Journal of Physical Education and Sport ® (JPES),Vol. 22 (issue 9), Art 273, pp. 2134 - 2140, September, 2022
online ISSN: 2247 - 806X; p-ISSN: 2247 – 8051; ISSN - L = 2247 - 8051 © JPES

Original Article

A Cross-sectional analysis of recreational badminton playing and its influence on body composition and cardiometabolic health in healthy older adults

SYED MURSHID SYED ZUBIR[1], ADAM LINOBY[2], RAJA NURUL JANNAT RAJA HUSSAIN[3], SITI AIDA LAMAT[4], IQBAL NORHAMZI[5], AQIL ZULKHAIRI[6], MOHAD ANIZU MOHD NOOR[7], HANNO FELDER[8]
[1,2,3,4]Faculty of Sports Science and Recreation, Universiti Teknologi MARA Cawangan Negeri Sembilan, Kampus Seremban, Negeri Sembilan, MALAYSIA
[2,5,6,7]Faculty of Sports Science and Recreation, Universiti Teknologi MARA Cawangan Selangor, Kampus Shah Alam, Selangor, MALAYSIA
[8]Institute for Sport Science, University Kaiserslautern, Kaiserslautern, GERMANY

Published online: September 30, 2022
(Accepted for publication September 15, 2022)
DOI:10.7752/jpes.2022.09273

Abstract:
Age-related chronic degeneration is associated with adverse changes in body composition, which can significantly affect cardiometabolic health in the elderly population. This study investigates whether playing weekly recreational badminton is linked to changes in body composition and initial cardiometabolic indices in the elderly. From the 98 potential seniors screened for eligibility (age >55 years old), the 36 volunteers deemed eligible are stratified into two badminton groups: high-playing time (9.72 ± 2.16 hours·week^{-1}, n = 18) and low-playing time (3.34 ± 1.53 hours-week^{-1}, n = 18). Non-racquet sports-playing control subjects (n = 16) are also recruited. For the instruments, blood analysis is measured using the finger prick test, and body composition is determined using BodyStat Quadscan 4000 analysis. Body fat percentage is found to be lower in the high-playing time group (20.7 ± 4.85%) compared to the control group (26.6 ± 8.52%) ($p<0.05$). It is also lower in comparison to the low-playing time group (25.3 ± 6.22%) ($p=0.06$). Lean body mass is higher in the high-playing time group (50.3 ± 4.89 kg) than the control group (45.6 ± 5.69 kg) ($p<0.05$), with no differences found with the low-playing time group (48.0 ± 4.04 kg) ($p>0.05$). Similarly, the fasting serum glucose is lower in the high-playing time group (HPT) compared to the control group ($p<0.05$), but not different from the low-playing time group (LPT). The value of LPT was not significantly different from the other two groups (the control group and HPT) (both $p>0.05$). No significant difference in the lipid profile is present between the three groups ($p>0.05$). The results indicate that although the elderly who played more badminton exhibited favourable body composition and glycaemic state compared to the control group, such participation does not appear to offer any additional health benefits when compared to the lower playing counterpart.
Key Words: - **Physical activity, Cardiometabolic, Body composition, Elderly, Racquet sports**

Introduction

Badminton is one of the most popular sports worldwide, with over a billion spectators since its debut at the 1992 Olympic Games in Barcelona, Spain. This non-contact racquet sport is suitable for mixed-gender participations of various ages and physical abilities. The evolution of the sport has seen badminton played at a faster pace with longer rallies (Gomez et al., 2020). The intermittent actions during a badminton game (i.e., a combination of high-intensity short rallies and longer rallies) require work from both the aerobic (approximately 30%) and anaerobic systems (approximately 60 – 70%) (Phomsoupha & Laffaye, 2015). Regularly playing badminton can benefit players' hand-eye coordination, as well as their general speed, upper-body strength and cardiovascular fitness (Preeti et al., 2019).

Physical activities strongly influence both physical and mental health, especially for the increasing elderly population living in highly mechanised countries around the world. Regular physical activity has been touted to have various physiological and metabolic health benefits (Morris & Roychowdhury, 2020). Despite the well-known advantages of physical activity, older adults fail to reach the recommended physical activity levels, which is a critical situation as age increases. Approximately 45% of people over 60 years of age do not meet the recommended physical activity level. This problem is rapidly increasing since the global number of people aged over 65 is expected to triple in the next 30 years (Franco et al., 2015). Evidently, a large-scale, multi-year longitudinal research discovered that for every extra 15 minutes of daily exercise, mortality from any cause could be lowered by as much as 5% (Wen et al., 2011). Intervention and encouragement of healthy ageing by increasing physical activity will lighten the burden of elderly health and social care (Hou et al., 2020). Several previous studies had attempted to encourage physical activity through exercise and aerobic training (Weber & Sharma, 2011).

Corresponding Author: ADAM LINOBY, E-mail: linoby@uitm.edu.my

A study by Costa-Silva et al. (2016) noted that regular physical activity enhances both cardiovascular function and insulin sensitivity. When exercising, insulin resistance and sensitivity in adipose and hepatic tissues improve, further promoting glucose uptake and glycogen restoration in muscles (Bird & Hawley, 2017). Regular physical activity and exercise also show clear protective benefits in improving lipid metabolism (Suk & Shin, 2015). During training, an energy reservoir (known as triacylglycerols) in adipose tissue is hydrolysed to free fatty acids, which are then released into the circulation to provide fuel for working muscles (Mika et al., 2019). Fang et al. (2019) also stated that physical activity is closely associated with individual lipid profiles. The study found that moderate or high-level physical activity associated with lower total cholesterol levels played a huge role in minimising the risk of cardiovascular mortality. Improvements in metabolic and cardiovascular functions with exercise training relatively depend on the intensity and duration of exercise (Linoby et al., 2020). Physical activity also influences body composition. A recent meta-analysis by Shehata & Mahmoud (2018) revealed that HIIT is superior in reducing fat mass compared to traditional exercise programs. Evidence has shown that after a period of high-intensity aerobic exercise, fat mass relatively decreases (Perissiou et al., 2020).

In recent years, participation in racquet sports as a recreational physical activity has been steadily increasing (Demeco et al., 2022). Based on a nationwide study by Chao et al. (2021), regular participation in racquet sports is associated with the lowest risk of cardiovascular-related diseases as well as the lowest all-cause mortality. The evidence indicates that consistent moderate to high-intensity intermittent exercise produces significant improvements in body composition (Sultana et al., 2019), lipid profile (Nazari et al., 2020) and glucose control (Linoby, Nurthaqif, et al., 2020; Liu et al., 2019). Badminton can potentially enhance the cardiovascular fitness, body composition and metabolic health of inactive senior adults. A sociodemographic survey of more than 7000 Taiwanese volunteers found that regularly playing badminton is linked to higher levels of HDL, a biomarker that is positively associated with a decreased risk of coronary heart disease (Nassef et al., 2019). Data has shown that regularly performing moderate to high-intensity intermittent exercise produces significant improvements in body composition (Wong et al., 2018). This is in line with a previous cross-sectional study which revealed that the elderly population with low body fat percentage did spend a significant amount of time performing vigorous physical activity (An et al., 2020).

Although participation in badminton training potentially offers numerous health benefits, little is known on whether the duration of playing recreational badminton influences certain physiological, cognitive and cardiometabolic health indicators. It is still unknown whether lengthy or short badminton exercise times lead to similar or greater body composition and cardiometabolic health effects in the elderly population. Thus, the aim of this study is to evaluate whether the length of playing recreational badminton leads to changes in body composition and primary cardiometabolic indices in healthy elderly players. It is hypothesised that the elderly who play more recreational badminton during the week would have a favourable body composition and cardiometabolic health compared to those who play less and those who do not play badminton at all.

Material & methods

Participants

All eligible and voluntary participants were requested to arrive at the laboratory at 08:00 am in a fasting state. The participants were specifically reminded not to eat or drink (other than plain water) for at least 8 to 12 hours before arriving at the laboratory (Linoby, Jumat, et al., 2020). Following the anthropometric measurement, a venous blood sample was taken from the participants for the blood metabolic biomarker analysis (Dewhurst-Trigg et al., 2018). Participants were asked to lie down for the body composition analysis (Linoby, Azrin, et al., 2020). Next, participants were asked to fill in the questionnaires (i.e., Global Physical Activity Questionnaire, GPAQ and modified Physical Activity Scale for Elderly, PASE) before leaving the testing centre. The rank stratification analysis was used to assign the badminton playing group to either the high-playing time (HPT) group or the low-playing time (LPT) group.

Study Protocol

All eligible and voluntary participants were requested to make themselves present to the laboratory at 08:00 am, in a fasting condition. Specifically, the participants were reminded not to take any food or drinks (other than plain water) for at least 8 to 12 hours prior to their arrival at the laboratory (Linoby, Jumat, et al., 2020). Following anthropometric measurement, subjects were provided a venous blood sample for the blood metabolic biomarkers analyses (Dewhurst-Trigg et al., 2018). Subsequently, the participants were asked to lie down for the body composition analysis (Linoby, Azrin, et al., 2020). Finally, participants were asked to fill in the questionnaires (i.e., Global Physical Activity Questionnaire, GPAQ, and modified Physical Activity Scale for Elderly, PASE) before leaving the testing center. The rank stratification analysis was used to assign the badminton playing group to high-playing time (HPT) and low-playing time (LPT).

Measurements

The anthropometric measurement of weight (kg) and height (cm) were determined using the stadiometer (Seca 220; Seca, Ltd, Hamburg, Germany) according to the manufacturer guidelines. The waist-to-hip ratio reading was evaluated using the Seca 201 tape (Seca, Ltd, Hamburg, Germany), providing a constant pulling tension. A trained personnel analysed the body fat percentage and lean body mass using the multi-frequency bioelectrical impedance analysis, BodyStat QuadScan 4000 (Bodystat Ltd.; Isle of Man, UK), according to the tetrapolar method that was previously outlined by Achamrah et al. (2018).

A certified medical technologist took the necessary venous blood samples. They were directly placed into 2 ml Vacuette® tubes with no additives and into 6 ml Vacutainer® containing ethylenediaminetetraacetic acid (EDTA). 10 µL of whole blood was extracted from the Vacuette® tubes and subsequently examined for blood lipid biomarkers (triglycerides [TG]; total cholesterol [T-Cho]; and high-density lipoprotein cholesterol [HDL]) using PTS Panels® lipid panel test strips with the CardioChek PA from PTS Diagnostics based in Indianapolis, USA. The low-density lipoprotein cholesterol (LDL) was subsequently obtained using Friedewald's formula. The blood samples from the Vacutainer® tubes containing EDTA were left for 20 minutes at room temperature before centrifugation at 4000 rpm for 8 minutes using a Hettich EBA 20 centrifuge (Andreas Hettich GmbH & Co., Tuttlingen, Germany). The serum was then extracted and analysed for [glucose], uric acid [UA] and C-reactive protein concentration [CRP]. To measure the serum [CRP], the samples were diluted 21-fold according to the manufacturer guidelines (Stukas et al., 2020).

The physical activity levels were determined using the GPAQ, as previously described by Silva et al. (2019). The total time spent and energy expenditure for specific activities during a week were measured and converted to metabolic equivalents (MET-min·week^{-1}). The badminton playing time was evaluated using the weekly badminton-playing records and a modified Physical Activity Scale for Elderly (PASE) questionnaire was developed. Stratification was initiated by ranking the total playing time (hr·week^{-1}) as reported by the badminton playing group. From a total of 36 eligible participants in the badminton playing group, ranks #18 and #19 were selected with a total playing time of 6.6 hr·week^{-1} and 7.5 hr·week^{-1}, respectively. Hence, the median of 7.05 hr·week^{-1} was used as the cut-off value to divide the badminton group into HPT (9.72 hr·week^{-1}) and LPT (3.34 hr·week^{-1}) groups.

Statistical Analysis

Differences in badminton playing history characteristics were evaluated using an independent sample t-test. A one-way repeated measure using Brown-Forsythe and Welch ANOVA was accomplished to detect the differences between groups in terms of physical attributes (height, weight, BMI and age), IPAQ total physical activity level, body composition indices (body fat percentage and lean body mass), blood lipid biomarkers ([TG], [T-Cho], [HDL] and LDL) and other blood biomarkers ([glucose], [UA] and [CRP]). Any significant effects were subsequently identified using Dunnett's T3 multiple comparison tests. The GraphPad Prism software (version 9.0, GraphPad Software Inc.; La Jolla, California, USA) was used for all data analyses, with statistical significance accepted at $p<0.05$.

Results

Physical Measurement, Badminton-Playing History, and Physical Characteristics

Of the 98 individuals screened for eligibility, 36 (36.7%) have successfully completed this study (HPT, n = 18; LPT, n = 18; CON, n = 18). Five individuals (5.1%) from the badminton group were excluded from the study since they were unable to continue due to personal reasons, and 22 (22.5%) were excluded from the control group. A considerable number of screened individuals (n = 35, 35.7%) did not meet the inclusion criteria. Table 1 presents the physical and anthropometric measurements, badminton playing history and physical activity characteristics of the three groups. A total of 32 male participants (58.2%) and 22 female participants (41.8%) in the badminton group have successfully completed this study.

Table 1. Physical measurements, badminton-playing history, and physical characteristics in high-playing time, low-playing time, and control groups.

Parameter	HPT	LPT	CON
Age	64.2 ± 2.81	63.3 ± 2.59	64.9 ± 2.89
Weight (kg)	64.8 ± 4.52	6.72 ± 4.58	66.3 ± 6.39
Height (cm)	165 ± 3.95	165 ± 3.58	164 ± 3.48
BMI (kg·m^{-2})	23.9 ± 1.46	24.8 ± 2.34	24.6 ± 2.31
Waist-to-hip ratio	0.90 ± 0.19	0.91 ± 0.12	0.92 ± 0.11
Playing experience (yrs)	28.6 ± 1.33	24.3 ± 3.03	-
Badminton playing frequency (day·week^{-1})	4.72 ± 1.13[a]	2.28 ± 1.02	-
Badminton playing hours (hrs·day^{-1})	2.14 ± 0.56[a]	1.51 ± 0.50	-
Total badminton playing time (hrs·week^{-1})	9.72 ± 2.16[a]	3.34 ± 1.53	-
Total physical activity level (METs)	3397 ± 913	3308 ± 1037	3180 ± 1186
Light intensity physical activity	1224 ± 160	1218 ± 513	1360 ± 452
Moderate intensity physical activity	1167 ± 252	1290 ± 409	1181 ± 477
Vigorous intensity physical activity	1114 ± 198	823 ± 248	716 ± 370

[a]Significantly different from LPT ($p<0.05$).

Body Composition

Figure 2 displays the body fat percentage and lean body mass of participants in the HPT, LPT and CON groups. A significant effect can be seen on body fat percentage (F[2–42.2] = 3.84; p=0.029) and lean body mass (F[2–47] = 4; p=0.025). Body fat percentage was lower in the HPT group (20.7 ± 4.85 %) compared to CON (26.6 ± 8.52 %) (p<0.05) and tended to be lower than the LPT group (25.3 ± 6.22 %) (p=0.06). Lean body mass was higher in the HPT group (50.3 ± 4.89 kg) compared to CON (45.6 ± 5.69 kg) (p<0.05) with no significant difference with the LPT group (48.0 ± 4.04 kg) (p>0.05). No significant difference in body fat percentage and lean body mass was found between the LPT group and CON (p>0.05).

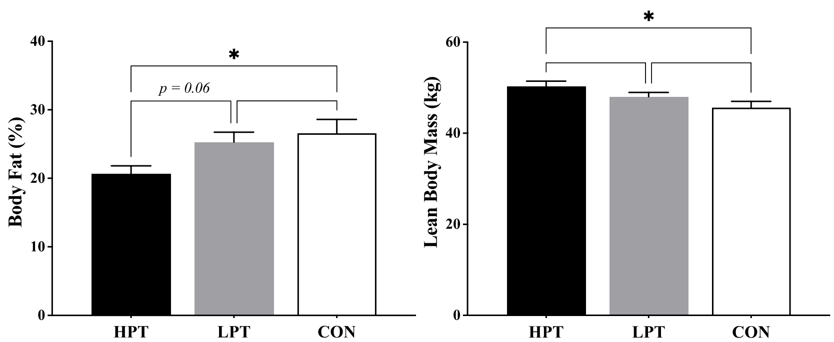

Fig. 1. Body fat % (left panel) and lean body mass (right panel) in the High-playing time, Low-playing time, and control group. *Significantly different from control (p<0.05).

Blood Metabolic Markers

A significant difference can be seen for the fasting serum [glucose] (F [2–42.8] = 3.34; p=0.042), but not for [UA] and [CRP] (p>0.05). The test revealed that serum [glucose] was lower in HPT compared to the CON group (p<0.05). The variables were not significantly different between LPT and the two other groups (CON and HPT) (p>0.05). No significant difference was present in the lipid profile (i.e., blood [TG], [T-Cho], [HDL]) and estimated blood (LDL) between the three groups (p>0.05).

Discussion

The current study found that body fat percentage and lean body mass were higher in the HPT group compared to the CON group. The body fat percentage and lean body mass were not significantly different between the LPT and CON groups. The present study found that with similar daily physical activity levels, participants in the HPT group exhibited a more desirable fasting serum [glucose] as compared to the CON group. Despite the fact that there is a notable difference in the amount of badminton played each week, no difference in blood biomarkers was present between the HPT and LPT groups in the current research.

In the present investigation, the GPAQ study revealed that HPT participants engaged in substantially more vigorous activities than other groups, which may partially explain why the body fat percentage was reduced by 22.2% for the HPT group compared to 18.2% for the CON and LPT groups (p<0.05), respectively. Numerous studies support the notion that active engagement in moderate-to-vigorous physical activity is a significant factor in managing body composition in young adults (Jumat et al., 2021; Silva et al., 2019) and the elderly (Hou et al., 2020). An extensive cross-sectional study in China found that whole-body fat percentage is much lower in elderly individuals who engage in greater intensity and higher amounts of physical activity than the WHO recommendation (Ma et al., 2021). The badminton group that participated in more frequent and vigorous exercise (i.e., HPT) have greater potential of improving their whole-body fat percentage compared to increasing muscle mass. These results are consistent with those of a meta-analysis conducted by Wu et al. (2021). The meta-analysis of 12 relevant studies found that high-intensity intermittent exercise led to a greater overall effect of reducing the percentage of whole-body fat compared to lean muscle mass for the elderly. Accordingly, Wu's meta-analysis and the result of the present study are consistent with the experimental analysis of Bruseghini et al. (2015). They found that high-intensity intermittent exercise induced a significant reduction in whole-body fat percentage and abdominal fat, but not lean muscle mass.

Incorporating regular exercise routines has a positive effect on the glycaemic status and insulin sensitivity in the elderly population (Liu et al., 2019). Previous reports show that glucose tolerance declines with age (Galloza et al., 2017), and this likelihood further increases for inactive and obese people (Jelstad et al., 2021). Not managing blood glucose levels can cause extensive damage to tissues and organs, including those that are essential for maintaining normal BP. The measures that focus on enhancing glucose management may also reduce the incidence of hypertension, particularly in older individuals. The present study discovered that the group that participated in the highest level of vigorous-intensity activities also exhibited significantly lower fasting serum [glucose], by ~4.3% (p<0.05), as compared to the control group. In their meta-analysis, Wu and colleagues discovered that high-intensity exercise increases glucose consumption, and the improvement in the glycaemic state is followed by an increase in lean body mass (Wu et al., 2021). This corresponded with the current results that body fat percentage was lower and lean body mass was higher in the HPT group compared to the group with the lowest level of strenuous exercise involvement (i.e., CON).

Consistent high-intensity intermittent exercise may further boost mitochondrial oxidative phosphorylation (Nordin et al., 2021), which aids in active glucose consumption (Nordin et al., 2021), especially for the elderly population (Wu et al., 2021). It was also suggested that seniors with a stronger tendency to perform high-intensity intermittent exercise will promote lipolysis metabolism and potentially reduce triglyceride levels significantly, as evident in a previous research by Jelstad et al. (2021). However, the present study found no significant difference between the lipid profile indices of the three groups (i.e., blood [TG], [T-Cho], [HDL] and LDL). It is possible that these results are due to the lack of lipid metabolic disorders in the present study, which only included healthy seniors. These results are also due to the improvements in blood glucose levels of participants since blood glucose influences the lipid profile (Gordon et al., 2014).

Conclusion

The outcomes of this study demonstrate that under similar daily physical activity levels, older adults who underwent longer badminton-playing time (HPT) have more significant influence on body composition (lean body mass and body fat percentage) and glycaemic state compared to those who underwent lower badminton-playing time (LPT). The present study is expected to lead to a greater understanding of how playing recreational badminton affects body composition and cardiometabolic health, particularly in the elderly population. The information provided by the current study is closely relevant to badminton practitioners. In the long-term, this knowledge may contribute to the physical well-being of the elderly population. The data presented in this study can serve as evidence for the cardiometabolic health of seniors who play recreational badminton. The findings encourage playing badminton as a means of promoting public health, especially for ageing populations.

Acknowledgment: The study was supported by a research grant (Grant No: INT16/6/2–040/2021), awarded to Universiti Teknologi MARA by the Badminton World Federation (BWF) Grant 2021–22.
Conflicts of interest: If the authors have any conflicts of interest to declare.

References

Achamrah, N., Colange, G., Delay, J., Rimbert, A., Folope, V., Petit, A., Grigioni, S., Déchelotte, P., & Coëffier, M. (2018). Comparison of body composition assessment by DXA and BIA according to the body mass index: A retrospective study on 3655 measures. *PloS One*, *13*(7), e0200465. https://doi.org/https://doi.org/10.1371/journal. pone.0200465

An, K. H., Han, K. A., Sohn, T. S., Park, I. B., Kim, H. J., Moon, S. D., & Min, K. W. (2020). Body fat is related to sedentary behavior and light physical activity but not to moderate-vigorous physical activity in type 2 diabetes mellitus. *Diabetes & Metabolism Journal*, *44*(2), 316. https://doi.org/10.4093/dmj.2019.0029

Bird, S. R., & Hawley, J. A. (2017). Update on the effects of physical activity on insulin sensitivity in humans. *BMJ Open Sport & Exercise Medicine*, *2*(1), e000143.

Bruseghini, P., Calabria, E., Tam, E., Milanese, C., Oliboni, E., Pezzato, A., Pogliaghi, S., Salvagno, G. L., Schena, F., Mucelli, R. P., & Capelli, C. (2015). Effects of eight weeks of aerobic interval training and of isoinertial resistance training on risk factors of cardiometabolic diseases and exercise capacity in healthy elderly subjects. *Oncotarget*, *6*(19), 16998–17015. https://doi.org/10.18632/oncotarget.4031

Chao, H.-H., Liao, Y.-H., & Chou, C.-C. (2021). Influences of Recreational Tennis-Playing Exercise Time on Cardiometabolic Health Parameters in Healthy Elderly: The ExAMIN AGE Study. *International Journal of Environmental Research and Public Health*, *18*(3), 1255. https://doi.org/10.3390/ijerph18031255

Costa-Silva, J. H., Simões-Alves, A. C., & Fernandes, M. P. (2016). Developmental origins of cardiometabolic diseases: role of the maternal diet. *Frontiers in Physiology*, *7*, 504.

Demeco, A., de Sire, A., Marotta, N., Spanò, R., Lippi, L., Palumbo, A., Iona, T., Gramigna, V., Palermi, S., Leigheb, M., Invernizzi, M., & Ammendolia, A. (2022). Match analysis, physical training, risk of injury and rehabilitation in padel: overview of the literature. *International Journal of Environmental Research and Public Health*, *19*(7), 4153. https://doi.org/10.3390/ijerph19074153

Dewhurst-Trigg, R., Yeates, T., Blackwell, J. R., Thompson, C., Linoby, A., Morgan, P. T., Clarke, I., Connolly, L. J., Wylie, L. J., Winyard, P. G., Jones, A. M., & Bailey, S. J. (2018). Lowering of blood pressure after nitrate-rich vegetable consumption is abolished with the co-ingestion of thiocyanate-rich vegetables in healthy normotensive males. *Nitric Oxide*, *74*, 39–46. https://doi.org/10.1016/j.niox.2018.01.009

Fang, F., Zhan, Y., Hammar, N., Shen, X., Wirdefeldt, K., Walldius, G., & Mariosa, D. (2019). Lipids, apolipoproteins, and the risk of parkinson disease: a prospective cohort study and a mendelian randomization analysis. *Circulation Research*, *125*(6), 643–652.

Galloza, J., Castillo, B., & Micheo, W. (2017). Benefits of exercise in the older population. *Physical Medicine and Rehabilitation Clinics of North America*, *28*(4), 659–669. https://doi.org/10.1016/j.pmr.2017.06.001

Gomez, M. A., Leicht, A. S., Rivas, F., & Furley, P. (2020). Long rallies and next rally performances in elite men's and women's badminton. *PloS One*, *15*(3), e0229604.

Gordon, B., Chen, S., & Durstine, J. L. (2014). The effects of exercise training on the traditional lipid profile and beyond. *Current Sports Medicine Reports*, *13*(4), 253–259. https://doi.org/10.1249/JSR.0000000000000073

Hou, X., Tang, Z.-Y., Liu, Y., Liu, Y.-J., & Liu, J.-M. (2020). Epidemiological study on the dose–effect association between physical activity volume and body composition of the elderly in China. *International Journal of Environmental Research and Public Health*, *17*(17), 6365. https://doi.org/10.3390/ijerph17176365

Jelstad, S., Ditta Valsdottir, T., Johansen, E. I., & Jensen, J. (2021). Eight sessions of endurance training decrease fasting glucose and improve glucose tolerance in middle-aged overweight males. *Archives of Physiology and Biochemistry*, *127*(1), 12–19. https://doi.org/10.1080/13813455.2018.1563189

Jumat, A. N., Nordin, A. S., Norhamazi, I. K., Mud Puad, S. M., & Linoby, A. (2021). Influence polysulphide-enriched garlic supplementation lowers blood pressure in healthy adults following high-intensity constant load exercise. *Malaysian Journal of Sport Science and Recreation*, *17*(2), 245–265. https://doi.org/10.24191/mjssr.v17i2.15391

Linoby, A., Azrin, A. A., Adnan, M. A., Za'don, N. H. A., Sariman, M. H., Mohd Nasir, M. Z., & Raja Hussain, R. N. J. (2020). A Randomized controlled trial of the effects of dietary nitrate supplementation on blood pressure, exhaled nitric oxide level and maximal isometric handgrip strength in pre-hypertensive women. In *International Conference on Movement, Health and Exercise* (pp. 389–398). Springer. https://doi.org/10.1007/978-981-15-3270-2_41

Linoby, A., Jumat, M. A. N., Nordin, A. S., Za'Don, N. H. A., Kusrin, J., & Puad, S. M. S. M. (2020). Acute moderate and high-intensity endurance exercise suppresses ad-libitum energy intake in obese males. *Pertanika Journal of Science and Technology*, *28*(1), 279–292.

Linoby, A., Md Yusof, S., Ismail, A. D., Isa, K. A., Syed Omar, S. S., Jamaludin, M., & Syed Mud Puad, S. M. (2020). The role of fitness status in the performance-enhancing effects of dietary inorganic nitrate supplementation: meta-analysis and meta-regression analysis. In *Lecture Notes in Bioengineering* (pp. 421–434). Springer. https://doi.org/10.1007/978-981-15-3270-2_44

Linoby, A., Nurthaqif, M., Mohamed, M. N., Mohd Saleh, M., Md Yusoff, Y., Md Radzi, N. A. A., Abd Rahman, S. A., & Mohamed Sabadri, S. N. S. (2020). Nitrate-rich red spinach extract supplementation increases exhaled nitric oxide levels and enhances high-intensity exercise tolerance in humans. In *Lecture Notes in Bioengineering* (pp. 412–420). https://doi.org/10.1007/978-981-15-3270-2_43

Liu, J., Zhu, L., Li, P., Li, N., & Xu, Y. (2019). Effectiveness of high-intensity interval training on glycemic control and cardiorespiratory fitness in patients with type 2 diabetes: a systematic review and meta-analysis. *Aging Clinical and Experimental Research*, *31*(5), 575–593. https://doi.org/10.1007/s40520-018-1012-z

Ma, W., Liu, Y., Wu, N., Zhang, H., Han, P., Wang, F., Wang, J., Xie, F., Niu, S., Hu, H., Zhang, C., Chen, N., Zhang, Y., Guo, Q., & Yu, Y. (2021). Obesity, even in the metabolically healthy, increases the risk of poor physical performance: a cross-sectional study of older people in a Chinese community. *Clinical Interventions in Aging*, *Volume 16*, 697–706. https://doi.org/10.2147/CIA.S302167

Marcos-Pardo, P. J., Orquin-Castrillón, F. J., Gea-García, G. M., Menayo-Antúnez, R., González-Gálvez, N., Vale, R. G. de S., & Martínez-Rodríguez, A. (2019). Effects of a moderate-to-high intensity resistance circuit training on fat mass, functional capacity, muscular strength, and quality of life in elderly: A randomized controlled trial. *Scientific Reports*, *9*(1), 7830. https://doi.org/10.1038/s41598-019-44329-6

Mika, A., Macaluso, F., Barone, R., di Felice, V., & Sledzinski, T. (2019). Effect of exercise on fatty acid metabolism and adipokine secretion in adipose tissue. *Frontiers in Physiology*, *10*, 26.

Morris, T., & Roychowdhury, D. (2020). Physical activity for health and wellbeing: the role of motives for participation. *Health Psychology Report*, *8*(4), 391–407. https://doi.org/10.5114/hpr.2020.100111

Nassef, Y., Lee, K.-J., Nfor, O. N., Tantoh, D. M., Chou, M.-C., & Liaw, Y.-P. (2019). The impact of aerobic exercise and badminton on HDL cholesterol levels in adult Taiwanese. *Nutrients*, *11*(3), 515.

Nazari, M., Minasian, V., & Hovsepian, S. (2020). Effects of two types of moderate- and high-intensity interval training on serum Salusin-α and Salusin-β levels and lipid profile in women with overweight and Obesity. *Diabetes, Metabolic Syndrome and Obesity: Targets and Therapy*, *Volume 13*, 1385–1390. https://doi.org/10.2147/DMSO.S248476

Nordin, A. S., Jumat, A. N., Norhamazi, I. K., Mud Puad, S. M., & Linoby, A. (2021). Polysulfide-enriched garlic supplementation improves cognitive function and reduces heart rate during high intensity intermittent exercise. *Malaysian Journal of Sport Science and Recreation*, *17*(2), 225–244. https://doi.org/10.24191/mjssr.v17i2.15390

Perissiou, M., Borkoles, E., Kobayashi, K., & Polman, R. (2020). The effect of an 8 week prescribed exercise and low-carbohydrate diet on cardiorespiratory fitness, body composition and cardiometabolic risk factors in obese individuals: a randomised controlled trial. *Nutrients*, *12*(2), 482. https://doi.org/10.3390/nu12020482

Phomsoupha, M., & Laffaye, G. (2015). The science of badminton: game characteristics, anthropometry, physiology, visual fitness and biomechanics. *Sports Medicine*, *45*(4), 473–495.

Preeti, ., Kalra, S., Yadav, J., & Pawaria, S. (2019). Effect of pilates on lower limb strength, dynamic balance, agility and coordination skills in aspiring state level badminton players. *Journal of Clinical And Diagnostic Research*, *13*(7). https://doi.org/10.7860/JCDR/2019/41713.12978

Shehata, A., & Mahmoud, I. (2018). Effect of high intensity interval training (HIIT) on weight, body mass index and body fat percentage for adults. *Science, Movement and Health*, *18*(2), 2018.

Silva, B. G. C. da, Silva, I. C. M. da, Ekelund, U., Brage, S., Ong, K. K., de Lucia Rolfe, E., Lima, N. P., Silva, S. G. da, França, G. V. A. de, & Horta, B. L. (2019). Associations of physical activity and sedentary time with body composition in Brazilian young adults. *Scientific Reports*, *9*(1), 5444. https://doi.org/10.1038/s41598-019-41935-2

Stukas, S., Hoiland, R. L., Cooper, J., Thiara, S., Griesdale, D. E., Thomas, A. D., Orde, M. M., English, J. C., Chen, L. Y. C., Foster, D., Mitra, A. R., Romano, K., Sweet, D. D., Ronco, J. J., Kanji, H. D., Chen, Y.-W. R., Wong, S. L., Wellington, C. L., & Sekhon, M. S. (2020). The association of inflammatory cytokines in the pulmonary pathophysiology of respiratory failure in critically ill patients with Coronavirus disease 2019. *Critical Care Explorations*, *2*(9), e0203. https://doi.org/10.1097/CCE.0000000000000203

Suk, M., & Shin, Y. (2015). Effect of high-intensity exercise and high-fat diet on lipid metabolism in the liver of rats. *Journal of Exercise Nutrition & Biochemistry*, *19*(4), 289.

Sultana, R. N., Sabag, A., Keating, S. E., & Johnson, N. A. (2019). The effect of low-volume high-intensity interval training on body composition and cardiorespiratory fitness: a systematic review and meta-analysis. *Sports Medicine*, *49*(11), 1687–1721. https://doi.org/10.1007/s40279-019-01167-w

Weber, A. S., & Sharma, M. (2011). Enhancing effectiveness of physical activity interventions among older adults. *American Journal of Health Studies*, *26*(1).

Wen, C. P., Wai, J. P. M., Tsai, M. K., Yang, Y. C., Cheng, T. Y. D., Lee, M.-C., Chan, H. T., Tsao, C. K., Tsai, S. P., & Wu, X. (2011). Minimum amount of physical activity for reduced mortality and extended life expectancy: a prospective cohort study. *The Lancet*, *378*(9798), 1244–1253. https://doi.org/10.1016/S0140-6736(11)60749-6

Wong, A., Sanchez-Gonzalez, M. A., Son, W.-M., Kwak, Y.-S., & Park, S.-Y. (2018). The effects of a 12-week combined exercise training program on arterial stiffness, vasoactive substances, inflammatory markers, metabolic profile, and body composition in obese adolescent girls. *Pediatric Exercise Science*, *30*(4), 480–486.

Wu, Z.-J., Wang, Z.-Y., Gao, H.-E., Zhou, X.-F., & Li, F.-H. (2021). Impact of high-intensity interval training on cardiorespiratory fitness, body composition, physical fitness, and metabolic parameters in older adults: A meta-analysis of randomized controlled trials. *Experimental Gerontology*, *150*, 111345. https://doi.org/10.1016/j.exger.2021.111345