance in the body and contribute to cellular damage [8]. Malondialdehyde (MDA) is one of the important biomarkers used to measure the level of oxidative stress in the body [9], [10]. Oxidative stress occurs when the production of free radicals exceeds the body's ability to neutralize them. In the context of exercise, intense physical activity can increase the production of free radicals, which, if not matched by antioxidant defence mechanisms, can cause oxidative damage to lipids, proteins and DNA [11].

MDA, as a by-product of lipid peroxidation, is often used as an indicator of oxidative stress in athletes. Elevated levels of MDA in the blood may indicate the presence of cellular damage that can affect an athlete's performance and overall health [12], Previous research has shown that submaximal exercise can increase the body's antioxidant capacity, which serves to counter the negative effects of oxidative stress. A study by [13], Found that athletes who underwent a submaximal training program had higher antioxidant levels compared to those who did not train. This suggests that although submaximal exercise may increase free radical production, the body also adapts by increasing antioxidant defence mechanisms. However, it is important to note that not all forms of submaximal exercise have the same effect on oxidative stress and MDA levels.

Factors such as duration, frequency and type of exercise can influence the results obtained. For example, aerobic exercise performed consistently over the long term may help increase antioxidant capacity, whereas anaerobic exercise at high intensity may produce more free radicals [14]. Therefore, a deep understanding of this relationship is crucial for coaches and athletes in designing effective exercise programs. In a health context, monitoring MDA levels, as well as other indicators of oxidative stress, can provide valuable insights into the physiological condition of athletes. By understanding the relationship between submaximal exercise and oxidative stress, coaches can optimize exercise programs to minimize the risk of injury and improve athlete performance. This study is expected to contribute to the development of better training strategies and increase understanding of the physiological adaptations that occur in athletes. Although these individual studies provide valuable insights, there is currently a lack of an integrative review that systematically analyzes how different characteristics of submaximal exercise (such as intensity, type, frequency, and duration) influence oxidative stress levels, particularly through the lens of MDA as a reliable biomarker. This gap in the literature makes it challenging for coaches, athletes, and sport scientists to develop evidence-based training programs that strike an optimal balance between promoting physiological adaptation and minimizing oxidative damage.

Given the increasing reliance on submaximal exercise in athletic training regimens, it is essential to better understand its physiological implications, especially in relation to oxidative stress and MDA levels. Gaining this understanding can help inform the design of personalized, targeted training protocols that support both performance and long-term health. Therefore, the aim of this literature review is to explore and synthesize existing research on the relationship between submaximal exercise, oxidative stress, and MDA levels in athletes. Specifically, this review will seek to identify patterns, inconsistencies, and key variables influencing this relationship, while highlighting the physiological adaptations that occur in response to different forms of submaximal training. By addressing this gap, the study hopes to contribute to the development of more effective and health-conscious training strategies. This study aims to examine the relationship between submaximal exercise, oxidative stress, and MDA levels, and their implications for health and physiological adaptation in athletes through an investigative literature review.

2. Materials and methods

Study Design

The method used in this study was a literature review approach. Data were collected from various relevant sources, including scientific journals, articles, and books that discuss submaximal exercise, oxidative stress, and MDA levels. The search process was conducted through academic databases such as PubMed, Google Scholar, and ScienceDirect using related keywords such as "submaximal exercise," "oxidative stress," and "malondialdehyde.". This study is a literature review by following the Preferred Reporting Items for literature review guidelines to conduct this review by using a comprehensive and structured approach to derive key issues, generate a research framework, identify research gaps, and answer research criteria, and used to synthesize existing research on "Submaximal Exercise and Oxidative Stress: How Can MDA Levels Be an Indicator of Athlete Health?".

Literature Search

A thorough literature search was conducted in various electronic databases, including PubMed, Science Direct, Web of Science, and Google Scholar. The search was conducted using a combination of relevant keywords and Boolean operators to improve specificity and accuracy. The core search string applied was: ("submaximal exercise" OR "HIIT" OR "moderate intensity exercise") AND ("oxidative stress") AND ("malondialdehyde" OR "MDA") AND ("athlete" OR "athletes") AND ("performance" OR "physical fitness" OR "health"). This strategy was adapted slightly depending on the syntax requirements of each database but maintained consistent thematic focus. The search was limited to peer-reviewed articles published in English from January 2018 to December 2025 to ensure the eligibility of recent and relevant studies.

Study Selection

Study Selection The initial search yielded 221 articles. After removing duplicates and screening titles and abstracts, 130 articles were selected for full-text review. Of these, 35 studies met the inclusion criteria and were included in the final analysis, i.e. 11 Articles. For more details, you can see figure 1 below:

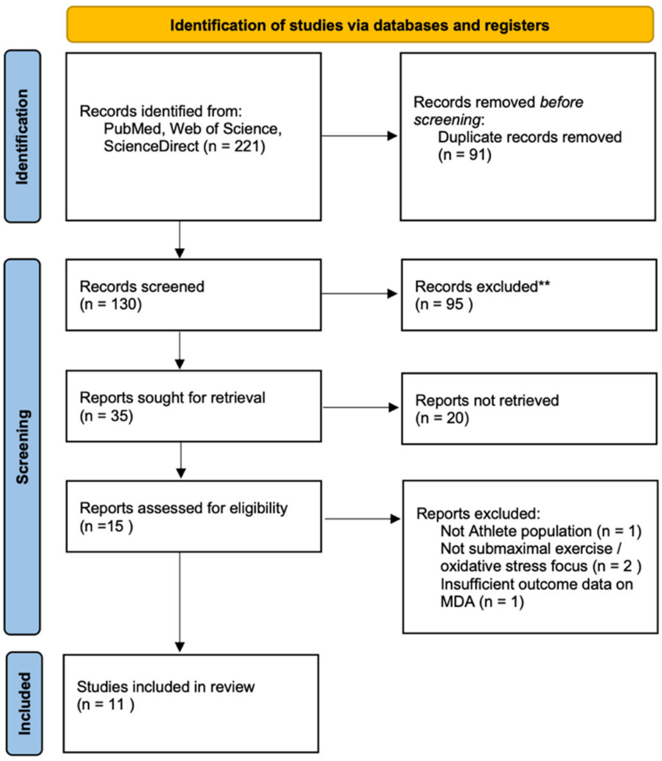

Figure 1. Diagram PRISMA Flow Chart

Inclusion and exclusion criteria

Selected based on: 1) population: athletes, 2) Results: "Submaximal Exercise and Oxidative Stress: How Can MDA Levels Be an Indicator of Athlete Health?", 3) study design: experimental studies, quantitative studies, and review articles. Exclusion criteria included 1) studies that did not include athletes, 2) outcomes that were not related to improved athlete performance, and 3) articles, reviews, commentaries, and editorials that were not peer-reviewed.

Data Extraction

Extracted data includes: 1) year of publication, country, and study design; 2) Main outcomes related to changes in MDA following the exercise intervention; 3) data from selected studies were extracted independently by two reviewers using a standardized extraction form, differences between reviewers were resolved through discussion and consensus.

3. Results

These articles were then further screened through several stages, resulting in the selection of 11 final articles that aligned with the research theme. Table 1 presents, for each study, the title of study, sample characteristic, publisher, study design, and results.

Table 1. Result of the literature review

Title	Sample Characteristic	Publisher	Study Design	Results
[15] Effect of High Intensity Interval Training on Antioxidant Status, Inflammatory Response and Muscle Damage Indices in Endurance Team Male Players	Sample characteristics, including age, fitness level, and sport experience, were clearly described, providing important context for interpretation of the results.	Apunts Sports Medicine	Experimental with a pre-test and post-test approach. and intervention to evaluate changes in antioxidant status, inflammatory response, and muscle damage index.	There was a significant increase in antioxidant levels in the body, which suggests that HIIT can help improve the body's ability to fight oxidative stress.
[16] Improvement of Lipids and Reduction of Oxidative Stress With Octacosanol After Taekwondo Training	The sample used consisted of experienced taekwondo athletes, with clear inclusion criteria. Sample characteristics included age, gender, level of experience in taekwondo, and general health condition.	Journal of Sports Physiology and Performance	Experimental with a randomized controlled approach	Research shows that octacosanol administration in taekwondo athletes: Improves lipid profile (LDL down, HDL up) Reduces oxidative stress (MDA down, antioxidant enzyme activity up) Octacosanol has a positive effect on reducing oxidative damage and improving the health of athletes
[17] Acute High-Intensity Exercise Test in Soccer Athletes Affects Salivary Biochemical Markers	Sample characteristics consisting of soccer athletes, age, gender, and level of experience, were well described.	International Journal of Sports Physiology and Performance,	This research uses an experimental method with a quantitative approach	Increased levels of cortisol and certain enzymes, indicating a physiological stress response produced by high-intensity exercise

[18] Impact of Mar'ke Bilar Healthy Drink on Blood Levels of Malondialdehyde, Superoxide Dismutase, and Hemoglobin in Soccer Athletes at PPLP North Sumatra	Sample of soccer athletes who train at PPLP North Sumatra. Sample characteristics include age, gender, and athlete fitness level.	Asian Journal of Sports Medicine	This study involved two groups, namely the group that consumed the Mar'ke Bilar healthy drink and the control group that did not consume the drink.	These results suggest that the healthy drink Mar'ke Bilar may help reduce oxidative stress and improve health.
[19] Oxidative Stress, Antioxidants and Hypertension	The sample consisted of adults with hypertension, as well as a control group without hypertension.		Using a cross-sectional method to evaluate the relationship between oxidative stress, antioxidant levels, and hypertension.	The study results indicate a significant relationship between oxidative stress levels and hypertension. The authors report that individuals with hypertension have higher oxidative stress biomarker levels compared to the control group.
[20] The Effect of Submaximal Exercise Preceded by Single Whole-Body Cryotherapy on the Markers of Oxidative Stress and Inflammation in Blood of Volleyball Players	Sample characteristics consisting of volleyball athletes, age, gender, and level of experience, were well described	Oxidative Medicine and Cellular Longevity	This study used an experimental design by comparing the effects of submaximal training preceded by cryotherapy versus without cryotherapy.	Cryotherapy before exercise decreased the activity of antioxidant enzymes (CAT and SOD) and levels of inflammatory cytokines (IL-1β and IL-6), indicating potential antioxidant and anti-inflammatory effects.
[21] Oxidative Stress and Exercise	The article reviews studies involving both human (trained athletes, sedentary individuals) and animal models (rats and mice) under various exercise conditions.	Journal *Antioxidants*	This editorial summarizes findings from ten selected articles, including original research and narrative reviews, focusing on oxidative stress responses to exercise, dietary interventions, and antioxidant supplementation.	The review concludes that Exercise intensity influences oxidative stress levels, and antioxidants may help reduce damage and support physiological adaptation.
[22] High-intensity functional training modulates oxidative stress and improves physical performance in adolescent male	Twenty adolescent male soccer players aged 14–16 years with at least two years of competitive experience participated	BMC Sports Science, Medicine and Rehabilitation	This was a randomized controlled trial comparing the effects of 8 weeks of high-intensity functional training (HIFT) versus	HIFT significantly improved VO_2peak, vertical jump, and power performance, while reducing MDA and H_2O_2 levels, indicating reduced oxidative stress and enhanced physiological adaptation compared to MITT.

soccer players: a randomized controlled trial	in this study.		moderate-intensity technical training (MITT) on oxidative stress markers and physical performance.	
[23] Comparing the Effects of Resistance Exercise Type on Serum Levels of Oxidative Stress and Muscle Damage Markers in Resistance-Trained Women	Ten healthy resistance-trained women aged ±26 years with a BMI of ±22.07 kg/m² participated in the study.	Journal *Sport Sciences for Health*	This quasi-experimental study compared the acute effects of hypertrophy-, strength-, and power-type resistance exercises on oxidative stress and muscle damage markers in resistance-trained women.	All exercise types significantly increased serum creatine kinase (CK) levels, particularly the power-type, while no significant changes were observed in oxidative stress markers (H_2O_2 and MDA) or serum lactate dehydrogenase (LDH).
[24] Effect of Different Running Exercise Modalities on Post-Exercise Oxidative Stress Markers in Trained Athletes	Thirteen male endurance-trained athletes (mean age 21.46 years) who trained at least 8 hours per week participated in the study.	International Journal of Environmental Research and Public Health	This randomized crossover study examined the effects of three running exercise modalities (continuous, 15/15 intermittent, and 30/30 intermittent) on oxidative stress biomarkers in trained athletes.	The 30/30 intermittent running induced a 55% increase in MDA levels and reduced SOD activity, while the 15/15 intermittent modality maintained oxidative balance better than both continuous and 30/30 exercise.
[25] Effects of physical exercise on biomarkers of oxidative stress in healthy subjects: A meta-analysis of randomized controlled trials	The meta-analysis included 458 healthy participants from 10 randomized controlled trials, with a median sample size of 42.5 per study.	Journal *Open Life Sciences*	This study was a systematic review and meta-analysis of randomized controlled trials evaluating the effects of different types, durations, and intensities of physical exercise on oxidative stress biomarkers in healthy individuals.	Physical exercise significantly increased total antioxidant status (TAS) and decreased malondialdehyde (MDA) levels, but had no significant effect on superoxide dismutase (SOD), glutathione peroxidase (GPx), or catalase (CAT), with greater MDA reductions seen in males, those with BMI < 25, and those performing low-to-moderate intensity or resistance/multicomponent exercise.

A total of 11 articles that met the inclusion criteria were analyzed to explore the relationship between physical exercise, nutritional/supplement interventions, and oxidative stress responses. In general, most studies employed experimental or randomized controlled trial (RCT) designs, with participants primarily consisting of young athletes (soccer, taekwondo, volleyball, and endurance sports), alongside some studies involving general populations such as individuals with hypertension. Sample characteristics were predominantly adolescents to young adults with good fitness levels, mostly drawn from well-trained athletic groups. The findings reveal consistent patterns: high-intensity training (HIIT, HIFT, or acute exercise tests) tended to elevate oxidative stress biomarkers such as malondialdehyde (MDA), H_2O_2, and muscle damage enzymes (CK, LDH), while also increasing stress hormones (cortisol). However, positive adaptations were also observed, as medium-to long-term training enhanced total antioxidant status (TAS) and the body's ability to neutralize free radicals.

Nutritional and physiological interventions also demonstrated beneficial effects. Octacosanol was shown to improve lipid profiles while reducing oxidative stress in taekwondo athletes, whereas the Mar'ke Bilar herbal drink reduced MDA and increased hemoglobin levels in soccer athletes. Similarly, cryotherapy prior to exercise in volleyball players provided protective effects by lowering pro-inflammatory cytokines (IL-1β, IL-6) and modulating antioxidant enzyme activity.

Several studies compared exercise modalities and highlighted notable differences. 15/15 intermittent running was more effective at maintaining oxidative balance than continuous or 30/30 intermittent running, the latter significantly increasing MDA. Meanwhile, research on resistance-trained women indicated that all exercise types (hypertrophy, strength, power) significantly elevated muscle damage markers (CK) but had little effect on oxidative stress biomarkers (MDA, H_2O_2).

In synthesis, these findings suggest that exercise intensity and type are key determinants of oxidative stress levels, while nutritional and physiotherapeutic strategies can help reduce oxidative damage and enhance physiological adaptation. This is further reinforced by meta-analytic evidence showing that exercise significantly decreases MDA and increases TAS, with stronger effects observed in males, individuals with BMI < 25, and those engaging in low-to-moderate intensity or multicomponent training. Overall, the 11 reviewed studies provide consistent evidence of a dynamic relationship between physical training, supplementary interventions, and oxidative stress biomarkers, with intensity, duration, exercise modality, and nutritional support emerging as the primary factors shaping the variability of outcomes across studies.

4. Discussion

The results of the review article you provided, focus on understanding how exercise and nutritional interventions influence oxidative stress and the health-related benefits of exercise: The results of this review article underscore the importance of the influence of physical exercise and nutritional interventions on oxidative stress levels in the athlete population. Most of the studies reviewed suggest that high-intensity exercise programs and the use of certain supplements can improve antioxidant status in the body, reduce biomarkers of oxidative stress, and improve overall health parameters. The effect training hight intensity , showed that High Intensity Interval Training (HIIT) can increase antioxidant levels, which suggests benefits in combating oxidative stress. This is in line with research [22], who reported that high-intensity functional training not only improved physical performance, but also reduced levels of malondialdehyde (MDA) and hydroperoxides (H_2O_2), which are indicators of oxidative stress. This finding is important because it shows that with appropriate training, athletes can improve their physiological abilities and reduce the risk of oxidation-induced cell damage.

Comparison of Research Exercise Modalities by [24], Illustrates that the type of exercise modality, such as continuous and interval running exercises, can have different effects on biomarkers of oxidative stress. The 15/15 intermittent modality showed better oxidative balance compared to the other exercises, highlighting the importance of considering not only the intensity but also the type of exercise performed. These findings provide valuable insights for coaches and athletes in designing exercise programs that focus not only on improving performance but also on long-term health. Nutritional Interventions On the other hand, the results of the study [16], Which showed that octacosanol administration in taekwondo athletes can improve lipid profiles and reduce oxidative stress, confirming the important role of nutrition in supporting athletes' health [18], reported that the Mar'ke Bilar healthy drink can reduce malondialdehyde levels and improve health, and that proper nutrition can contribute to oxidative stress management and support athlete performance. Oxidative Stress and Pathology Research Results [18], Showed an association between oxidative stress and hypertension, noting that individuals with high blood pressure had higher biomarkers of oxidative stress than the control group. These findings explicitly highlight that exercise and nutritional interventions are not only beneficial for athletes but also important for populations with specific health risks, emphasizing the relevance of this topic in a public health context.

Limitations and Suggestions for Future Research Although many studies have shown the benefits of exercise and nutrition in reducing oxidative stress, some limitations need to be addressed. Variability in study design, population, and analysis methods may affect the conclusions drawn. Therefore, further studies with more robust longitudinal designs and more diverse populations are needed to confirm these results and develop more effective intervention guidelines. Conclusion Overall, the results of this review article demonstrate that both physical exercise and nutritional interventions have a significant impact on oxidative stress and athlete health. Appropriate strategies in exercise selection and supplementation can help optimize athlete performance and health. Further research is needed to understand the underlying mechanisms and determine best practices in the management of oxidative stress in the wider population.

5. Conclusions

Conclusion From the results of this review article, it can be concluded that both high-intensity physical training and nutritional interventions play an important role in the management of oxidative stress in athletes. Various studies have shown that exercise programs, especially those related to interval training and functional training, not only contribute to improved physical performance but also help improve antioxidant status and reduce biomarkers of oxidative stress such as malondialdehyde (MDA) and hydroperoxides (H_2O_2). Specific nutritional interventions, such as the use of octacosanol and other health drinks, also showed a positive impact in reducing oxidative stress and improving the health profile of athletes. These findings suggest that the combination of proper training and good nutrition is critical to achieving optimal performance and long-term health. Although the results are promising, there are still limitations in some studies related to methodology, sample size and population characteristics. Further research is needed with more robust and comprehensive designs to explore the effects of various exercise modalities and nutritional interventions on oxidative stress levels. By understanding the underlying mechanisms, we can better guide athletes and coaches in designing programs that support performance and overall health. In conclusion, a deeper understanding of the relationship between exercise, nutrition and oxidative stress may make this aspect a key focus for the development of more effective exercise programs to support athletes at all levels.

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