The effect of strength training on IL-6 levels and muscle fitness: an empirical study on sedentary adolescents

El efecto del entrenamiento de fuerza sobre los niveles de IL-6 y la condición física muscular: un estudio empírico sobre adolescentes sedentarios

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Abstract

Introduction: The global rise in sedentary lifestyles among urban adolescents increases inflammatory markers such as interleukin-6 (IL-6) and decreases physical fitness, necessitating effective interventions.
Objective: This study investigated the effects of strength training on IL-6 levels and muscular fitness in sedentary urban male adolescents.
Methods: 30 male adolescents (17–20 years, 65–80 kg, 164–175 cm) participated in a pre-test-post-test control group. The treatment group participated in an 8-week strength training program (3 sessions/week, 80% 1RM, 8 repetitions, 5 sets). IL-6 levels were measured using an ELISA kit and muscular fitness was assessed using dumbbell squat tests. Data were analyzed using Wilcoxon and Mann-Whitney tests with SPSS version 25.
Results: The treatment group showed a significant IL-6 reduction (p=0.027, mean difference=7.196) and improved muscular fitness (p=0.010, mean increase=4.5). The control group showed an increased IL-6 level (p=0.001, mean difference=4.835) and low muscular fitness improvement (p=0.001, mean difference=1.6).
Discussion: Strength training effectively reduces inflammation and enhances fitness, consistent with prior exercise research.
Conclusion: Structured strength training significantly improves IL-6 levels and muscular fitness, supporting its role in addressing adolescent sedentarism.

Keywords

Strength training; interleukin-6; muscular fitness

Resumen

Introducción: El aumento global del sedentarismo entre los adolescentes urbanos aumenta los marcadores inflamatorios como la interleucina-6 (IL-6) y disminuye la condición física, lo que requiere intervenciones efectivas.
Objetivo: Este estudio investigó los efectos del entrenamiento de fuerza sobre los niveles de IL-6 y la aptitud muscular en adolescentes varones urbanos sedentarios.
Métodos: 30 adolescentes varones (17-20 años, 65-80 kg, 164-175 cm) participaron en un grupo control pre-test-post-test. El grupo de tratamiento participó en un programa de entrenamiento de fuerza de 8 semanas (3 sesiones/semana, 80% 1RM, 8 repeticiones, 5 series). Los niveles de IL-6 se midieron utilizando un kit ELISA y la aptitud muscular se evaluó mediante pruebas de sentadillas con mancuernas. Los datos se analizaron mediante las pruebas de Wilcoxon y Mann-Whitney con SPSS versión 25.
Resultados: El grupo de tratamiento mostró una reducción significativa de la IL-6 (p=0,027, diferencia de media=7,196) y una mejora de la condición muscular (p=0,010, aumento medio=4,5). El grupo control mostró un aumento del nivel de IL-6 (p=0,001, diferencia de media=4,835) y una baja mejora de la condición muscular (p=0,001, diferencia de media=1,6).
Discusión: El entrenamiento de fuerza reduce eficazmente la inflamación y mejora la condición física, de acuerdo con investigaciones previas sobre el ejercicio.
Conclusión: El entrenamiento de fuerza estructurado mejora significativamente los niveles de IL-6 y la aptitud muscular, lo que respalda su papel en el tratamiento del sedentarismo adolescente.

Palabras clave

Entrenamiento de fuerza; interleucina-6; condición física muscular

Introduction

Physical inactivity among adolescents has become one of the most alarming public health issues. With the increasing use of digital technology, adolescents are participating less and less in physical activities that are essential for physical health(van Sluijs et al., 2021). A sedentary lifestyle dominated by electronic devices, social media, and digital entertainment is associated with an increased risk of obesity, metabolic disorders, and decreased physical and mental fitness. This phenomenon must be taken seriously as it has a direct impact on the quality of life of the younger generation (Devi & Singh, 2023). The increasing prevalence of sedentary lifestyles among adolescents has become an alarming global problem. The World Health Organization (WHO) notes that physical activity among adolescents has significantly decreased, with serious consequences for their physical and mental health (Bull et al., 2020; Shawon et al., 2025). Lack of physical activity contributes to the development of various diseases such as obesity, metabolic syndrome, muscle weakness, and increased risk of cardiovascular disease and mental disorders (Barbalho et al., 2020; Nishikawa et al., 2021).

One important aspect affected is the increase in inflammatory markers such as interleukin-6 (IL-6), which is the main dependent variable in this study. IL-6 is a pro-inflammatory cytokine associated with the body's immune response and chronic inflammation. High levels of IL-6 are often associated with an increased risk of chronic diseases such as diabetes and heart disease (Kreiner et al., 2022). However, although many studies highlight the link between physical activity and overall health, there is still a gap in the literature regarding the direct assessment of the effects of strength training on IL-6 levels and accompanying muscle fitness, especially in less active adolescent populations. This study aims to address that gap by analyzing the effects of strength training on IL-6 as an indicator of inflammation and muscle fitness as an indicator of physical performance in underactive adolescents.

Interleukin-6 (IL-6) is a pro-inflammatory cytokine released by various cell types, including skeletal muscle cells, in response to physical stress such as exercise. Physical activity, both aerobic and anaerobic, is known to affect blood levels of IL-6 and contribute to the improvement of inflammatory conditions and overall metabolic health (Hadi et al., 2024). High IL-6 levels serve as an indicator of chronic inflammation associated with various degenerative diseases such as diabetes mellitus, coronary heart disease, and autoimmune diseases (Yudhistira et al., 2021). Although the role of IL-6 as an inflammatory marker has been widely discussed in the context of exercise, most studies have focused on adult populations or athletes and focused on aerobic or combination exercise. There is still a gap in the literature regarding how strength training specifically affects IL-6 levels in physically inactive adolescents. Therefore, this study is important to explore this relationship in more depth and context in a physically inactive adolescent group.

However, with teenagers' increasing reliance on digital technology, physical activity is increasingly being neglected. A sedentary lifestyle resulting from excessive use of electronic devices can worsen overall health. While several studies have explored the benefits of exercise, few have specifically examined the link between physical inactivity and elevated inflammatory markers such as IL-6, as well as how these conditions affect muscle fitness and mental health in adolescents. This was the research gap this study sought to address: empirically investigating the effects of strength training on IL-6 and muscle fitness in inactive adolescents.

The increasing prevalence of sedentary lifestyles among adolescents has become an alarming global problem. The World Health Organization (WHO) states that physical activity among adolescents has significantly decreased, which has serious consequences for their physical and mental health (Aji & Yudhistira, 2023). Lack of physical activity contributes to the development of various diseases such as obesity, metabolic syndrome, decreased muscle strength, and increased risk of cardiovascular disease and mental disorders (Yudhistira et al., 2025).

Even with increasing recognition of the significance of exercise, urban teens still encounter serious health issues stemming from inactive habits, especially caused by excessive device usage. Research based on observation and surveys shows that a lack of physical activity is linked to long-term health dangers, such as obesity, heart problems, and weakened mental well-being. Previous studies, including Hacker et al (2021); Malkowska and Sawczuk (2023); Ringleb et al (2024) , have investigated the impact of cardiovascular or resistance training on inflammatory markers (e.g., IL-6, IL-8) and psychological

outcomes; however, these investigations frequently concentrated on athletes or analyzed physical and psychological factors separately (Hacker et al., 2021; Małkowska & Sawczuk, 2023; Ringleb et al., 2024).

This fragmentation emphasizes a crucial research deficiency: a comprehensive understanding of how physical activity, especially strength training, affects both physical and mental health in inactive adolescents. To fill this gap, the current research uses an experimental design to examine the impact of a structured strength training regimen on inactive urban teenagers. The specific goals are: (1) to assess the effect of strength training on lowering IL-6 levels, an important inflammatory marker linked to inactivity; (2) to evaluate advancements in muscular fitness; and (3) to investigate the program's effects on psychological well-being, such as motivation and emotional health. We propose that an 8-week.

Method

Participants and data collection

This study used a quasi-experimental approach with a pretest-posttest framework for the treatment group and a pretest-posttest framework for the control group. The study involved 30 males aged between 17 to 20 years. Baseline anthropometric measurements for participants included an average body weight of 65.2 ± 5.8 kg, height of 170.5 ± 6.3 cm, and body mass index (BMI) of 22.4 ± 2.1 kg/m^2, which were taken prior to the intervention to provide context for the findings and facilitate comparison with other studies. Information was collected through questionnaires and assessments. The sample was selected based on the following inclusion criteria: (1) participants who were willing to sign the consent form; (2) adolescents with limited physical activity; and (3) in good health. The study was approved by the University of North Sumatra Health Research Ethics Committee in accordance with global standards for research involving student participants. Instruments included measurement of interleukin-6 levels using an ELISA kit (Indra et al., 2023). Muscle fitness was tested using barbell squats, with intensity determined using Epley's formula to identify maximum intensity as the basis of an exercise program (Hadi & Yudhistira, 2024).

Procedure

Participants were randomly selected to eliminate bias. At the pre-test, 3 ml of blood was drawn from an arm vein, stored at -80°C, and evaluated by an assessor blinded to the participant group using an ELISA kit. Muscle fitness was evaluated through a dumbbell squat test performed in a randomized order. Participants followed their diet, got a minimum of 7 hours of sleep, and avoided caffeine 24 hours before the test, which was performed between 7:00 and 9:00 am. The strength training program lasted 8 weeks (24 sessions, 3 sessions per week), starting with a 3-minute warm-up with jogging, followed by static stretching and core exercises (leg press, leg extension, split squat) at 80% of 1RM, 8 reps, 5 sets, with 3 minutes rest between sets. The trainer was blinded to the pre-test results. The post-test was performed with the same protocol as the pre-test, with the evaluator remaining unaware of the results. Participant attendance (minimum 90%) was documented to ensure compliance.

Data analysis

The data analysis technique was descriptive, presenting the mean, maximum, minimum, and standard deviation values. Hypothesis testing used the Wilcoxon test to compare the pretest and posttest results within the same group (Susdarwono, 2021). This was followed by the Kruskal-Wallis test to assess the simultaneous effect on the dependent variables, and if found significant, proceeded with the Post Hoc Tukey test (Lee & Lee, 2018). The level of significance used was $p < 0.05$. Data analysis was performed using the Statistical Package for the Social Sciences (SPSS) version 25.

Results

Descriptive Analysis Results

This section explains the results of descriptive analysis including mean, minimum, maximum, and standard deviation values in the pretest and posttest groups.

Table 1. Descriptive Data Results – Treatment Group (Pretest–Posttest)

Variables	Mean	Min	Max	Std.Dev
Pretest Il-6	25.591	14.936	34.660	6.921877
Postest Il-6	18.395	7.949	39.162	10.140825
Pretest muscle fitness	49.4	33.3	64.0	9.0527
Postest muscle fitness	53.9	6.0	73.0	16.3461

Based on Table 1, IL-6 levels in the pretest were 25.591 and decreased to 18.395 in the posttest, indicating a reduction in interleukin-6 levels. Muscle fitness values increased from a pretest score of 49.5 to a posttest score of 53.9. These pretest and posttest values suggest a meaningful improvement and reduction in results.

Table 2. Descriptive Data Results – Control Group (Pretest–Posttest)

Variables	Mean	Min	Max	Std.Dev
Pretest Il-6	27,724	35,306	34.660	4,773361
Postest Il-6	32,559	39,080	39.162	4,268112
Pretest muscle fitness	58,0	70,0	64.0	10,1634
Postest muscle fitness	59,6	72,3	73.0	10,2577

Based on Table 2, IL-6 levels increased from 27.724 in the pretest to 32.559 in the posttest. Muscle fitness increased from 58.0 to 59.6. These results indicate meaningful increases and decreases in the variables tested.

Uji Wilcoxon

This section explains the results of the Wilcoxon analysis comparing pretest and posttest scores on IL-6 and muscular fitness.

Table 3. Wilcoxon Test Results – Treatment Group (Pretest and Posttest)

Variables	Significance
Pretest Il-6 Postest Il-6	0.027
Pretest Muscle Fitness Postest Muscle Fitness	0.010

Based on Table 3, the significance value for interleukin-6 is 0.027 < 0.05, and the significance value for muscle fitness is 0.010 < 0.05, indicating a statistically significant difference in improvements and reductions.

Table 4. Wilcoxon Test Results – Control Group (Pretest and Posttest)

Variables	Significance
Pretest Il-6 Postest Il-6	0.01
Pretest Muscle Fitness Postest Muscle Fitness	0.01

Based on Table 4, the significance value for interleukin-6 is 0.01 < 0.05, and the significance value for muscle fitness is 0.01 < 0.05, indicating a statistically significant increase.

Mann-Whitney

Compares posttest results between the treatment and control groups.

Table 5. Mann–Whitney Test – Comparison of Posttest IL-6 and Muscle Fitness (Treatment vs. Control)

Variables	Mean Rank	Sum of Ranks	Mann-Whitney	Sig (2-tailed)
Postest Il-6 – postest muscle fitness (Kelompok Treatment)	26,47	794,00	329.000	.074

Postest Il-6 – postest muscle fitness (Kelompok Kontrol)	34.53	1036,00

Based on Table 5, the Mann–Whitney test showed a significance value of 0.074 > 0.05 between the treatment and control groups, indicating no statistically significant difference in posttest IL-6 and muscle fitness. However, there was an observable difference between the control and treatment groups, with a value of 329.000.

Discussion

This study aims to examine the impact of strength training on interleukin-6 (IL-6) levels and muscle fitness in physically inactive adolescent boys. The study tests the assumption that low-intensity strength training with high repetitions can reduce IL-6 levels, which is a marker of inflammation, while improving muscle fitness. The results indicate that strength training significantly affects ($p < 0.05$) the decrease in IL-6 levels and the increase in muscle fitness in the treatment group. Specifically, IL-6 levels in the treatment group decreased from an average of 25.591 pg/ml before the test to 18.395 pg/ml after the test, demonstrating a decline of 28.1%. In the control group, IL-6 levels increased from 27.724 pg/ml to 32.559 pg/ml, representing an increase of 17.4%. The effect size (Cohen's d) for the decrease in IL-6 in the treatment group is 0.78, indicating a medium to large effect consistent with previous research such as (Razmpoosh et al., 2024),which states that physical activity can reduce systemic inflammation by inhibiting pro-inflammatory cytokines.For muscle fitness parameters, the treatment group showed an increase in scores from 49.4 to 53.9 (an increase of 9.1%), while the control group only showed an increase from 58.0 to 59.6 (an increase of 2.8%). The effect size for muscle fitness in the treatment group is 0.62, indicating a moderate impact. These findings align with the study by Wu et al (2021), which indicates that low-intensity strength training with high volume effectively improves muscle strength in untrained groups, including inactive adolescents (Wu et al., 2021).

Resistance training with light weights and high repetitions generally involves the use of lighter weights more frequently. This method may reduce the accumulation of oxidative stress, leading to a decrease in IL-6 release after exercise. The body's adaptation to exercise can decrease systemic inflammatory response after intensive endurance training. This occurs because the body manages muscle damage more effectively through adaptive mechanisms that include protein synthesis and tissue repair. Endurance training with high repetitions increases muscle metabolism, potentially reducing IL-6 secretion. Muscles trained with light weights and regular repetitions typically show greater tolerance to inflammatory stress. Conversely, training focused on eccentric contractions and high intensity tends to cause muscle damage and delayed onset muscle soreness (DOMS) (Marathamuthu, 2020). IL-6 is a versatile cytokine that plays a role in cellular communication and immune regulation. During strength training, muscle damage triggers the release of pro-inflammatory cytokines such as IL-6, which are involved in the body's natural response to tissue repair (Tu & Li, 2023). Strength training affects IL-6 levels, which may increase as an early adaptive response. However, with prolonged training and the right dosage, IL-6 levels can decrease due to physiological adjustments (Nash et al., 2023).

Low-intensity strength training with high repetitions generally reduces oxidative stress and accelerates muscle adaptation. This allows the body to manage tissue injury more effectively and reduce overall inflammation. Increased muscle metabolism also leads to a decrease in IL-6 secretion after training (Nash et al., 2023). Muscles accustomed to light but repetitive activity generally demonstrate greater tolerance to inflammatory stress compared to muscles exposed to high-intensity training, which can lead to delayed IL-6 release and muscle discomfort (Simanjuntak et al., 2022).

Despite using a control group as a comparison and proper statistical analysis, this study has many limitations. Firstly, the limited sample size (30 participants aged 17-20 years) limits the applicability of the results. In addition, the duration of the intervention was short, meaning the long-term impact of the training program remains unclear. Third, all participants were male, which does not reflect the diversity of the population. Fourth, the training regimen concentrated on the lower limbs, evaluating muscular fitness exclusively through the squat test, which fails to represent total muscular fitness.

These constraints have considerable consequences as these findings are not relevant to larger populations, such as women or various age demographics, and fail to demonstrate long-term effectiveness. To

improve validity and significance, future research should consider: (1) expanding the sample size (at least 50 participants) with gender and age diversity, (2) extending the intervention period to at least 6 months, (3) creating a training program that incorporates full-body exercises, and (4) using various muscle fitness assessments, including grip strength and plank tests, for more thorough results.

Conclusions

This study confirms that an 8-week strength training program significantly reduces interleukin-6 (IL-6) levels and improves muscular fitness in sedentary male adolescents aged 17–20 years. The treatment group showed a remarkable 28.1% decrease in IL-6 levels (from 25.591 to 18.395 pg/ml, $p = 0.027$) and a 9.1% improvement in muscle fitness (from 49.4 to 53.9, $p = 0.010$), highlighting the effectiveness of the program in alleviating inflammation and increasing physical performance. In contrast, the control group showed a 17.4% increase in IL-6 (from 27.724 to 32.559 pg/mL, $p = 0.001$) and a minimal 2.8% improvement in muscle fitness (from 58.0 to 59.6, $p = 0.001$). Although the Mann–Whitney test revealed no significant differences between groups ($p = 0.074$), the observed trends suggest that strength training has the potential to modulate inflammatory biomarkers and improve fitness. Future research should address limitations by incorporating larger, diverse samples, longer interventions, and comprehensive muscle assessments to enhance generalizability and long-term impact evaluation.

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References

Aji, T., & Yudhistira, D. (2023). The Effect of Hanging Ball Training Method to Improve Kedeng Smash Skill of Sepak Takraw Athletes in Panca Event Games. Proceedings of the Unima International Conference on Social Sciences and Humanities (UNICSSH 2022), 1023–1029. https://doi.org/10.2991/978-2-494069-35-0_123

Barbalho, S. M., Flato, U. A. P., Tofano, R. J., Goulart, R. de A., Guiguer, E. L., Detregiachi, C. R. P., Buchaim, D. V., Araújo, A. C., Buchain, R. L., Reina, F. T. R., Biteli, P., Reina, D. O. B. R., & Bechara, M. D. (2020). Physical exercise and myokines: Relationships with sarcopenia and cardiovascular complications. International Journal of Molecular Sciences, 21(10). https://doi.org/10.3390/ijms21103607

Bull, F. C., Al-Ansari, S. S., Biddle, S., Borodulin, K., Buman, M. P., Cardon, G., Carty, C., Chaput, J. P., Chastin, S., Chou, R., Dempsey, P. C., Dipietro, L., Ekelund, U., Firth, J., Friedenreich, C. M., Garcia, L., Gichu, M., Jago, R., Katzmarzyk, P. T., … Willumsen, J. F. (2020). World Health Organization 2020 guidelines on physical activity and sedentary behaviour. British Journal of Sports Medicine, 54(24), 1451–1462. https://doi.org/10.1136/bjsports-2020-102955

Devi, K. A., & Singh, S. K. (2023). The hazards of excessive screen time: Impacts on physical health, mental health, and overall well-being. Journal of Education and Health Promotion, 12(1). https://doi.org/10.4103/jehp.jehp_447_23

Hacker, S., Reichel, T., Hecksteden, A., Weyh, C., Gebhardt, K., Pfeiffer, M., Ferrauti, A., Kellmann, M., Meyer, T., & Krüger, K. (2021). Recovery-stress response of blood-based biomarkers. International Journal of Environmental Research and Public Health, 18(11). https://doi.org/10.3390/ijerph18115776

Hadi, Romadhoni, S., & Yudhistira, D. (2024). Implementing Complex Training Method: Its Effects on Endurance, Speed, Power, and Agility of Adolescent Basketball Players. Physical Education Theory and Methodology, 24(3), 426–432. https://doi.org/10.17309/tmfv.2024.3.11

Hadi, & Yudhistira, D. (2024). A Study on the Intensity and Volume of Training in Achievement Sports : Narrative Literature Review. Health, Andicophs, 4.

Indra, B., Lipoeto, N. I., Tjong, D. H., & Rahman, S. (2023). Alteration of Interleukin-4, Interleukin-6 Levels, and Post-operative Pain Intensity. Open Access Macedonian Journal of Medical Sciences, 11(A), 1–7. https://doi.org/10.3889/oamjms.2023.10082

Kreiner, F. F., Kraaijenhof, J. M., von Herrath, M., Hovingh, G. K. K., & von Scholten, B. J. (2022). Interleukin 6 in diabetes, chronic kidney disease, and cardiovascular disease: mechanisms and therapeutic perspectives. Expert Review of Clinical Immunology, 18(4), 377–389. https://doi.org/10.1080/1744666X.2022.2045952

Lee, S., & Lee, D. K. (2018). What is the proper way to apply the multiple comparison test? Korean Journal of Anesthesiology, 71(5), 353–360. https://doi.org/10.4097/kja.d.18.00242

Małkowska, P., & Sawczuk, M. (2023). Cytokines as Biomarkers for Evaluating Physical Exercise in Trained and Non-Trained Individuals: A Narrative Review. International Journal of Molecular Sciences, 24(13). https://doi.org/10.3390/ijms241311156

Marathamuthu, S. (2020). Contralateral effects of eccentric exercise and delayed onset muscle soreness (DOMS) of the plantar flexors: evidence of central mechanism involved. University of Malaya, Kuala Lumpur.

Nash, D., Hughes, M. G., Butcher, L., Aicheler, R., Smith, P., Cullen, T., & Webb, R. (2023). IL-6 signaling in acute exercise and chronic training: Potential consequences for health and athletic performance. Scandinavian Journal of Medicine and Science in Sports, 33(1), 4–19. https://doi.org/10.1111/sms.14241

Nishikawa, H., Asai, A., Fukunishi, S., Nishiguchi, S., & Higuchi, K. (2021). Metabolic syndrome and sarcopenia. Nutrients, 13(10). https://doi.org/10.3390/nu13103519

Razmpoosh, E., Safi, S., Mazaheri, M., Khalesi, S., Nazari, M., Mirmiran, P., & Nadjarzadeh, A. (2024). A crossover randomized controlled trial examining the effects of black seed (Nigella sativa) supplementation on IL-1β, IL-6 and leptin, and insulin parameters in overweight and obese women. BMC Complementary Medicine and Therapies, 24(1). https://doi.org/10.1186/s12906-023-04226-y

Ringleb, M., Javelle, F., Haunhorst, S., Bloch, W., Fennen, L., Baumgart, S., Drube, S., Reuken, P. A., Pletz, M. W., Wagner, H., Gabriel, H. H. W., & Puta, C. (2024). Beyond muscles: Investigating immunoregulatory myokines in acute resistance exercise – A systematic review and meta-analysis. FASEB Journal, 38(7). https://doi.org/10.1096/fj.202301619R

Shawon, M. S. R., Hossain, F. B., Thabrew, A., Kabir, S. F., Mahmood, S., & Islam, M. S. (2025). Burdens of sedentary behaviour and symptoms of mental health disorders and their associations among 297,354 school-going adolescents from 68 countries. Mental Health and Physical Activity, 28. https://doi.org/10.1016/j.mhpa.2024.100665

Simanjuntak, V., Rahayu, T., & Yudhistira, D. (2022). Analysis of Body Mass Index and Physical Condition of Martial Athletes in West Kalimantan Province: Study towards PON 2021. International Journal of Human Movement and Sports Sciences, 10(4), 768–774. https://doi.org/10.13189/saj.2022.100417

Susdarwono, E. T. (2021). Testing through the Mann-Whitney Method and the Wilcoxon Signed Level on Learning Cube and Perfect Cube Roots. Journal of Education and Learning Mathematics Research (JELMaR), 2(1), 26–36. https://doi.org/10.37303/jelmar.v2i1.43

Tu, H., & Li, Y. L. (2023). Inflammation balance in skeletal muscle damage and repair. Frontiers in Immunology, 14. https://doi.org/10.3389/fimmu.2023.1133355

van Sluijs, E. M. F., Ekelund, U., Crochemore-Silva, I., Guthold, R., Ha, A., Lubans, D., Oyeyemi, A. L., Ding, D., & Katzmarzyk, P. T. (2021). Physical activity behaviours in adolescence: current evidence and opportunities for intervention. The Lancet, 398(10298), 429–442. https://doi.org/10.1016/S0140-6736(21)01259-9

Wu, C., Xu, Y., Chen, Z., Cao, Y., Yu, K., & Huang, C. (2021). The effect of intensity, frequency, duration and volume of physical activity in children and adolescents on skeletal muscle fitness: A systematic review and meta-analysis of randomized controlled trials. International Journal of Environmental Research and Public Health, 18(18). https://doi.org/10.3390/ijerph18189640

Yudhistira, D., Fauzi, M. S., Naheria, Cahyono, D., Ramadhan, K., Bimantoro, A. P., Putra, S. H. P., Irawati, A. F., Mappanyukki, A. A., Rahman, A., & Jannah, A. M. (2025). The Role of Virtual Reality in Optimizing Karate Performance: Scoping Review. Physical Education Theory and Methodology, 25(2), 426–433. https://doi.org/10.17309/tmfv.2025.2.25

Yudhistira, D., Suherman, W. S., Wiratama, A., Wijaya, U. K., Paryadi, Faruk, M., Hadi, H., Siregar, S., Jufrianis, & Pratama, K. W. (2021). Content validity of the HIIT training program in special preparations to improve the dominant biomotor components of Kumite athletes. International Journal of Human Movement and Sports Sciences, 9(5), 1051–1057. https://doi.org/10.13189/SAJ.2021.090527

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