J Frailty Aging 2024;13(4)427-431
Published online September 10, 2024, http://dx.doi.org/10.14283/jfa.2024.68

Original Research

Muscle Strength Matters Most for Risk of Falling Apart from Body Mass Index in Older Adults: A Mediated-Moderation Analysis

F. Rodrigues[1,2], M. Izquierdo[3], D. Monteiro[1,2], M. Jacinto[1,2], R. Matos[1,2], N. Amaro[1,2], R. Antunes[1,2], D.S. Teixeira[4,5]

1. ESECS – Polytechnic of Leiria, Leiria, Portugal; 2. Research Center in Sports, Health, and Human Development, Vila Real, Portugal; 3. Navarrabiomed, University Hospital of Navarra (HUN), Public University of Navarra (UPNA), IdiSNA, Pamplona, Spain; CIBER of Frailty and Healthy Aging (CIBERFES), Carlos III Health Institute, Madrid, Spain; 4. Faculty of Physical Education and Sport - Lusófona University of Humanities and Technologies, Lisbon, Portugal; 5. Research Center in Sport, Physical Education, and Exercise and Health, Lisbon, Portugal

Corresponding Author: Miguel Jacinto, Polytechnic Institute of Leiria, Portugal, miguel.s.jacinto@ipleiria.pt

Abstract

The primary objective of this study was to analyze the moderating effect of body mass index (BMI) on the association between lower body strength, agility, and dynamic balance, considering the mediating influence of lower body flexibility and aerobic endurance in community-dwelling older adults. This study included a sample of 607 community-dwelling older adults (female = 443; male = 164) aged between 60 and 79 years (M = 69.24; SD = 5.12). Participants had a mean body mass index of 28.33kg/m^2 (SD = 4.45). In the mediation-moderation model, positive associations were found between lower body strength and lower body flexibility, aerobic endurance, and agility and dynamic balance ($p < 0.05$). As for the moderation effects and interactions, BMI was found to have a significant interaction with lower body strength on agility and dynamic balance (β = -.04, [-.06, -.03]), representing an R2-change of 0.04 ($p < .001$). Conditional direct effects were estimated at BMI scores of 23.9 (β = -.09, [-.15, -.03]), 27.7 (β = -.19, [-.24, -.14]), and 32.7 (β = -.33, [-.40, -.26]) kg/m^2. Older adults with high levels of muscular strength tended to have shorter timed up-and-go test times, regardless of BMI. Also, individuals with lower levels of lower body strength were found to have longer timed up-and-go test times, and this relationship became more pronounced with increasing BMI.

Key words: Body mass index, older adults, physical fitness.

Introduction

Muscle strength is crucial for maintaining quality of life and independence as individuals age (1–3). According to current assumptions, higher levels of muscle mass and strength in older adults also represent greater fitness capacity and are key contributors to reducing the risk of falls. Given that falls have a prevalence rate of approximately 33% for individuals aged 65 and above (4) and that it tends to increase with age (5), it is evident that the ability of muscle fiber contraction and neuromuscular activation can lead to a lower incidence of falls (6). Furthermore, older adults who have fallen have a higher risk of recurrence and may become increasingly reliant on others or even institutionalized. Additionally, the fear of falling can lead to a reduction in physical activity, which in turn leads to a gradual loss of muscle mass and strength, potentially indicative of sarcopenia (7). This downward spiral between muscle strength and risk of falls has been associated with an increase in body composition in the form of body fat. Indeed, the reduction in physical activity in the population has led to lower caloric expenditure, with a maintenance or possibly an increase in caloric intake that is stored in the body as fat. This increase in body composition associated with low levels of physical activity and muscle strength may further increase the risk of falls (8–10).

Muscle plays a significant role in not only the ability to generate force but also in locomotion speed and flexibility, as demonstrated by several authors (11, 12). Maintaining muscle mass enables individuals to perform daily tasks that require force generation, such as picking up objects from the ground, and muscle endurance is also important for activities like walking, climbing and descending stairs, and maintaining basic activities of independence and autonomy in older adults. Research suggests that higher levels of muscle strength are associated with aerobic endurance due to muscle activation during aerobic activities, such as walking (13). Moreover, physical movements that involve strength and performed with greater ranges of motion, such as picking up objects from the ground, lead to the preservation of flexibility (14). In the case of community-dwelling older adults, tasks previously described are essential; thus, higher levels of physical fitness are crucial for a higher quality of life and lower risk of falls.

There is empirical evidence demonstrating a relationship between physical fitness and fall risk (15, 16), although it remains unclear whether muscle strength alone is the most salient factor. Mediation analysis could elucidate the connection between muscle strength and the risk of falls. Additionally, investigating Body Mass Index (BMI) allows for an examination of its potential moderating role in the aforementioned relationship. Unlike conventional analyses, such as correlation and mean group comparison, moderation analysis affords insight into how associations may vary in response to the moderator variable's effect. In the proposed study, we sought to determine whether BMI would affect the correlation between muscle strength and the risk of falls. Drawing on prior theoretical foundations, it was proposed that physical fitness categories, such as flexibility and aerobic endurance, would mediate the relationship between muscle strength, agility, and dynamic balance, which collectively serve as an indicator of fall risk. Furthermore, we hypothesized that BMI would exert a moderating influence on these associations, suggesting that a higher BMI would have a considerable impact on the relationship between lower body strength and the risk of falls. The primary objective of this study was to analyze the

Received June 11, 2024
Accepted for publication August 17, 2024

moderating effect of BMI on the association between lower body strength, agility, and dynamic balance, considering the mediating influence of lower body flexibility and aerobic endurance in community-dwelling older adults.

Methods

Participants

Prior to conducting the study, sample size calculations were performed according to the recommendations of several authors (17–19) and the G*Power for simulations (20). Fritz and MacKinnon's recommendations for small α and β paths (the most restrictive condition when 1-β = .80) indicate a minimum of 558 individuals. For a simple moderation simulation (one moderator) using f^2 = .15, α = .05, and 1-β = .80, a sample size greater than 77 is recommended. Considering that no clear indication exists on how to calculate an adequate sample size for the model under study, we selected a sample size that would (i) surpass the simulations performed under the most restrictive conditions of mediation and (ii) the minimum number of cases for the number of interactions to be tested.

Participants were included in the study if they met the following inclusion criteria: aged between 60- and 80-years old living in the community, not suffering from cognitive disorders, not having medical contraindications for physical fitness and body composition tests, voluntarily participating, and being able to move autonomously or with the use of a manual mobility device.

Procedures

Before data collection began, approval was obtained from the ethics committee (numbers omitted for review purposes). Subsequently, an existing community program in central Portugal with over 1000 registered participants, was contacted for convenience. After obtaining authorization from the municipal council, the program directors were contacted, and the objectives of the study were explained to them. All the participants met the inclusion criteria. Potential participants were informed of the study objective, anonymity, voluntary participation, and withdrawal at any time. Physical fitness tests and body composition measurements were also performed. The technical team received specific training on how to collect the data. All potential participants who wished to participate in this study signed an informed consent form before undergoing the physical fitness tests and body composition measurements. All participants who consented to participate underwent the tests at the beginning of the sport season, namely in September and October, following a one-month break during the vacation program.

Instruments

The 30-second chair stand test (21) was used to assess lower body strength. During the test, the participant was seated in a chair, crossed their arms, and instructed to perform repeated movements of standing up and sitting down in the chair for 30 s, with the aim of completing as many repetitions as possible.

The chair sit and reach test (21) was used to assess lower body flexibility. During the test, the participant sat in a chair, extended the dominant leg forward with the foot flexed, then leaned forward, trying to reach as far as possible towards the feet, keeping the knee in complete extension with one palm overlapped on the other, and the reached (or not reached) distance was recorded.

The 2-minute step test (21) was employed to evaluate aerobic endurance. The participants were instructed to step up and down a 12-inch step for 2 minutes continuously. This test assessed the efficiency of the cardiovascular system in sustaining physical activity over a prolonged period, and the maximum steps were recorded.

The timed up-and-go test (21) allows the evaluation of agility and dynamic balance, indicating the risk of falls. It consisted of walking a distance in a straight line, starting from a seated position in a chair, going to a cone placed 2.44m away, circumventing it, and returning to the initial chair. During the test explanation, the importance of rising, walking quickly without running, circling the cone, returning to the chair, and sitting down again was emphasized. An initial measurement was conducted for familiarization. The time required to complete the test was determined.

Height was measured using a portable Seca 213 stadiometer with an integrated leveler (GmbH & Co. KG; Hamburg, Germany). Participants were positioned with their backs on a wall where the stadiometer was fixed, ensuring contact of the back of the head, back, and buttocks with the wall. With the weight evenly distributed on both bare feet and heels together and touching the wall, participants were instructed to look straight ahead, inhale, and hold their breath. The stadiometer gauge was then lowered to the highest point of the head, and measurements were recorded. Weight was measured using the Seca 761 brand scale (GmbH & Co. KG, Hamburg, Germany) was placed on a stable surface. The participants were weighed without shoes or coats, keeping the rest of their clothing. They were instructed to step on the scale with their feet on the scale's reference, looking straight ahead, and remaining still during the measurement. Body mass index (BMI) was calculated using the following formula: BMI (kg/m^2) = weight (kg) / $height^2$ (m).

Statistical analysis

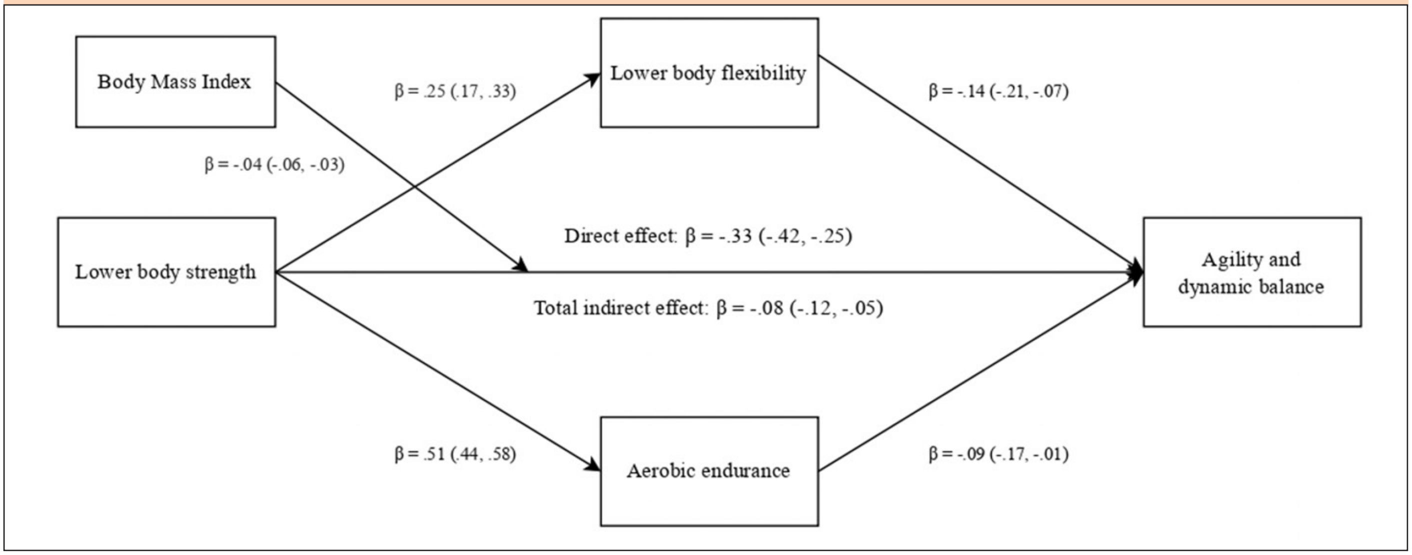
All statistical analyses were performed using the IBM SPSS Statistics 29.0 (IBM, Armonk, USA). Descriptive statistics were calculated using the mean and standard deviation. Bivariate correlations were also calculated to understand possible associations between variables. Subsequently, a mediated-moderation model was developed following the recommendations proposed by Hayes et al. (18) using PROCESS version 4.2, and model 5 for hypothesis testing. This model assumes the existence of an independent variable (lower body strength), parallel mediators (lower body flexibility and aerobic endurance), a dependent variable (agility and

Table 1. Descriptive statistics, composite reliability coefficients, and latent correlations

Variables	Test	M	SD	Min	Max	1	2	3	4	5
1. Lower body strength	30-second chair stand test	14.59	3.82	3	31	1				
2. Lower body flexibility	Chair sit and reach	0.57	9.82	-33	31	.25*	1			
3. Aerobic endurance	2-minute step test	109.31	64.28	0	390	.51*	.16*	1		
4. Agility and dynamic balance	Timed up and go test	6.31	2.37	1.10	39.80	-.44*	-.26*	-.32*	1	
5. Body mass index	Weight / height^2	28.33	4.45	18.67	47.09	-.25*	-.14*	-.27*	.30*	1

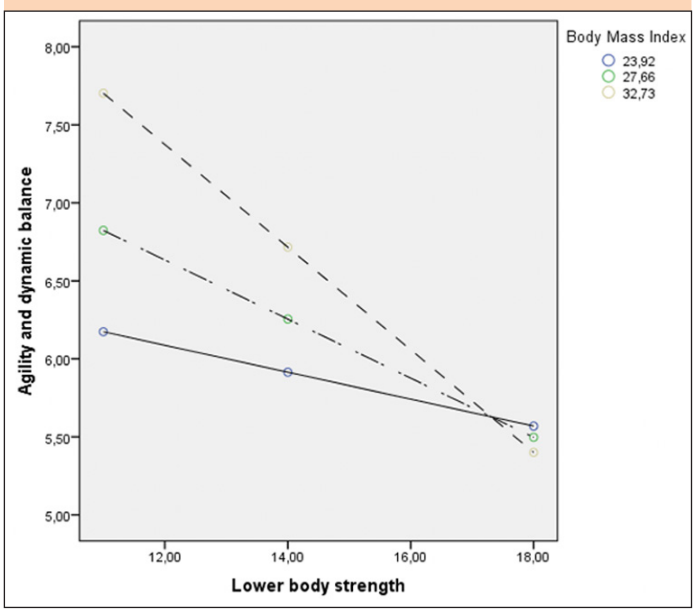
Notes: * p < .01.

Figure 1. Mediated-moderation model



dynamic balance), and a moderator (BMI as a continuous variable). The values were conditioned at the 16th, 50th, and 84th percentiles. A bootstrap with 5,000 samples was used for the 95% confidence interval estimation, and significant effects were considered if the interval did not encompass zero.

Figure 2. Interaction effects



Results

This study included a sample of 607 community-dwelling older adults (female = 443; male = 164) aged between 60 and 79 years (M = 69.24; SD = 5.12). Participants had a body mass ranging from 45 kg to 122 kg (M = 71.78; SD = 12.35) and a height ranging from 1.30m to 1.89m (M = 1.59; SD = 0.07). Regarding age groups, 323 participants were aged between 60 and 69 years and 284 were aged between 70 and 79 years.

The bivariate correlations are consistent with the hypothesis that lower body strength and flexibility, as well as aerobic endurance, are negatively associated with the timed up and go test, since shorter times in this test are associated with higher levels of agility and dynamic balance. Additionally, a significant positive association was observed between agility, dynamic balance, and BMI (Table 1).

The results of the moderated mediation analysis are presented in Figure 1 and Figure 2. In the tested model, a significant direct effect was detected (lower body muscle strength → agility and dynamic balance; β = -.33, [-.42, -.25]). Positive associations were found between lower body strength and lower body flexibility (β = .25, [.17, .33]) and between lower body strength and aerobic endurance (β = .51, [.44, .58]). Lower body flexibility was positively associated with agility and dynamic balance (β = -.14, [-.21, -.07]). A similar pattern was observed for aerobic endurance, agility and dynamic balance (β = -.09, [-.17, -.01]). In addition, a significant total indirect effect was found (β = -.08, [-.12, -.05]). As for the moderation effects and interactions (Figure 2), BMI was found to have a significant interaction with lower body muscle strength on agility and dynamic balance (β = -.04, [-.06, -.03]), representing an R2-change of 0.04 ($p < .001$). Conditional direct effects were estimated at BMI scores of 23.9 (β = -.09, [-.15, -.03]), 27.7 (β = -.19, [-.24, -.14]), and 32.7 (β = -.33, [-.40, -.26]) kg/m^2.

Discussion

This research aimed to investigate the moderating influence of BMI on the relationship between lower body strength, agility, and dynamic balance, while also considering the mediating role of lower body flexibility and aerobic endurance in community-dwelling older adults. The study's findings indicate a number of significant relationships between physical fitness and body composition, with higher levels of lower body strength being indicative of greater agility and dynamic balance, as evidenced by shorter timed up-and-go test completion times, a measure commonly used to assess fall risk in the elderly. Additionally, it is worth noting that higher body composition was found to be significantly associated with both agility and dynamic balance, with higher BMI levels being linked to longer timed up-and-go test times. One of the novel aspects of this study was the examination of the moderating role of BMI, which yielded two noteworthy findings. Firstly, older adults with high levels of muscular strength tended to have shorter timed up-and-go test times, regardless of BMI. Secondly, individuals with lower levels of lower body strength were found to have longer up-and-go test times, and this relationship became more pronounced with increasing BMI. Consequently, it can be speculated that individuals with a higher BMI (e.g., those who are overweight) but who are physically active may possess higher levels of physical fitness and consequently, a lower risk of falls.

The findings from the moderated mediation model reveal the potential existence of three categories of BMI based on the cut-off criteria of Winter et al. (22). As illustrated in Figure 1, individuals with lower muscular strength in their lower body tend to exhibit higher BMI, particularly older individuals with an approximate value of 33 kg/m^2. The significant interaction between BMI and lower body strength on agility and dynamic balance (β = -.04, [-.06, -.03]) suggests that BMI modulates the effectiveness of muscle strength in reducing fall risk. Specifically, higher BMI diminishes the positive impact of muscle strength on dynamic balance and agility. This moderation effect was evident across different BMI categories, with conditional direct effects intensifying at higher BMI levels: 23.9 (β = -.09, [-.15, -.03]), 27.7 (β = -.19, [-.24, -.14]), and 32.7 kg/m^2 (β = -.33, [-.40, -.26]). Trevian et al. (23) detected a U-shaped association between BMI and risk of falls in older adults, with a nadir between 24.5 and 30. Therefore, a BMI greater than 30 kg/m^2 and lower body muscle strength are both indicators of an increased risk of falls.

This study highlights the need to examine body composition in older adults beyond the overall BMI, since greater BMI may mislead exercise and health professionals to assume health-related risks, such as greater risk of falls (8). In this sense, professionals should assess free fat mass and body fat percentage separately, and muscle strength as a means to comprehend how older adults are physically capable, since muscle strength is associated with flexibility and aerobic endurance as should in the results section. As observed in the present study, greater muscle strength, which is part of the overall body composition, is associated with greater agility and dynamic balance, which may translate into a lower risk of falls. This shows that muscle strength should be preserved or even increased in this population. This may be attained by maintaining daily physical activity or adding regular exercise through participation in community programs, which seems to increase (15).

Limitations and agenda for future research

While the sample was relatively large, the cross-sectional design limited the interpretation of the results and prevented the assumption of causality. Nevertheless, the current results provide preliminary evidence for the moderating role of BMI in the association between muscle strength and agility. There is a need to examine free fat mass and body fat percentage to understand the implications of each tested association. Additionally, we were unable to track the prevalence of falls in this sample, which could have implications for the interpretation of physical fitness. Another limitation was the convenience of the sample. We collected data from community-dwelling older adults, who are typically more active than institutionalized individuals. In addition, we gathered data without assessing the previous exercise participation. In fact, an exploratory analysis showed that less than 1% had an increased risk of falls, considering the 13 second cutoff for performing the timed up and go test. Thus, this population was already at low risk and showed greater physical fitness.

Conclusion

The results revealed interesting associations between the physical fitness levels and body composition. Specifically, elevated levels of lower body strength correlate with enhanced agility and dynamic balance, as evidenced by reduced completion times in the timed up-and-go test, a recognized marker of fall risk among older adults. Additionally, noteworthy findings highlight the moderating role of BMI, in which greater muscle strength indicates a lower risk of fall, independent of BMI. However, lower muscle strength indicates a greater risk of falls and increases with greater BMI. Muscle strength continues to be an important indicator of health since its maintenance can be associated with independence.

Data availability statement: The data used in this study were obtained under a specific license exclusively for the purposes of this study. The data supporting the findings of this study are not publicly available, but can be requested and accessed upon reasonable inquiry, subject to permission from the Research Center in Sports, Health and Human Development, and the Municipal Council of Leiria.

Conflicts of Interest: The authors declare no conflict of interest.

Ethical standards: This study received ethical approval from the Ethics Committee of the Polytechnic University of Leiria ensuring that all research procedures adhered to the ethical guidelines established by the institutional and national research committee. The study was conducted in accordance with the principles outlined in the 1964 Helsinki Declaration and its subsequent revisions or comparable ethical standards.

Funding note: This work was funded by National Funds through FCT - Foundation for Science and Technology under the project UIDB/04045/2020 (https://doi.org/10.54499/UIDB/04045/2020). Open access funding provided by FCT|FCCN (b-on).

References

1. Fragala MS, Cadore EL, Dorgo S, et al. Resistance Training for Older Adults: Position Statement From the National Strength and Conditioning Association. J Strength Cond Res. 2019;33(8):2019-2052. doi:10.1519/JSC.0000000000003230
2. Larsson L, Degens H, Li M, et al. Sarcopenia: Aging-Related Loss of Muscle Mass and Function. Physiol Rev. 2019;99(1):427-511. doi:10.1152/physrev.00061.2017
3. Izquierdo M, Merchant RA, Morley JE, et al. International Exercise Recommendations in Older Adults (ICFSR): Expert Consensus Guidelines. J Nutr Health Aging. 2021;25(7):824-853. doi:10.1007/s12603-021-1665-8
4. Salari N, Darvishi N, Ahmadipanah M, Shohaimi S, Mohammadi M. Global prevalence of falls in the older adults: a comprehensive systematic review and meta-analysis. J Orthop Surg. 2022;17(1):334. doi:10.1186/s13018-022-03222-1
5. Li Y, Hou L, Zhao H, Xie R, Yi Y, Ding X. Risk factors for falls among community-dwelling older adults: A systematic review and meta-analysis. Front Med. 2023;9:1019094. doi:10.3389/fmed.2022.1019094
6. da Silva Costa AA, Moraes R, Hortobágyi T, Sawers A. Older adults reduce the complexity and efficiency of neuromuscular control to preserve walking balance. Exp Gerontol. 2020;140:111050. doi:10.1016/j.exger.2020.111050
7. Rodrigues F, Domingos C, Monteiro D, Morouço P. A Review on Aging, Sarcopenia, Falls, and Resistance Training in Community-Dwelling Older Adults. Int J Environ Res Public Health. 2022;19(2):874. doi:10.3390/ijerph19020874
8. Waters DL, Qualls CR, Cesari M, Rolland Y, Vlietstra L, Vellas B. Relationship of Incident Falls with Balance Deficits and Body Composition in Male and Female Community-Dwelling Elders. J Nutr Health Aging. 2019;23(1):9-13. doi:10.1007/s12603-018-1087-4
9. García-Hermoso A, Ramirez-Vélez R, Sáez de Asteasu ML, et al. Safety and Effectiveness of Long-Term Exercise Interventions in Older Adults: A Systematic Review and Meta-analysis of Randomized Controlled Trials. Sports Med. 2020;50(6):1095-1106. doi:10.1007/s40279-020-01259-y
10. Ramírez-Vélez R, Martínez-Velilla N, Correa-Rodríguez M, et al. Lipidomic signatures from physically frail and robust older adults at hospital admission. GeroScience. 2022;44(3):1677-1688. doi:10.1007/s11357-021-00511-1
11. Tsukasaki K, Matsui Y, Arai H, et al. Association of Muscle Strength and Gait Speed with Cross-Sectional Muscle Area Determined by Mid-Thigh Computed Tomography - A Comparison with Skeletal Muscle Mass Measured by Dual-Energy X-Ray Absorptiometry. J Frailty Aging. 2020;9(2):82-89. doi:10.14283/jfa.2020.16
12. Izquierdo M, Duque G, Morley JE. Physical activity guidelines for older people: knowledge gaps and future directions. Lancet Healthy Longev. 2021;2(6):e380-e383. doi:10.1016/S2666-7568(21)00079-9
13. Moored KD, Qiao YS, Rosso AL, et al. Dual Roles of Cardiorespiratory Fitness and Fatigability in the Life-Space Mobility of Older Adults: The Study of Muscle, Mobility and Aging (SOMMA). J Gerontol A Biol Sci Med Sci. 2023;78(8):1392-1401. doi:10.1093/gerona/glad037
14. Emilio EJML, Hita-Contreras F, Jiménez-Lara PM, Latorre-Román P, Martínez-Amat A. The Association of Flexibility, Balance, and Lumbar Strength with Balance Ability: Risk of Falls in Older Adults. J Sports Sci Med. 2014;13(2):349-357.
15. Rodrigues F, Amaro N, Matos R, Mendes D, Monteiro D, Morouço P. The impact of an exercise intervention using low-cost equipment on functional fitness in the community-dwelling older adults: A pilot study. Front Physiol. 2022;13. Accessed June 5, 2023. https://www.frontiersin.org/articles/10.3389/fphys.2022.1039131
16. Zhang K, Ju Y, Yang D, Cao M, Liang H, Leng J. Correlation analysis between body composition, serological indices and the risk of falls, and the receiver operating characteristic curve of different indexes for the risk of falls in older individuals. Front Med. 2023;10:1228821. doi:10.3389/fmed.2023.1228821
17. Fritz MS, MacKinnon DP. Required Sample Size to Detect the Mediated Effect. Psychol Sci. 2007;18(3):233-239. doi:10.1111/j.1467-9280.2007.01882.x
18. Hayes AF. Introduction to Mediation, Moderation, and Conditional Process Analysis: A Regression-Based Approach. 2nd ed. New York, NY: The Guilford Press; 2018.
19. Ma Z wei, Zeng W nan. A Multiple Mediator Model: Power Analysis Based on Monte Carlo Simulation. Am J Appl Psychol. 2014;3(3):72-79. doi:10.11648/j.ajap.20140303.15
20. Faul F, Erdfelder E, Buchner A, Lang AG. Statistical power analyses using G*Power 3.1: Tests for correlation and regression analyses. Behav Res Methods. 2009;41(4):1149-1160. doi:10.3758/BRM.41.4.1149
21. Rikli RE, Jones CJ. Development and Validation of Criterion-Referenced Clinically Relevant Fitness Standards for Maintaining Physical Independence in Later Years. The Gerontologist. 2013;53(2):255-267. doi:10.1093/geront/gns071
22. Winter JE, MacInnis RJ, Wattanapenpaiboon N, Nowson CA. BMI and all-cause mortality in older adults: a meta-analysis. Am J Clin Nutr. 2014;99(4):875-890. doi:10.3945/ajcn.113.068122
23. Trevisan C, Crippa A, Ek S, et al. Nutritional Status, Body Mass Index, and the Risk of Falls in Community-Dwelling Older Adults: A Systematic Review and Meta-Analysis. J Am Med Dir Assoc. 2019;20(5):569-582.e7. doi:10.1016/j.jamda.2018.10.027

How to cite this article: F. Rodrigues, M. Izquierdo, D. Monteiro, et al. Muscle Strength Matters Most for Risk of Falling Apart from Body Mass Index in Older Adults: A Mediated-Moderation Analysis. J Frailty Aging 2024;13(4)427-431; http://dx.doi.org/10.14283/jfa.2024.68