International Journal of EXERCISE SCIENCE

Original Research

The Association Between Handgrip Strength Asymmetry Severity and Future Morbidity Accumulation: Results from the Health and Retirement Study

LUKUS A. KLAWITTER†, KYLE S. COLLINS†, DAWSON RINGHOFER*, BRYAN K. CHRISTENSEN‡, and RYAN MCGRATH‡

Department of Health, Nutrition, and Exercise Sciences, North Dakota State University, Fargo, ND, USA

*Denotes undergraduate student author, †Denotes graduate student author, ‡Denotes professional author

ABSTRACT

International Journal of Exercise Science 15(3): 1133-1141, 2022. Analyzing the severity of handgrip strength (HGS) asymmetry in aging populations may help to screen for morbidities and add utility to handgrip dynamometer testing. Our study sought to determine the relationships between HGS asymmetry severity and future accumulating morbidities in older Americans. Secondary analyses from the 2006-2016 waves of the Health and Retirement Study included 18,506 adults ≥ 50 years old. The highest recorded HGS values from each hand were used to calculate HGS asymmetry ratio (non-dominant HGS/dominant HGS). If the HGS asymmetry ratio < 1.0, it was inversed to make all asymmetry ratios ≥ 1.0. Participants were categorized into groups based on the severity of their HGS asymmetry ratio: 1) 0.0% - 10.0%, 2) 10.1% - 20.0%, 3) 20.1% - 30.0%, and 4) > 30.0%. Healthcare provider-diagnosed morbidities (hypertension, diabetes, cancer, chronic lung disease, cardiovascular disease, stroke, arthritis, and psychiatric problems) were self-reported. Covariate-adjusted ordinal generalized estimating equations evaluated the relationships between HGS asymmetry severity on future accumulating morbidities. Results showed 8,936 (48.3%) participants had HGS asymmetry 0.0%-10.0%, 6,105 (33.0%) participants had HGS asymmetry 10.1%-20.0%, 2,411 (13.0%) participants had HGS asymmetry 20.1%-30.0%, and 1,054 (5.7%) participants had HGS asymmetry > 30.0%. Overall, every 10% increase in HGS asymmetry was associated with a 1.17 (CI: 1.05, 1.32) greater odds of future morbidity accumulation. Additionally, asymmetry between 10.1% - 20.0%, 20.1% - 30.0%, and > 30.0% was associated with a 1.10 (CI: 1.05, 1.15), 1.11 (CI: 1.04, 1.18), and 1.20 (CI: 1.09, 1.33) greater odds for morbidity accumulation during aging. These findings suggest that severe functional asymmetries may elevate the odds for accumulating morbidities.

KEY WORDS: Environment, public health, muscular atrophy, multimorbidity, health status

INTRODUCTION

The older adult population is growing rapidly, and by the year 2050 nearly one fifth of Americans will be 65 years and older (22). Aging is closely linked with losses in muscle mass (sarcopenia), strength, and physical function (21). A gradual decline in muscle mass begins after about the age of 30 years and accelerates into older adulthood (7). While the loss of muscle mass and strength are related, reductions in muscular strength contribute directly to functional deterioration (22), and the rate of decline in muscle strength can exceed losses in muscle size (4, 7). Low muscular strength is a risk factor for several age-related morbidities (28). Concurrent morbidities can have risks with managing multiple diseases and related medications, as well as increasing the burden of a poorer quality of life (11). This underscores the importance of implementing strategies to maintain healthy muscle tissue during aging (7, 23).

HGS is a convenient and reliable assessment of strength capacity that is likewise associated with age-related morbidities when HGS is low or declines during aging (13). Strength asymmetries between limbs, as measured by HGS asymmetry, may represent another form of muscle impairment that is linked with morbidity (17). Low HGS (or weakness), which can differentially be determined with a multitude of HGS cut-points (16), is robustly associated with several clinically relevant health outcomes (1). For example, low HGS is strongly related to the presence of chronic diseases during aging (13, 20). While HGS is measured as the greatest isometric grip force regardless of hand, assessing the strength for each hand may add more utility to the measure (13). Strength asymmetries between hands can be characterized as HGS asymmetry, which has been shown to be associated with falls (17), functional disability (19), and early all-cause mortality (18). HGS asymmetry can be quantified as the strongest HGS on one hand over the strongest HGS on the other hand. Recently, HGS asymmetry and weakness has been shown to be associated with greater odds for a worsening morbidity status during aging (13).

Previous studies have shown that HGS asymmetry is associated with morbidity (12), though these studies used a 10% asymmetry cut-point (18). Examining asymmetry severity in older populations may help to better determine morbidity accumulation risk and provide insights for meaningful asymmetry thresholds. A deeper understanding of HGS asymmetry may also help in the examination of potential neuromuscular issues between dominant and non-dominant limbs. Further assessment of the severity of HGS asymmetry and associations with morbidity accumulation may prove useful for clinicians screening their patients for health status. Therefore, the purpose of this study was to determine the relationships between HGS asymmetry severity and future morbidity accumulation in aging Americans. It was hypothesized that severer asymmetries would increase the odds of morbidity accumulation.

METHODS

Participants

This investigation performed a secondary analysis of data from the 2006-2016 waves of the Health and Retirement Study (HRS) (9). Individual HRS data files were joined to the RAND HRS dataset as needed. The HRS provides publicly available data related to health and economic factors for a national sample of Americans aged at least 50-years. A longitudinal-panel experimental design was used by the HRS, and after entering the study, HRS participants complete core interviews biennially until their death (6). To help maintain widespread sampling for this ongoing population-based study, new cohorts of participants join the HRS. Additional details about the HRS are available elsewhere (25).

Beginning in the 2006 wave, more detailed physical measures (e.g., HGS) were collected from HRS participants (24). As such, the HRS implemented a mixed-mode design for the collection of these physical measures, wherein half of the sample alternates completion of the physical measures at each wave alongside core interviews. The analytic sample for our study included 18,847 adults aged at least 50-years who had at least one wave of HGS measured bilaterally with information regarding hand dominance and at least one follow-up wave of morbidity status examined during the 2006-2016 study period. Participant response rates for the HRS have been > 80% (26). The University's Behavioral Sciences Committee Institutional Review Board approved HRS study protocols and participants provided written informed consent.

Protocol

Morbidity accumulation: Respondents reported if a healthcare provider (i.e., doctor) had ever diagnosed them with the following conditions: hypertension, diabetes, cancer, chronic lung disease, cardiovascular disease, stroke, arthritis, and psychiatric problems. Given that HGS is linked to each of these health conditions, and that overlap may exist between conditions, we included morbidity accumulation in our analyses as an ordinal variable.

Handgrip strength asymmetry: A Smedley spring-type handgrip dynamometer (Scandidact; Odder, Denmark) was used to measure HGS. Persons that had a surgical procedure in the last six months, or swelling, inflammation, severe pain, or an injury to both hands within the month before the physical measures interview did not engage in HGS testing. Trained interviewers explained HGS procedures and fit the dynamometer to the hand size of participants before completing a practice trial. Participants were advised to stand with their arm at the side and elbow flexed at 90-degreees while holding the dynamometer. Hand dominance was reported before HGS testing, and beginning on the non-dominant hand, participants squeezed the dynamometer with maximal effort twice on each hand, alternating between hands. Persons that were unable to stand or position their arm while holding the dynamometer could be seated and use a supporting object during HGS testing (2).

The highest recorded HGS values from the non-dominant and dominant hands were used for the calculation of HGS asymmetry ratio (non-dominant HGS (kilograms)/dominant HGS (kilograms)). Those with asymmetry ratios of < 1.0 had their ratio inverted to make all ratios ≥ 1.0. Participants were thereafter categorized into HGS asymmetry groups based on the severity of their inverted HGS asymmetry ratio: 1) 0.0% - 10.0%, 2) 10.1% - 20.0%, 3) 20.1% - 30.0%, and 4) > 30.0% (17).

Covariates: Age, sex, race, educational achievement (not a high school graduate, at lease a high school graduate or equivalency exam passed), cigarette smoking status (current smoker, previous smoker, never smoked), standing height, and body mass were self-reported. Body mass index was calculated from standing height and body mass, and persons with a body mass index ≥ 30 kilograms per meters-squared were considered obese (10). The single highest HGS value recorded regardless of hand dominance was included as maximal HGS.

Ability to complete six basic self-care tasks were reported: dressing, eating, bed transferring, toileting, bathing, and walking across a small room. Persons suggesting difficulty or an inability to complete any task were considered as having an activities of daily living limitation. Participants that indicated engaging in moderate-to-vigorous physical activity participation at least once a week were classified as participating in moderate-to-vigorous physical activity (5). Participants also reported their perceived health with a single item measure ("excellent", "very good", or "good"; "fair" or "poor").

Social engagement was examined by three items at each wave: 1) volunteer activities at religious, educational, health-related, or other organizations for at least an hour in the past year, 2) at least weekly contact with parents or in-laws, and 3) current employment status. Scores ranged from 0-3, with higher scores suggesting greater social engagement (8). The 8-item Center for Epidemiologic Studies Depression scale was used to determine depressive symptomology (27). Respondents indicated if they experienced any negative or positive emotions during the week prior to the interview date. Scores ranged from 0-8 with higher scores signifying more depressive symptoms. Persons with scores ≥ 3 were considered as depressed. Cognitive functioning was evaluated with the Telephone Interview of Cognitive Status, a well-validated and frequently used screening tool from the Mini-Mental State Examination that was designed for population-based studies such as the HRS (24). A 27-point composite scale was used for participates aged under 65-years, and individuals with scores < 12 were considered as having a cognitive impairment (3). A 35-point scale was used for participants aged ≥ 65-years that included three additional assessment items, and persons with scores < 11 were classified as having a cognitive impairment (14). Covariate information was recorded for each wave and those with missing or outlier covariates (i.e., asymmetry ratio > 112) were excluded (n = 341).

Statistical Analysis

All analyses were conducted with SAS 9.4 (SAS Institute; Cary, NC). A power analysis was not applicable for this investigation because our sample size is large. Each participant entered our study when HGS was first measured. Morbidity status and other covariates were evaluated at each wave wherein HGS was collected. Our outcome was accumulating morbidities at the next available wave. Time to follow-up between waves whereby HGS was examined was adjusted for in the analyses. An outline for when participants first entered our study and when morbidity was subsequently examined is described elsewhere (13).

The means and 95% confidence intervals (CI) by HGS asymmetry group (0.0%-10.0%, 10.1% - 20.0%, 20.1% - 30.0%, > 30.0%) were presented to make comparisons for the baseline descriptive characteristics of the participants. Separate ordinal generalized estimating equations evaluated the associations between 1) HGS asymmetry 10.1% - 20.0%, 2) HGS asymmetry 20.1% - 30.0%, 3) HGS asymmetry > 30.0% and future accumulating morbidities (reference group: HGS asymmetry 0.0% - 10.0%). Moreover, another ordinal generalized estimation equation examined the association between continuous HGS asymmetry ratio and future accumulating morbidities. Each model was first run as crude where only follow-up years were adjusted. Thereafter, each model was adjusted for hand dominance, maximal HGS, activities of daily living, obesity status, sex, race, age, cigarette smoking status, social engagement, self-rated health, depression status, moderate-to-vigorous physical activity participation, cognitive functioning, and educational achievement. Repeated measures were accounted for in all of the ordinal generalized estimating equations with a multinomial distribution, and the outcome for the next wave participated used. Results from the fully-adjusted ordinal models were considered our principal findings. An alpha level of 0.05 was used for all analyses.

RESULTS

Table 1 presents the baseline descriptive characteristics of the 18,506 participants. There were 8,936 (48.3%) participants with HGS asymmetry 0.0% - 10.0%, 6,105 (33.0%) participants with HGS asymmetry 10.1%-20.0%, 2,411 (13.0%) participants with HGS asymmetry 20.1%-30.0%, and 1,054 (5.7%) participants with HGS asymmetry > 30.0%. Interestingly, as HGS asymmetry became more severe, maximal HGS decreased: 33.3 (CI: 33.1, 33.6) kilograms for HGS asymmetry 0.0%-10.0%, 32.7 (CI: 32.4, 33.0) kilograms for HGS asymmetry 10.1%-20.0%, 31.4 (CI: 31.0, 31.9) kilograms for HGS asymmetry 20.1%-30.0%, and 28.7 (CI: 28.0, 29.5) kilograms for HGS asymmetry > 30.0%. Likewise, persons with HGS asymmetry at > 30.0% had more reported morbidities at the next wave (2.5 (CI: 2.4, 2.6)) compared to those with HGS asymmetry 0.0%-10.0% (2.0 (CI: 1.9, 2.0)).

Table 1. Baseline Descriptive Characteristics of the Participants.

	HGS Asymmetry 0.0% - 10.0% (*n* = 8,936)	**HGS Asymmetry 10.1% - 20.0% (*n* = 6,105)**	**HGS Asymmetry 20.1% - 30.0% (*n* = 2,411)**	**HGS Asymmetry > 30.0% (*n* = 1,054)**
HGS (kilograms)	33.3 (33.1, 33.6)	32.7 (32.4, 33.0)	31.4 (31.0, 31.9)	28.7 (28.0, 29.5)
Age (years)	64.4 (64.2, 64.6)	64.9 (64.7, 65.2)	65.9 (65.8, 66.3)	67.3 (66.6, 67.9)
Older Adult (%)	45.8 (44.7, 46.8)	47.6 (46.4, 48.9)	51.7 (49.7, 53.7)	53.2 (50.2, 56.2)
White Race (%)	75.9 (74.9, 76.7)	74.0 (72.9, 75.1)	72.2 (70.5, 74.0)	68.6 (65.8, 71.4)
Female (%)	53.3 (52.3, 54.3)	59.9 (58.6, 61.1)	64.1 (62.2, 66.0)	65.6 (62.7, 68.5)
Right Hand Dominant (%)	89.4 (88.7, 90.0)	93.2 (92.5, 93.8)	93.4 (92.5, 94.4)	90.3 (88.5, 92.1)
BMI (kilograms per meters-squared)	28.6 (28.5, 28.7)	28.6 (28.5, 28.8)	28.9 (28.7, 29.2)	29.4 (28.9, 29.8)
Obese (%)	34.8 (33.7, 35.7)	34.5 (33.3, 35.6)	36.6 (34.7, 38.5)	38.6 (35.6, 41.5)
ADL Limitation (%)	12.3 (11.5, 12.9)	13.5 (12.6, 14.3)	15.4 (13.9, 16.8)	30.4 (27.6, 33.2)
Cognitive Impairment (%)	10.6 (10.0, 11.2)	9.8 (9.1, 10.6)	10.2 (9.0, 11.4)	13.7 (11.6, 15.8)
Depression (%)	19.9 (19.0, 20.6)	20.2 (19.2, 21.2)	21.0 (19.4, 22.7)	33.0 (30.1, 35.8)
Never Smoked Cigarettes (%)	42.7 (41.7, 43.8)	44.1 (42.9, 45.4)	44.1 (42.1, 46.1)	43.9 (40.9, 46.9)
MVPA Participation (%)	61.5 (60.5, 62.6)	58.8 (57.6, 60.0)	58.0 (56.0, 60.0)	50.0 (47.0, 53.1)
Not a High School Graduate (%)	17.5 (16.7, 18.3)	18.1 (17.2, 19.1)	19.6 (18.0, 21.2)	23.6 (21.0, 26.1)
Social Engagement	1.6 (1.5, 1.6)	1.4 (1.4, 1.5)	1.4 (1.3, 1.4)	1.1 (1.1, 1.2)
Fair or Poor Self-Rated Health (%)	24.2 (23.3, 25.1)	25.5 (24.4, 26.6)	28.9 (27.1, 30.7)	40.8 (37.8, 43.7)
Years to Follow-Up	2.1 (2.0, 2.1)	2.1 (2.0, 2.1)	2.1 (2.0, 2.1)	2.1 (2.0, 2.1)
Reported Morbidities at Present Wave	1.8 (1.7, 1.8)	1.8 (1.8, 1.9)	1.9 (1.9, 2.0)	2.3 (2.2, 2.4)
Reported Morbidities at Next Wave	2.0 (1.9, 2.0)	2.0 (2.0, 2.1)	2.1 (2.1, 2.2)	2.5 (2.4, 2.6)

Note: Results are presented in mean or percentage (95% confidence interval). HGS = handgrip strength; BMI = body mass index; ADL = activities of daily living; MVPA = moderate-to-vigorous physical activity.

The results for the associations between the HGS asymmetry groups and future morbidity accumulation are shown in Table 2. Relative to participants with HGS asymmetry 0.0% - 10.0%, persons in the other HGS asymmetry groups had greater odds for future morbidity accumulation. The 10.1%-20.0% group had 1.10 (CI: 1.05, 1.15; $p < 0.05$) greater odds, the 20.1%-30.0% had 1.11 (CI: 1.04, 1.18; $p < 0.05$) greater odds, and the > 30.0% had 1.20 (CI: 1.09, 1.33; $p < 0.05$) greater odds for future morbidity accumulation. Table 3 reveals the results for the associations between continuous HGS asymmetry ratio and future morbidity accumulation. Every 0.10 (i.e., 10%) increase in HGS asymmetry ratio was associated with 1.17 (CI: 1.05, 1.32; $p < 0.05$) greater odds for future morbidity accumulation.

Table 2. Results for the Associations Between the Handgrip Strength Asymmetry Categories and Future Morbidity Accumulation.

	Crude Models		Fully-Adjusted Models	
	Odds Ratio	**95% Confidence Interval**	**Odds Ratio**	**95% Confidence Interval**
HGS Asymmetry 10.1%-20.0%‡	1.08	1.03, 1.13	1.10	1.05, 1.15
HGS Asymmetry 20.1%-30.0%‡	1.23	1.15, 1.31	1.11	1.04, 1.18
HGS Asymmetry >30.0%‡	1.84	1.67, 2.02	1.20	1.09, 1.33

‡Reference = HGS asymmetry 0.0%-10.0%.
Note: All results are $p < 0.05$. Crude models were adjusted for follow-up years. Fully-adjusted models were adjusted for hand dominance, handgrip strength, activities of daily living limitations, sex, race, age, obesity status, cigarette smoking status, social engagement, self-rated health, depressive symptomology, moderate-to-vigorous physical activity participation, cognitive functioning, educational achievement, and follow-up years.

Table 3. Results for the Associations Between Continuous Handgrip Strength Asymmetry Ratio and Future Morbidity Accumulation.

	Crude Model		Fully-Adjusted Model	
	Odds Ratio	**95% Confidence Interval**	**Odds Ratio**	**95% Confidence Interval**
HGS Asymmetry Ratio (Every 0.10 Increase)	1.93	1.71, 2.18	1.17	1.05, 1.32

Note: All results are $p < 0.05$. Crude models were adjusted for follow-up years. Fully-adjusted models were adjusted for hand dominance, handgrip strength, activities of daily living limitations, sex, race, age, obesity status, cigarette smoking status, social engagement, self-rated health, depressive symptomology, moderate-to-vigorous physical activity participation, cognitive functioning, educational achievement, and follow-up years.

DISCUSSION

This investigation showed that HGS asymmetry is associated with morbidity accumulation during aging, and as HGS asymmetry becomes more severe the odds for morbidity accumulation increase. Specifically, every 10% increase in HGS asymmetry was associated with a 17% greater odds of morbidity accumulation. Additionally, asymmetry between 10.1%-20.0%, 20.1%-30.0%, and > 30.0% was associated with 10%, 11%, and 20% greater odds for morbidity accumulation during aging, respectfully. These findings suggest that functional asymmetries may represent another form of muscle dysfunction that is linked to age-related diseases.

Similar studies have identified asymmetry to be associated with morbidity in older adults (15). Although our current findings demonstrate that greater the HGS asymmetry the greater risk of morbidity, previous research has combined HGS asymmetry and weakness to further increase the risk of developing a morbidity with age (13). For example, HGS asymmetry combined with muscle weakness is associated with functional disabilities (2), and increased odds of morbidity by 46% in older Americans (13). Comparably, a study utilizing data from the National Health and Nutrition Examination Survey on Americans aged at least 40 years old determined about 46% of adults with multimorbidity also had HGS asymmetry (12).

HGS asymmetry measured via dynamometers may provide additional information for muscle function than HGS alone as HGS is only a single measure of muscle strength capacity. Therefore, HGS asymmetry should be examined alongside maximal strength to determine risk for multimorbidity in older Americans. Our findings align with Klawitter et al., (12) wherein HGS asymmetry was linked to chronic diseases in older American adults. Additionally, HGS asymmetry may help in screening muscle function impairments that are linked to age-related diseases.

Some limitations should be acknowledged. Persons included in our study must have had at least two waves of data to be included, and individuals that were lost to follow-up after their baseline assessments may have had declining health. Most of our sample was White and right hand dominant, limiting the generalizability of our findings. We were also limited to the morbidities included in the RAND HRS, and some morbidities may have been more strongly linked to muscle impairments than others. Morbidity accumulation was treated as an ordinal variable because the morbidities included in our analyses could be related to other diseases that may not be observed with a dichotomous response variable. Direction of asymmetry (dominant, non-dominant) was not examined because of sampling.

This study found that as HGS asymmetry became severer, the odds for future accumulating morbidities became greater. Functional asymmetries between limbs may represent another form of muscle impairment that is associated with age-related disease. We recommend that HGS asymmetry examined alongside strength capacity in HGS protocols. Advancing our assessments of muscle function will help healthcare providers and exercise professionals in the early identification of muscle impairments for proper referrals and interventions. Such referrals and interventions will, in turn, help our rapidly growing older American population live longer, healthier lives.

REFERENCES

1. Alley DE, Shardell MD, Peters KW, McLean RR, Dam TTL, Kenny AM, et al. Grip strength cutpoints for the identification of clinically relevant weakness. J Gerontol A Biol Sci Med Sci 69(5): 559–566, 2014.

2. Crimmins EM, Guyer H, Langa KM, Ofstedal MB, Wallace RB, Weir DR. Documentation of physical measures, anthropometrics, and blood pressure in the Health and Retirement Study. HRS Documentation Report 1–17, 2008.

3. Crimmins EM, Kim JK, Langa KM, Weir DR. Assessment of cognition using surveys and neuropsychological assessment: the health and retirement study and the aging, demographics, and memory study. J Gerontol B Psychol Sci Soc Sci 66(Suppl 1): i162-i171, 2011.

4. Delmonico MJ, Harris TB, Visser M, Park SW, Conroy MB, Velasquez-Mieyer P, et al. Longitudinal study of muscle strength, quality, and adipose tissue infiltration. Am J Clin Nutr 90: 1579–1585, 2009.

5. Feng X, Croteau K, Kolt GS, Astell-Burt T. Does retirement mean more physical activity? A longitudinal study. BMC Public Health 16: 605, 2016.

6. Fisher GG, Ryan LH. Overview of the health and retirement study and introduction to the special issue. Work Aging Retire 4(1): 1–9, 2018.

7. Fragala MS, Cadore EL, Dorgo S, Izquierdo M, Kraemer WJ, Peterson MD, et al. Resistance training for older adults: Position statement from the National Strength and Conditioning Association. J Strength Cond Res 33: 2019–2052, 2019.

8. Howrey B, Avila JC, Downer B, Wong R. Social engagement and cognitive function of older adults in Mexico and the United States: How universal is the interdependence in couples? J Gerontol B Psychol Sci Soc Sci 76: S41–S50, 2021.

9. HRS Data Book | Health and Retirement Study. US Department of Health and Human Services. Available from: https://hrs.isr.umich.edu/about/data-book-2006; 2017.

10. Jensen MD, Ryan DH, Apovian CM, Ard JD, Comuzzie AG, Donato KA, et al. 2013 AHA/ACC/TOS guideline for the management of overweight and obesity in adults: A report of the American College of Cardiology/American Heart Association task force on practice guidelines and the obesity society. Circulation. 129(25 Suppl 2): S102-S138, 2014.

11. Johnston MC, Crilly M, Black C, Prescott GJ, Mercer SW. Defining and measuring multimorbidity: A systematic review of systematic reviews. Eur J Public Health 29(1): 182–189, 2019.

12. Klawitter L, Bradley A, Hackney KJ, Tomkinson GR, Christensen BK, Kraemer WJ, et al. The associations between asymmetric handgrip strength and chronic disease status in American adults: Results from the national health and nutrition examination survey. J Funct Morphol Kinesiol 6(4): 79, 2021.

13. Klawitter L, Vincent B, Choi B, Smith J, Hammer K, Jurivich D, et al. Handgrip strength asymmetry and weakness are associated with future morbidity accumulation in Americans. J Strength Cond Res 36(1): 106-112, 2022.

14. Langa KM, Larson EB, Karlawish JH, Cutler DM, Kabeto MU, Kim SY, et al. Trends in the prevalence and mortality of cognitive impairment in the United States: Is there evidence of a compression of cognitive morbidity? Alzheimer's Dement 4(2): 134–144, 2008.

15. Liu M, Liu S, Sun S, Tian H, Li S, Wu Y. Sex Differences in the associations of handgrip strength and asymmetry with multimorbidity: Evidence from the English longitudinal study of ageing. J Am Med Dir Assoc 23(3): 493-498.e1, 2022.

16. McGrath R, Cawthon PM, Clark BC, Fielding RA, Lang JJ, Tomkinson GR. Recommendations for reducing heterogeneity in handgrip strength protocols. J Frailty Aging 11(2): 143-150, 2022.

17. McGrath R, Clark BC, Cesari M, Johnson C, Jurivich DA. Handgrip strength asymmetry is associated with future falls in older Americans. Aging Clin Exp Res 33(9): 2461–2469, 2021.

18. McGrath R, Tomkinson GR, LaRoche DP, Vincent BM, Bond CW, Hackney KJ. Handgrip strength asymmetry and weakness may accelerate time to mortality in aging Americans. J Am Med Dir Assoc 21: 2003-2007.e1, 2020.

19. McGrath R, Vincent BM, Jurivich DA, Hackney KJ, Tomkinson GR, Dahl LJ, et al. Handgrip strength asymmetry and weakness together are associated with functional disability in aging Americans. J Gerontol A Biol Sci Med Sci 76: 291–296, 2021.

20. McGrath RP, Kraemer WJ, Al Snih S, Peterson MD. Handgrip strength and health in aging adults. Sports Med 48: 1993–2000, 2018.

21. Melov S, Tamopolsky MA, Bechman K, Felkey K, Hubbard A. Resistance exercise reverses aging in human skeletal muscle. PLoS One 2: e465, 2007.

22. Ortman JM, Velkoff VA, Hogan H. An aging nation: The older population in the United States population estimates and projections current population reports. US Census Bur. Available from: www.census.gove/content/dam/Census/library/publications/2014/demo/p25-1140.pdf; 2014.

23. Papa EV, Dong X, Hassan M. Resistance training for activity limitations in older adults with skeletal muscle function deficits: A systematic review. Clin Interv Aging 12: 955–961, 2017.

24. Plassman BL, Newman TT, Welsh KA, Helms M, Breitner JCS. Properties of the telephone interview for cognitive status: Application in epidemiological and longitudinal studies. Neuropsychiatry Neuropsychol Behav Neurol 7: 235–241, 1994.

25. RAND HRS Data File (v.N) | RAND. Available from: http://www.rand.org/labor/aging/dataprod/hrs-data.html; nd.

26. Sonnega A, Faul JD, Ofstedal MB, Langa KM, Phillips JWR, Weir DR. Cohort profile: The health and retirement study (HRS). Int J Epidemiol 43: 576–585, 2014.

27. Turvey CL, Wallace RB, Herzog R. A revised CES-D measure of depressive symptoms and a DSM-based measure of major depressive episodes in the elderly. Int Psychogeriatr 11: 139–148, 1999.

28. Volaklis KA, Halle M, Meisinger C. Muscular strength as a strong predictor of mortality: A narrative review. Eur J Intern Med 26: 303–310, 2015.