REVIEW ARTICLE

https://doi.org/10.6063/motricidade.33372

Can physical exercise potentiate the effects of the vaccine?

O exercício físico pode potencializar os efeitos da vacina?

Antônio Carlos Leal Cortez[1,2]*, Daniel Alfonso Botero-Rosas[3], Francisco José Gondim Pitanga[4], Carlos Eduardo Lima Rocha de Oliveira[5], Estélio Henrique Martin Dantas[3,6]

ABSTRACT

The outbreak of the COVID-19 pandemic, due to its high infectivity and pathogenicity, spread across the planet in just over three months, with issues related to its clinical course and still inconclusive risk factors. The pandemic, therefore, surprised all health professionals, leaving a question: What is the impact of regular physical exercise on the effects of vaccination and disease control? The study in question is a theoretical essay on health, addressing definitions and central characteristics of intersectoral actions for health through qualitative data using the MEDLINE databases via the PubMed portal, Embase, Cochrane Library and Scopus. Throughout the article, scientific evidence is presented that the regular practice of physical exercises can normalise the inflammatory profile of the practitioner and improve the body's immune response. The close relationship between inflammatory and immune responses and the chronic effect that physical exercise exerts on the body allows it to be considered a therapy that strengthens the body's defence not only against COVID-19 but for all infections of the same nature, including the adaptive effect it has on the respiratory system. It is concluded, according to the evidence presented here, that the regular and guided practice of physical exercises, respecting the principles of sports training, acts significantly as an auxiliary tool in the strengthening and preparation of the immune system against COVID-19, which may potentiate the effects of their vaccines, as evidenced with other types of vaccines, such as H1N1.

KEYWORDS: physical exercise; vaccine; COVID-19; coronavirus.

INTRODUCTION

On March 11, 2020, the World Health Organization (WHO) raised the level of contamination of the new coronavirus to the pandemic due to the rapid and uncontrollable spread of viruses, causing all health organisations in all countries of the world to adopt sanitary and protective measures to contain the progress and spread of COVID-19 (WHO, 2020a).

Since the beginning of the pandemic, several research studies have been carried out to elucidate the epidemiological and clinical issues of COVID-19, with some theories being raised about the clinical course and risk factors associated with COVID-19. Scientific evidence on the current epidemiological aspects of the disease reports that clinical conditions such as hypertension, respiratory, cardiovascular, metabolic and immunological diseases, in addition to advanced age, are classified as important risk factors for the severity of COVID-19 (Huang et al., 2020; WHO, 2020a; Yang et al., 2020).

[1]Centro Universitário Santo Agostinho – Teresina (PI), Brazil.
[2]Universidade Federal do Estado do Rio de Janeiro, Programa de Pós-graduação Stricto Sensu em Enfermagem e Biociências – Rio de Janeiro (RJ), Brazil.
[3]Universidade de La Sabana – Bogotá, Colombia.
[4]Universidade Federal da Bahia, Instituto de Ciências da Saúde, Programa de Pós-Graduação em Ciências da Reabilitação – Salvador (BA), Brazil.
[5]Universidade Federal de Sergipe, Programa de Pós Graduação Stricto Sensu em Educação Física – Aracaju (SE), Brazil.
[6]Universidade Tiradentes, Programa de Pós-graduação Stricto Sensu em Saúde e Ambiente – Aracaju (SE), Brazil.
*Corresponding author: Departamento de Educação Física, Centro Universitário Santo Agostinho, Av. Prof. Valter Alencar, 665, São Pedro – CEP: 64019-625 – Teresina (PI), Brazil. E-mail: antoniocarloscortez@hotmail.com

Conflict of interests: nothing to declare. Funding: Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – CAPES) - Funding Code 001.
Received: 10/23/2022. Accepted: 12/22/2022.

Thus, the lack of specific preventive or therapeutic measures for the new coronavirus, coupled with its high rate of transmission and contamination, caused several government officials and WHO (2020b) to recommend the adoption of non-pharmacological interventions (INF) for the initial fight against COVID-19, such as individual and collective health security measures, among which we highlight the social restriction, with some public authorities even decreeing a total (lockdown), which drastically altered the lifestyle of all populations in the world (Garcia & Duarte, 2020).

Among the changes in the population's lifestyle caused by social restriction, we can highlight the emergence of emotional problems such as stress and/or depression, excessive use of alcohol or tobacco, reduction in the population's level of physical exercise and increased behaviour sedentary, leading to body weight gain and possible emergence of comorbidities associated with increased cardiovascular risk, such as obesity, increased blood pressure, glucose intolerance, as risk factors for the appearance of comorbidities, which increase the risk of developing the form most severe disease of COVID-19 (García Álvarez, Saiz Martínez, García-Portilla González, & Bobes, 2020; Peçanha, Goessler, Roschel, & Gualano, 2020).

However, being a new disease, there are still gaps in the scientific literature correlating the effects of physical exercise and vaccination against COVID-19. Thus, the present study proposes the following question: What is the impact of regular physical exercise on the effects of vaccination and disease control?

So, the primary objective is to elucidate, through a theoretical health essay, the related scientific evidence on how physical exercise can potentiate the effects of vaccines.

METHODOLOGY

Methodological design

The study in question is a theoretical health essay with a qualitative approach, aiming to bring a discussion, a new perspective and insights on issues of current interest (Magna, 2014).

The study was conducted in accordance with the guidelines of the Committee on Publication Ethics (COPE, 2022), which contains information on research ethics for authors and editors.

Formulation of the research question

To guide the retrieval of information, the research question was structured in order to guarantee not only the internal validity but also the extrapolation power of the results of the theoretical test since the scientific evidence of safety and efficacy are applicable between populations in different regions of the world and through the selection of studies comprehensively and exhaustively, through the adoption of criteria and evaluation of the quality and validity of the studies retrieved in the searches (Brasil, 2012).

Definition of eligibility criteria

The inclusion and exclusion criteria for selecting documents are detailed in Table 1.

Selection of studies

The terms and interterms were defined from consultations by the exchanged index in the DeCS, from which the descriptors in Portuguese and their respective MeSH were extracted, submitted to later research to identify their interterms in the MEDLINE databases via PubMed portal, Embase, Cochrane Library and Scopus. The search for the definition of these terms and terms was carried out in April 2022.

Strategies were listed to guide the identification and screening of studies. First, the research period was defined between January 2020 and April 2022. Second, the electronic search will be carried out in the following databases: MEDLINE via PubMed portal, Embase, Cochrane Library, and Scopus. This choice was made in order to ensure greater coverage of peer-reviewed articles (Prayag & Ozanne, 2018) and because they contemplate a variety of journals with higher impact factors.

The chosen keywords were 'Physical Exercise', 'Vaccine', 'COVID-19', and 'Coronavirus', using the Boolean operators AND/OR, as well as their synonyms, having as search scope the respective terms in the title, abstract and words of articles published in journals. This choice is due to a previous evaluation in the literature, in which the correlation between them and the frequency with which they are used in studies was verified.

Table 1. Description of inclusion and exclusion criteria for selection of studies.

Inclusion	Studies in Portuguese, Spanish and English of the type were included: randomised clinical trials and clinical studies that evaluated related scientific evidence on how physical exercise can potentiate the effects of vaccines.
Exclusion	Publications that do not deal with the research object in question, studies with animals, studies that did not have published results, as well as studies that did not mention the conflict of interests were excluded.

RESULTS

Therefore, the results presented by the theoretical essay in question propose a discussion based on scientific evidence, aiming to elucidate the immunological effects of regular physical exercise and its action with vaccines and, therefore, serve as a basis for future research on the subject, since there are still epidemiological and clinical gaps on how physical exercise may or may not potentiate the effects of vaccination against COVID-19.

DISCUSSION

Thus, we chose to section the discussion of the theoretical essay addressing the following topics: Physical Exercise and Immunosafety and the relationship between physical exercise and vaccination.

Physical exercise and immunosecurity

According to Cortez et al. (2020) and Nogueira, Cortez, de Oliveira Leal, and Dantas (2021), regular practice of physical exercise by the population is important due to its prophylactic and therapeutic effects on the health and quality of life of the population, increasing the responses of the immune system, contributing to the reduction of inflammation and the risk of infection.

These prophylactic and therapeutic effects are possible since each session of moderate exercise promotes a transient increase in immunosafety. When repeated for weeks or months, it promotes a systemic and tissue anti-inflammatory effect through a chronic adaptation of the organism. Studies by Duggal, Niemiro, Harridge, Simpson, and Lord (2019), Soltani, Marandi, Kazemi and Esmaeil (2020), and Wang, Li, Lu, and Huang (2020) scientifically evidence that physical exercise promotes a potent anti-inflammatory effect, decreasing inflammation in several comorbidities such as diabetes, hypertension, obesity and ageing, which are risk factors in the disease of COVID-19. These prophylactic and therapeutic effects of physical exercise have great implications for protection against COVID-19 since most fatal cases occur in populations with these comorbidities and with the elderly (Nikolich-Zugich et al., 2020).

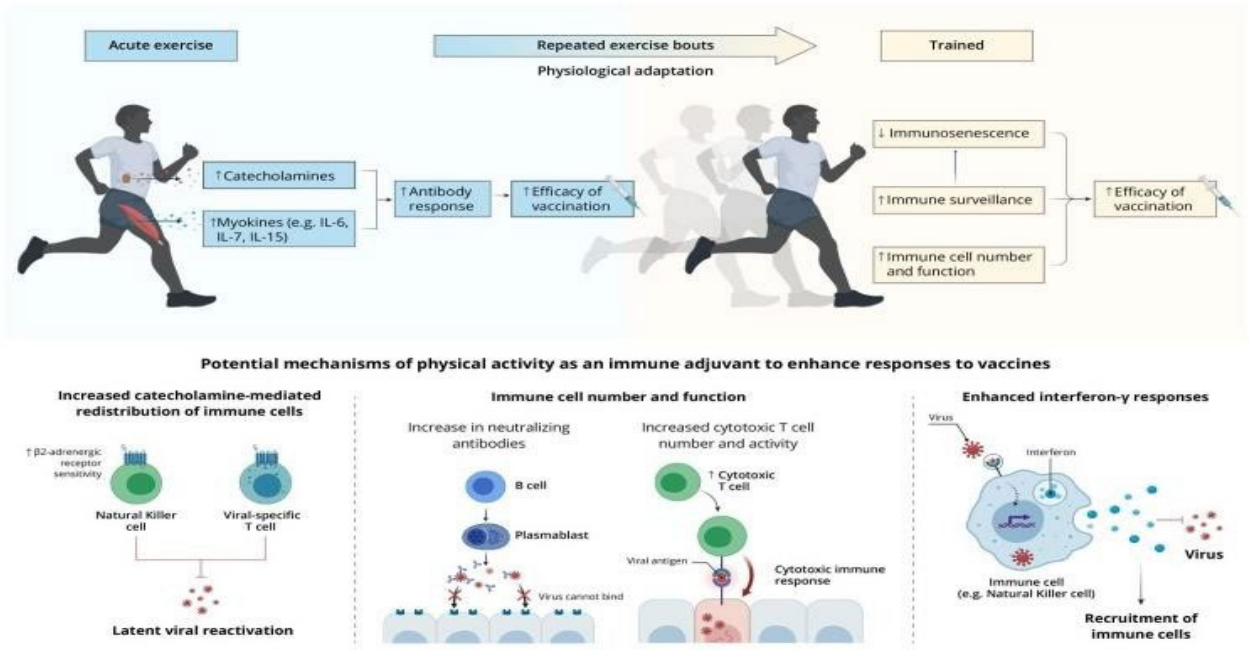
In the case of the elderly, it is emphasised that the immune response to the virus depends on factors such as genetics, physical state and age itself, the main input receptor being the angiotensin-converting enzyme 2, with physical exercises acting as a modulator of the immune system, since during and after physical exercise, pro and anti-inflammatory cytokines are released, IL-2, IL-6, IL-7, IL-10, G-CSF, IP-10, MCP-1, MIP-1A e TNF-α, which increase lymphocyte circulation and also cellular recruitment. Such practice has an effect on the lower incidence, intensity of symptoms and mortality from viral infections observed in people who exercise regularly, and its correct execution must be considered to avoid damage (da Silveira et al., 2021).

Despite the lack of accurate data on how physical exercise improves the immune response against the new coronavirus, there is evidence such as that by Grande, Keogh, Silva, and Scott (2020) of lower incidence rates of acute respiratory infections (ARI), duration and intensity of symptoms, and risk of mortality from infectious respiratory diseases in individuals who exercise at appropriate levels, with moderate intensity (Nogueira et al., 2021). Furthermore, different studies suggest that regular exercise is directly related to decreased mortality from pneumonia and influenza, improvements in cardiorespiratory function, vaccine response, glucose, lipid and insulin metabolism, in this specific case, providing greater immunological and metabolic support for people's health obese and with metabolic diseases (Laddu, Lavie, Phillips, & Arena, 2021, Simpson & Katsanis, 2020).

For Duggal et al. (2019), an active lifestyle prevents possible changes in the immune response (decreased, unchanged or even increased) by various organic mechanisms, as shown in Figure 1. Immune reactions show an increase in lymphocyte β2-adrenergic receptors, which will allow relocation of these cells mediated by catecholamines of natural killer (NK) cells and virus-specific T cells between blood and tissues at each physical exercise session.

Also, according to the author mentioned above, Duggal et al. (2019), it is important to emphasise that at each physical exercise session, there is a redistribution of NK cells and T cells specific to the virus, thus increasing the immunovigilance that will decrease the frequency of latent viral reactivation, reducing the antigenic capacity deposited in T cell compartments, as well as preventing the accumulation of 'senescent' T cells, maintaining the number and variety of naive peripheral T cells.

Scientific evidence, Cao Dinh et al. (2019) and Merellano-Navarro et al. (2021) point out that physically active older people have fewer 'senescent' T cells and more 'naive' T cells compared to sedentary people of the same age. In this sense, cytokines such as interleukin 7 (IL-7) will have their immunological activities increased, producing antigen-specific naive T cells, essential in mounting immune responses to new antigens and differentiating into 'memory' T cells for long-term immunity and, in the case of interleukin 5 (IL-5) they will maintain peripheral T and NK cell compartments, in order



IL: interleukin.
Source: Valenzuela et al. (2021).

Figure 1. Potential mechanisms explaining the benefits of regular - and potentially acute - exercise performed before vaccination to enhance the immune response.

to ensure that they proliferate and function optimally when encountering virus-infected cells.

Thus, with the organic adaptations generated by physical exercise, we can have a reduction in the effects of immunosenescence, which deals with the decline of immune function and the consequent increase in susceptibility to infections, in addition to a reduction in the vaccine response, which may help to improve immune responses as a result of vaccination, maintaining the pool of peripheral T cells and their ability to respond to new vaccine antigens (Valenzuela, Simpson, Castillo-García, & Lucia, 2021). As shown in Figure 1.

In a systematic review and meta-analysis study carried out by Xu et al. (2020) on the scientific evidence for the treatment of COVID-19 through physical exercise, presented in their discussion that regular and guided exercise acts significantly in increasing the body's immune capacity, in addition to reducing the probability of infection by diseases infectious/viral, acting in a prophylactic and therapeutic way to combat COVID-19 (Barrett et al., 2012; Simpson, Kunz, Agha, & Graff, 2015).

Other meta-analytic evidence carried out by Chaabene et al. (2021) on the beneficial effects of physical exercise on the improvement of physical fitness components in the elderly, with relevance to COVID-19, highlighted the importance of regular and guided physical exercise practice by the elderly, acting significantly against the deleterious effects of physical inactivity on the health and quality of life of this population. In this regard (WHO) (2020b) launched a campaign "be active at home during the COVID-19 outbreak" to encourage people, especially older adults, to remain physically active.

Thus, physical exercise has been related to increased immune surveillance against infections, in addition to being responsible for improving the immune response. When physical exercise is performed with moderate volume and intensity, the immune system responds quickly to the physiological stress caused by physical exercise through its acute and chronic effects, acting, among others, on the effects of immunosenescence. Physical exercise is responsible for providing an increase in the antipathogenic activity of macrophages, while elevations in the circulation of immune cells, immunoglobulins and anti-inflammatory cytokines occur, thus reducing the burden of the pathogen on organs such as the lung and the risk of lung damage due to the influx of inflammatory cells (Nieman & Wentz, 2019).

Physical exercise and vaccine

A study by Pawelec and McElhaney (2020) on "Recent Advances in Influenza Vaccines" reports the efforts of

researchers to improve the effectiveness of vaccines against different types of influenza, as well as COVID-19, including the development of universal vaccines independent of the circulating strains in any season of the year and the stimulation of cellular and humoral responses, especially in the elderly, showing in their results improved cellular and humoral responses in physically active people, emphasising that physical exercise and general fitness can be crucial in the increase immunological capacity and efficacy in the effect of vaccines (Ledo et al., 2020).

According to Campbell and Turner (2018), with the increase in research on the effects of physical exercise on the action of vaccines, it can provide positive effects to prevent clinically important diseases, such as COVID-19. According to Laddu et al. (2021), there is already a consensus in the literature on the positive immunological effects of the regular practice of physical exercise in the reduction of health problems resulting from transmissible diseases. Another important data on the immunological effects of physical exercise on health is that it can increase immunity after vaccination, with aerobic exercise of moderate intensity, respecting the principles of training, showing positive effects on the immune responses to the vaccine against influenza and pneumonia in adults and the elderly (Song et al., 2020).

Based on current information, there is a consensus in the literature that the regular practice of physical exercise acts significantly in increasing the autoimmune system and resistance against viral infections of the respiratory tract, such as COVID-19, since, combined with a healthy lifestyle, physical exercise can act, enhancing the immunological effects generated by the COVID-19 vaccination (Li, 2020; Luzi & Radaelli, 2020). In addition, a recent publication suggested that regular physical activity can have an important influence on the effect of the vaccine against COVID-19, both concerning the duration and magnitude of immunisation (Pitanga, Pitanga, & Beck, 2020). According to the results of the study by Gualano et al. (2021), which aimed to investigate the association between physical activity and persistent anti-SARS-CoV-2 antibodies 6 months after the schedule of two doses of CoronaVac in patients with autoimmune rheumatic diseases (ARD), identified that, among patients In immunocompromised patients, being physically active was associated with an increase in antibody persistence over 6 months after a full course of an inactivated SARS-CoV-2 vaccine.

However, although studies of randomised clinical trials with the different types of vaccines against COVID-19 have not been carried out, there is already scientific evidence from previous vaccination programs, such as influenza and flu, pointing out that regular exercise can be an effective strategy in strengthening the immune system as well as increasing antibody responses after vaccination.

CONCLUSIONS

Therefore, according to the evidence presented here, we understand that the regular and guided practice of physical exercises, respecting the principles of sports training, act significantly as an auxiliary tool in strengthening and preparing the immune system against the harmful effects COVID-19 has on health, as well as the effectiveness of the effect of vaccines against types of influenza, especially for risk groups, such as people with advanced age, hypertension, diabetes, obesity, heart and chronic respiratory diseases.

It is important to emphasise that only with vaccination can we fight the contagion, spread and COVID-19 health problems, emphasising that in addition to the regular practice of physical exercise, it is important to adhere to other preventive measures, such as good habits of life, social distancing, mask use and good hygiene, being important allies in the effectiveness of vaccines, especially for risk groups.

ACKNOWLEDGMENT

Nothing to declare.

REFERENCES

Barrett, B., Hayney, M. S., Muller, D., Rakel, D., Ward, A., Obasi, C. N., & Coe, C. L. (2012). Meditation or exercise for preventing acute respiratory infection: a randomized controlled trial. *The Annals of Family Medicine, 10*(4), 337-346. https://doi.org/10.1370/afm.1376

Brasil (2012). Ministério da Saúde. Secretaria de Ciência, Tecnologia e Insumos Estratégicos. Departamento de Ciência e Tecnologia. *Diretrizes metodológicas: elaboração de revisão sistemática e metanálise de ensaios clínicos randomizados.* Ministério da Saúde (Série A: Normas e Manuais Técnicos).

Campbell, J. P., & Turner, J. E. (2018). Debunking the myth of exercise-induced immune suppression: redefining the impact of exercise on immunological health across the lifespan. *Frontiers in Immunology, 9*, 648. https://doi.org/10.3389/fimmu.2018.00648

Cao Dinh, H., Njemini, R., Onyema, O. O., Beyer, I., Liberman, K., De Dobbeleer, L., & Bautmans, I. (2019). Strength endurance training but not intensive strength training reduces senescence-prone T cells in peripheral blood in community-dwelling elderly women. *The Journals of Gerontology: Series A, 74*(12), 1870-1878. https://doi.org/10.1093/gerona/gly229

Chaabene, H., Prieske, O., Herz, M., Moran, J., Höhne, J., Kliegl, R., & Granacher, U. (2021). Home-based exercise programmes improve physical fitness of healthy older adults: A PRISMA-compliant systematic review and meta-analysis with relevance for COVID-19. *Ageing Research Reviews, 67*, 101265. https://doi.org/10.1016/j.arr.2021.101265

Committee on Publication Ethics (COPE) (2022). *Portal*. COPE. Retrieved from https://publicationethics.org/

Cortez, A. C. L., Pitanga, F. J. G., Almeida-Santos, M. A., Nunes, R. A. M., Botero-Rosas, D. A., & Dantas, E. H. M. (2020). Centers of physical activities and health promotion during the COVID-19 pandemic. *Revista da Associação Médica Brasileira*, *66*(10), 1328-1334. https://doi.org/10.1590/1806-9282.66.10.1328

da Silveira, M. P., da Silva Fagundes, K. K., Bizuti, M. R., Starck, É., Rossi, R. C., & de Resende E Silva, D. T. (2021). Physical exercise as a tool to help the immune system against COVID-19: an integrative review of the current literature. *Clinical and Experimental Medicine*, *21*(1), 15-28. https://doi.org/10.1007/s10238-020-00650-3

Duggal, N. A., Niemiro, G., Harridge, S. D., Simpson, R. J., & Lord, J. M. (2019). Can physical activity ameliorate immunosenescence and thereby reduce age-related multi-morbidity? *Nature Reviews Immunology*, *19*(9), 563-572. https://doi.org/10.1038/s41577-019-0177-9

García Álvarez, L., Saiz Martínez, P. A., García-Portilla González, M. P., & Bobes, J. (2020). Will changes in alcohol and tobacco use be seen during the covid-19 lockdown? *Adicciones*, *32*(2), 85-90. https://doi.org/10.20882/adicciones.1546

Garcia, L. P., & Duarte, E. (2020). Intervenções não farmacológicas para o enfrentamento à epidemia da COVID-19 no Brasil. *Epidemiologia e Serviços de Saúde*, *29*(2), e2020222. https://doi.org/10.5123/S1679-49742020000200009

Grande, A. J., Keogh, J., Silva, V., & Scott, A. M. (2020). Exercise versus no exercise for the occurrence, severity, and duration of acute respiratory infections. *Cochrane Database of Systematic Reviews*, *4*(4), cd010596. https://doi.org/10.1002/14651858.cd010596.pub3

Gualano, B., Lemes, Í. R., Silva, R., Pinto, A. J., Mazzolani, B., Smaira, F. I., & Bonfa, E. (2021). Physical Activity Associates with Greater Antibody Persistence through 6 Months after the Second Dose of CoronaVac in Patients with Autoimmune Rheumatic Diseases. https://doi.org/10.21203/rs.3.rs-1202511/v1

Huang, C., Wang, Y., Li, X., Ren, L., Zhao, J., Hu, Y., & Cao, B. (2020). Clinical features of patients infected with 2019 novel coronavirus in Wuhan, China. *The Lancet*, *395*(10223), 497-506. https://doi.org/10.1016/s0140-6736(20)30183-5

Laddu, D. R., Lavie, C. J., Phillips, S. A., & Arena, R. (2021). Physical activity for immunity protection: Inoculating populations with healthy living medicine in preparation for the next pandemic. *Progress in Cardiovascular Diseases*, *64*, 102-104. https://doi.org/10.1016/j.pcad.2020.04.006

Ledo, A., Schub, D., Ziller, C., Enders, M., Stenger, T., Gärtner, B. C., & Sester, M. (2020). Elite athletes on regular training show more pronounced induction of vaccine-specific T-cells and antibodies after tetravalent influenza vaccination than controls. *Brain, Behavior, and Immunity*, *83*, 135-145. https://doi.org/10.1016/j.bbi.2019.09.024

Li, J. (2020). Rehabilitation management of patients with COVID-19: lessons learned from the first experience in China. *European Journal of Physical and Rehabilitation Medicine*, *56*(3), 335-338. https://doi.org/10.23736/s1973-9087.20.06292-9

Luzi, L., & Radaelli, M. G. (2020). Influenza and obesity: its odd relationship and the lessons for COVID-19 pandemic. *Acta Diabetologica*, *57*(6), 759-764. https://doi.org/10.1007%2Fs00592-020-01522-8

Magna, C. O. (2014). *Gênero Textual Ensaio Acadêmico - Suas especificidades e regularidades*.

Merellano-Navarro, E., Olate-Briones, A., Norambuena-Mardones, L., Rojas-Ramos, V., Plata-Luna, A. M. D. L., Faúndez-Acuña, J. Y., & Herrada, A. A. (2021). Un Número Reducido de Células T Vírgenes se Correlaciona con un Aumento de la Inflamación Sistémica de Bajo Grado Durante el Envejecimiento y puede ser Modulado por la Actividad Física. *International Journal of Morphology*, *39*(3), 789-796. https://doi.org/10.4067/S0717-95022021000300789

Nieman, D. C., & Wentz, L. M. (2019). The compelling link between physical activity and the body's defense system. *Journal of Sport and Health Science*, *8*(3), 201-217. https://doi.org/10.1016/j.jshs.2018.09.009

Nikolich-Zugich, J., Knox, K. S., Rios, C. T., Natt, B., Bhattacharya, D., & Fain, M. J. (2020). SARS-CoV-2 and COVID-19 in older adults: what we may expect regarding pathogenesis, immune responses, and outcomes. *Geroscience*, *42*(2), 505-514. https://doi.org/10.1007/s11357-020-00186-0

Nogueira, C. J., Cortez, A. C. L., de Oliveira Leal, S. M., & Dantas, E. H. M. (2021). Recomendações para a prática de exercício físico em face do COVID-19: uma revisão integrativa. *Revista Brasileira de Fisiologia do Exercício*, *20*(1), 101-124. https://doi.org/10.33233/rbfex.v20i1.4254

Pawelec, G., & McElhaney, J. (2020). Recent advances in influenza vaccines. *F1000Research*, *9*. https://doi.org/10.12688%2Ff1000research.22611.1

Peçanha, T., Goessler, K. F., Roschel, H., & Gualano, B. (2020). Social isolation during the COVID-19 pandemic can increase physical inactivity and the global burden of cardiovascular disease. *American Journal of Physiology-Heart and Circulatory Physiology*, *318*(6), 1441-1446. https://doi.org/10.1152/ajpheart.00268.2020

Pitanga, F. J. G., Pitanga, C. P. S., & Beck, C. C. (2020). Can physical activity influence the effect of the COVID-19 vaccine on older adults? *Revista Brasileira de Cineantropometria & Desempenho Humano*, *22*, e76586. https://doi.org/10.1590/1980-0037.2020v22e76586

Prayag, G., & Ozanne, L. K. (2018). A systematic review of peer-to-peer (P2P) accommodation sharing research from 2010 to 2016: progress and prospects from the multi-level perspective. *Journal of Hospitality Marketing & Management*, *27*(6), 649-678. https://doi.org/10.1080/19368623.2018.1429977

Simpson, R. J., & Katsanis, E. (2020). The immunological case for staying active during the COVID-19 pandemic. *Brain, Behavior, and Immunity*, *87*, 6-7. https://doi.org/10.1016%2Fj.bbi.2020.04.041

Simpson, R. J., Kunz, H., Agha, N., & Graff, R. (2015). Exercise and the regulation of immune functions. *Progress in Molecular Biology and Translational Science*, *135*, 355-380. https://doi.org/10.1016/bs.pmbts.2015.08.001

Soltani, N., Marandi, S. M., Kazemi, M., & Esmaeil, N. (2020). The exercise training modulatory effects on the obesity-induced immunometabolic dysfunctions. *Diabetes, Metabolic Syndrome and Obesity: Targets and Therapy*, *13*, 785-810. https://doi.org/10.2147%2FDMSO.S234992

Song, Y., Ren, F., Sun, D., Wang, M., Baker, J. S., István, B., & Gu, Y. (2020). Benefits of exercise on influenza or pneumonia in older adults: a systematic review. *International Journal of Environmental Research and Public Health*, *17*(8), 2655. https://doi.org/10.3390/ijerph17082655

Valenzuela, P. L., Simpson, R. J., Castillo-García, A., & Lucia, A. (2021). Physical activity: A coadjuvant treatment to COVID-19 vaccination? *Brain, Behavior, and Immunity*, *94*, 1-3. https://doi.org/10.1016%2Fj.bbi.2021.03.003

Wang, B., Li, R., Lu, Z., & Huang, Y. (2020). Does comorbidity increase the risk of patients with COVID-19: evidence from meta-analysis. *Aging*, *12*(7), 6049-6057. https://doi.org/10.18632/aging.103000

World Health Organization (WHO, 2020a). *Be active at home during the COVID-19 outbreak*. WHO. Retrieved from: https://www.who.int/news-room/campaigns/connecting-the-world-to- combat-coronavirus/healthyathome/healthyathome-physical-activity

World Health Organization (WHO, 2020b). *Coronavirus disease (COVID-19) pandemic*. WHO.

Xu, Z., Chen, Y., Yu, D., Mao, D., Wang, T., Feng, D., Li, T., Yan, S., & Yu, Y. (2020). The effects of exercise on COVID-19 therapeutics: A protocol for systematic review and meta-analysis. *Medicine*, *99*(38), e22345. https://doi.org/10.1097/md.0000000000022345

Yang, J., Zheng, Y., Gou, X., Pu, K., Chen, Z., Guo, Q., & Zhou, Y. (2020). Prevalence of comorbidities in the novel Wuhan coronavirus (COVID-19) infection: a systematic review and meta-analysis. *International Journal of Infectious Disease*, *94*, 91-95. https://doi.org/10.1016/j.ijid.2020.03.017