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Handgrip Strength Asymmetry and Weakness Together are Associated with Functional Disability in Aging Americans

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ABSTRACT

Background: Evaluating handgrip strength (HGS) asymmetry may help improve the prognostic value of HGS. This study sought to determine the associations of HGS asymmetry and weakness on future activities of daily living (ADL) disability in a national sample of aging Americans.

Methods: The analytic sample included 18,468 Americans aged 50-years and older from the 2006-2016 waves of the Health and Retirement Study. A handgrip dynamometer measured HGS. Those with HGS >10% stronger on either hand were considered as having any HGS asymmetry. Persons with HGS >10% stronger on their dominant or non-dominant hand were considered as having dominant or non-dominant HGS asymmetry, respectively. Men with HGS <26-kilograms and women with HGS <16-kilograms were considered weak. ADLs were self-reported. Generalized estimating equations analyzed the associations of each HGS asymmetry and weakness group for future ADL disability.

Results: Relative to those with symmetric HGS and no weakness, each HGS asymmetry and weakness group had increased odds for future ADL disability: 1.11 (95% confidence interval (CI): 1.02-1.20) for any HGS asymmetry alone, 1.42 (CI: 1.16-1.74) for weakness alone, and 1.81 (CI: 1.52-2.16) for both any HGS asymmetry and weakness. Further, most weakness and HGS asymmetry dominance groups had increased odds for future ADL disability: 1.30 (CI: 1.13-1.50) for non-dominant HGS asymmetry only, 1.42 (CI: 1.16-1.74) for weakness only, 1.72 (CI: 1.29-2.29) for both weakness and non-dominant HGS asymmetry, and 1.86 (CI: 1.52-2.28) for both weakness and dominant HGS asymmetry.

Conclusions: HGS asymmetry and weakness together may increase the predictive utility of handgrip dynamometers.

Keywords: Biomarkers; Disablement Process; Epidemiology; Functional Performance

INTRODUCTION

Handgrip strength (HGS) is a convenient assessment of overall strength capacity that is associated with a wide range of health conditions (1). Weakness, as measured by HGS, is also part of decision algorithms for determining sarcopenia and dynapenia (2, 3), and is included in validated frailty assessments (4). Similarly, muscle strength is a sub-domain of the intrinsic capacity construct (5). As such, measures of HGS are recommended for routine health assessments and considered clinically-viable for determining weakness (6). Given the rich health information that HGS provides, measures of HGS are a powerful biomarker of aging and vital sign of health status (7).

Guidelines for standardizing HGS protocols have been provided in effort to reduce internal threats to validity, develop uniformity in assessments, and enable comparisons of results across studies that measure HGS (8). Within these guidelines, it is recommended that hand dominance be reported, measures of HGS be performed multiple times on each hand, and the highest ascertained value from these measurements be included in the analyses as maximal HGS (8). Large, population-based studies that have measured HGS, such as the Health and Retirement Study (HRS), similarly record hand dominance and values from multiple measures of HGS (9). However, it is conventional in assessments of HGS to include the highest measured value on either hand in analyses (8), with hand dominance and non-maximal HGS measurements typically being disregarded.

Although HGS may vary between each hand and depend on handiness, the "10% rule" suggests that the HGS of the dominant hand is generally 10% stronger than that of the non-dominant hand (10). Muscle strength asymmetry is linked to functional deficits in older populations. For example, asymmetric knee extension strength was associated with slower gait

speed, greater gait variability, and asymmetry at near maximal speeds in a cross-sectional study of 24 older women (11). Nakao et al. (12) showed that increased knee extensor strength asymmetry and decreased absolute knee extensor strength was associated with poorer gait ability in a cross-sectional investigation of 30 older women. Another cross-sectional study of 20 older women found that asymmetric lower limb explosive power was larger in fallers than non-fallers (13). Given that asymmetric knee extensor strength may help to predict declines in function and mobility, it is also possible that HGS asymmetry may factor into future functional deficits in aging populations.

The use of HGS and knee extensor strength together has been recommended as a better measure of muscle strength than HGS alone (14); however, Bohannon (15) suggests that HGS and knee extension strength share a common construct (maximal limb muscle strength), and HGS is preferred because it is easier to measure. Examining HGS asymmetry, in combination with maximal HGS, may improve assessments of strength capacity by introducing a new construct (strength imbalance) that helps to ameliorate the limitations of performing dynamometry at a single site on the body (3, 14). Moreover, evaluating HGS asymmetry still preserves the feasibility of HGS assessments because they are already part of HGS protocol guidelines (8). Yet, the role of HGS asymmetry in assessments of strength capacity is not well understood, nor has HGS asymmetry been shown to be associated with health conditions that are connected to low muscle strength. For example, maximal HGS is robustly associated with activities of daily living (ADL) (16, 17), and recommended for inclusion-exclusion criteria, baseline evaluations, and end-point assessments for studies evaluating muscle function (18). Thus, examining HGS asymmetry in combination with maximal HGS may help to improve assessments of strength capacity and predictions of future health conditions in older adults such

as functional disability. The purposes of this study were to determine the association of HGS asymmetry and weakness on future ADL disability in a national sample of aging Americans.

METHODS

Participants

Data from 18,810 Americans aged 50 years and over who had at least one wave of HGS measured with information about hand dominance (right, left), and at least one follow-up wave of ADL assessed in the 2006-2016 waves of the HRS were analyzed for this investigation. The HRS is a continual panel study that monitors health and economic factors in aging Americans (19). New cohorts of participants are introduced to the HRS and interviewed biennially until death (20). More details about the HRS are available elsewhere (20).

Beginning in the 2006 wave, data collections in the HRS expanded to include face-to-face interviews with physical measures such as HGS and biomarkers to provide greater depth in well-being. To minimize participant burden, the enhanced face-to-face interviews alternated completion at each wave, wherein enhanced interviews were performed on half of the sample, while the other half sample only completed the core interview, usually by telephone (19). Interview response rates for the HRS have been >80% at each wave (19). Written informed consent was provided by participants before entering the HRS and the University's Behavioral Sciences Committee Institutional Review Board approved study protocols.

Measures

Functional Disability

Ability to complete six ADLs was reported at each wave: dressing, eating, transferring in or out of bed, toileting, bathing, and walking across a small room. Those indicating difficulty or an inability to complete an ADL were considered as having an ADL disability.

Weakness

A Smedley spring type hand-grip dynamometer (Scandidact; Odder, Denmark) measured HGS. Before testing, interviewers explained HGS protocols and fit the dynamometer to the hand size of each participant before they performed a practice trial with their arm at the side and elbow flexed at a 90-degree angle. Participants responded to the question, "which is your dominant hand?" before HGS testing, and beginning on the non-dominant hand, participants squeezed the dynamometer with maximal effort. Two measures were completed on each hand, alternating between hands. Those unable to stand or position their arm while grasping the dynamometer could be seated and rest their upper arm on a supporting object during HGS testing.

Participants who had a surgical procedure in the last 6-months, or swelling, inflammation, severe pain or an injury to both hands in the previous month before the interview did not engage in testing. More details about HGS testing in the HRS are published elsewhere (9). The single greatest HGS value recorded from either hand was used for determining weakness. Men with maximal HGS <26-kilograms and women with maximal HGS <16-kilograms were considered weak (21).

Handgrip Strength Asymmetry

The highest recorded HGS values from the non-dominant and dominant hand were used to calculate HGS ratio (*non-dominant HGS (kg) / dominant HGS (kg)*). The "10% rule" guided

how we determined HGS asymmetry, wherein participants who had a HGS ratio <0.90 (i.e., 10%) were considered as having asymmetric dominant HGS, and those that had a HGS ratio >1.10 (i.e., 10%) were classified as having asymmetric non-dominant HGS (10). Moreover, those with either dominant or non-dominant HGS asymmetry were also considered as having any HGS asymmetry.

Covariates

Respondents told interviewers their age, sex, race and ethnicity, height, and body mass at each wave. Those with obesity had a body mass index ≥30-kilograms per meters-squared. Morbidities were collected by self-reported healthcare provider diagnosed hypertension, diabetes, cancer (excluding minor skin cancer), lung disease such as bronchitis or emphysema, heart condition, stroke, emotional or psychiatric problems, and arthritis or rheumatism. The number of affirmative morbid diagnoses were summed at each wave and included in the analyses. Those who engaged in moderate-to-vigorous physical activity "one a week" or more were considered as participating in moderate-to-vigorous physical activity. Respondents reported their educational achievement and were categorized as either not graduating from high school, graduating from high school or passing a high school equivalency exam and completed some college, or a college graduate or above. Respondents also indicated if they had ever smoked more than 100 cigarettes in their lifetime and if they were currently smoking cigarettes. Further, a single-item measure of self-rated health was collected at each wave, whereby respondents perceived their health as either "excellent", "very good", "good", "fair", or "poor".

Social engagement was assessed by three variables at each wave: 1) volunteer activities at religious, education, health-related, or other organizations for at least one 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 more social engagement. The continuous scores were included in the analyses (22).

Depressive symptoms were evaluated using the 8-item Center for the Epidemiologic Studies Depression scale (23). Respondents indicated if they experienced any negative or positive emotions during the week before the interview date. Scores ranged from 0-8, with higher scores suggesting more depressive symptoms. Those with scores ≥3 were considered as depressed (23).

Cognitive function was assessed in each wave by the Telephone Interview of Cognitive Status, a validated screening tool from the Mini-Mental State Examination that was designed for population-based studies (24). A 27-point composite scale was used for those under 65 years of age, and those with scores <12 were considered as having a cognitive impairment (25). A 35-point scale was used for those aged at least 65 years that used three additional assessment items, and persons with scores <11 were considered as having a cognitive impairment (26). Participants with missing or implausible covariates (HGS >100-kilograms) were excluded (n=342).

Statistical Analyses

All analyses were conducted with SAS 9.4 software (SAS Institute; Cary, NC). Participants entered our study when HGS was first measured. Current ADL disability status and other covariates were assessed at each wave in which HGS was collected. The outcome was ADL disability at the next available wave. Time to follow-up between waves in which HGS was measured and the outcome was adjusted for in the analyses. Table 1A provides a breakdown for when participants first entered our study and when ADLs were assessed. For most participants, ADL status was determined at the next wave of the HRS, such that time-to-follow up was

approximately two years. Participants were included for all waves in which they had HGS measured, and Table 1B provides this breakdown. The descriptive characteristics of the participants are presented as mean±standard deviation for continuous variables or frequency and percentage for categorical variables. Means and 95% confidence intervals (CI) for the descriptive characteristics of the participants were also presented to allow for comparisons between HGS asymmetry groups.

To examine how weakness and any HGS asymmetry interacted, separate generalized estimating equations ((GEE) PROC GENMOD) were performed for the associations with future ADL disability. The GEEs examined the associations of 1) weakness alone on future ADL disability (reference: not-weak), 2) any HGS asymmetry alone on future ADL disability (reference: symmetric HGS), 3) weakness alone (reference: not-weak) and any HGS asymmetry alone (reference: symmetric HGS) on future ADL disability, and 4) each weakness and any HGS asymmetry group (reference: both symmetric HGS and not-weak) on future ADL disability. The findings from the GEE that determined the associations of each weakness and any HGS asymmetry group on future ADL disability were considered our principal results.

To examine how weakness and HGS asymmetry dominance interacted, these GEEs were performed again after further classifying any HGS asymmetry into HGS asymmetry dominance (symmetric HGS, dominant HGS asymmetry, non-dominant HGS asymmetry). The findings from the GEE that determined the association of each weakness and HGS asymmetry dominance group on future ADL disability were considered our principal results.

As secondary analyses, separate GEEs examined the associations for each weakness and any HGS asymmetry group (reference: both symmetric HGS and not-weak) on future ADL disability stratified by 1) hand dominance (right-handed, left-handed), 2) age group (aged 50-64

years, ≥65 years), and 3) sex. Further, separate GEEs determined the associations of each weakness and HGS asymmetry dominance group (reference: not-weak and symmetric HGS) on future ADL disability stratified by 1) hand dominance, 2) age group, and 3) sex. All GEEs were adjusted for ADL disability at current wave, age, sex, race and ethnicity, hand dominance, obesity, morbidities, moderate-to-vigorous physical activity participation, educational achievement, smoking history, current smoking status, self-rated health, social engagement, depression, cognitive functioning, and time between waves. For all GEEs, repeated measures were accounted for and the outcome for the next wave participated was used. An alpha level of 0.05 was used for all analyses.

RESULTS

The descriptive characteristics of the 18,468 participants are in Table 2. Of these participants, 8,920 (48.3%) had symmetric HGS, 9,548 (51.7%) had any HGS asymmetry, 7,983 (43.2%) had asymmetric dominant HGS, and 1,565 (8.5%) had asymmetric non-dominant HGS. Figure 1 displays a histogram for the differences in HGS between the dominant and non-dominant hands. The means and 95% CI for the descriptive characteristics are shown in Appendix 1. Maximal HGS (kilograms) was significantly lower in those with asymmetric non-dominant (29.9; CI: 29.4-30.5) and dominant HGS (32.4; CI: 32.2-32.7) compared to those with symmetric HGS (33.3; CI: 33.1-33.6).

Table 3 presents the results for the lagged associations of any HGS asymmetry and weakness on future ADL disability. Relative to those who were not-weak and had symmetric HGS, each weakness and any HGS asymmetry group had increased odds for future ADL disability: 1.11 (CI: 1.02-1.20) for any HGS asymmetry only, 1.42 (CI: 1.16-1.74) for weakness only, and 1.81 (CI: 1.52-2.16) for both weak and any HGS asymmetry. These results are also

depicted in Figure 2A. The interaction for these strength capacity metrics by time was not significant (p=0.10). Appendix 2 shows the results for the lagged associations of any HGS asymmetry and weakness on future ADL disability stratified by hand dominance, age group, and sex.

The results for the lagged associations of HGS asymmetry dominance and weakness on future ADL disability are shown in Table 4. Compared to those who were not-weak and had symmetric HGS, most weakness and HGS asymmetry dominance groups had increased odds for future ADL disability: 1.30 (CI: 1.13-1.50) for non-dominant HGS asymmetry only, 1.42 (CI: 1.16-1.74) for weakness only, 1.72 (CI: 1.29-2.29) for both weakness and non-dominant HGS asymmetry, and 1.86 (CI: 1.52-2.28) for both weakness and dominant HGS asymmetry. There were null findings for the association of those with dominant HGS asymmetry only and future ADL disability (odds ratio: 1.07; CI: 0.98-1.16). Figure 2B also depicts these results. The interaction for these strength capacity metrics by time was not significant (p=0.29). Appendix 3 presents the results for the lagged associations of HGS asymmetry dominance and weakness on future ADL disability stratified by hand dominance, age group, and sex.

DISCUSSION

The principal results of this investigation revealed that HGS asymmetry and weakness were associated with future functional disability in a national sample of aging Americans. Specifically, those with HGS asymmetry alone had 11% increased odds for future ADL disability, persons with weakness alone had 42% increased odds for future ADL disability, and those with both any HGS asymmetry and weakness had 81% increased odds for future ADL disability. Moreover, those with both dominant HGS asymmetry and weakness had 86% increased odds for future ADL disability, and aging Americans with asymmetric non-dominant

HGS and weakness had 72% increased odds for future ADL disability. Similar trends were observed in some of these factors alone such that those with weakness only and asymmetric non-dominant HGS only had 42% and 30% increased odds for future ADL disability, respectively. These findings suggest that combining assessments of HGS asymmetry with weakness may help to better predict future ADL disability and improve HGS as a screening tool for functional disability compared to maximal HGS measures alone.

While our findings support previous research that has found weakness is associated with functional disability in aging populations (16), we also found that HGS asymmetry was associated with future ADL disability. HGS is intricately linked to the neural systems that mediate the control of coordinated movement, and declines in hand dexterity and maximal HGS are indicative of age-related muscle coordination deficits (27). Aging may also influence the functioning of the Corpus Callosum and interhemispheric communications that are responsible for bimanual coordination (28, 29). Given that bimanual hand coordination is important for executing ADLs, deterioration of the nervous system during aging may have factored into poor bimanual hand coordination (30), which in turn, may help to explain why our findings showed HGS asymmetry was associated with future ADL disability in aging Americans. Although HGS asymmetry was associated with functional disability, the direction of the asymmetry may also provide valuable insights for ADL disability risk.

The amount of force produced during HGS measurements are generally stronger in the dominant hand (10), and the dominant hand often excels in motor performance tasks compared to the non-dominant hand (31). As such, the non-dominant hand, and side of the body, could be at risk for neuromuscular and musculoskeletal imbalances that may manifest into clinical issues (32). This may help to explain why both dominant HGS asymmetry and weakness were

associated with functional disability in our study. Similarly, adults experience age-related changes in handiness due to overuse, hemispheric asymmetry, environmental factors, and use-dependent plasticity (33). Older adults may experience higher HGS in their non-dominant hand relative to their dominant (34). Having higher HGS in the non-dominant hand and body size asymmetry may also be an indicator for weakness (35, 36). Each of these factors may help to explain why non-dominant HGS asymmetry and weakness were also associated with future ADL disability. Healthcare providers should incorporate measures of HGS asymmetry in assessments of maximal strength capacity, communicate the potential health consequences of HGS asymmetry to their older patients, and converse strategies for not only improving weakness, but also strength balance. Older adults with both weakness and HGS asymmetry should especially be targeted for appropriate interventions to help preserve function.

Indeed, our findings revealed that weakness alone and asymmetric HGS alone were associated with future functional disability in aging Americans. The odds ratios for future ADL disability increased in those who had both weakness and HGS asymmetry. We recommend that maximal HGS measurements on both hands and assessments of HGS asymmetry be considered in evaluations of strength capacity with handgrip dynamometers. Including such information in HGS protocols may help to improve the predictive utility of HGS for poor health outcomes. Further, consideration for HGS asymmetry may refine consensus definitions of sarcopenia and dynapenia, and how functional performance is assessed (37, 38). Future research should continue investigating HGS asymmetry with different experimental designs and analytical approaches, and how it is linked to other health conditions during aging. Refining HGS methods and technologies may also help to provide novel insights. Similarly, identifying effective

strategies that not only help to retain muscle strength, but also symmetry in strength between limbs may better decelerate the disabling process.

Some limitations should be acknowledged. Participants must have had at least two waves of data to be included in the analyses and those who may have been lost to follow-up after their first interview may have experienced rapid declines in their strength and functional capacity. Ambidextrous participants and those only able to complete HGS testing on one hand were excluded. Hand dominance was reported by participants without details regarding hand usage to complete tasks and reasons why hand dominance may have shifted. While the "10% rule" was used as the threshold for determining HGS asymmetry in our study, the differences in HGS between hands may vary (39). Therefore, consideration should be given to asymmetry misclassifications for those near the 10% threshold at individual-levels. This provides opportunities for other studies to generate precise HGS asymmetry cut-points. Most of our sample were White race and right hand dominant, so the generalizability of our findings is limited with respect to non-White races and left-handed persons. Future research is needed to better generalize HGS asymmetry results to non-White races and left-handed individuals for their risk of future ADL disability.

Conclusions

We found that HGS asymmetry and weakness was associated with increased odds for future functional disability in a national sample of aging Americans. The probability of detecting future ADL disability also improved when HGS asymmetry was included with weakness. These findings suggest that HGS asymmetry, in combination with assessments of weakness, could improve evaluations of muscle strength and the prediction of health conditions associated with strength capacity compared to maximal HGS alone. Assessments of HGS asymmetry also

preserves the cost-efficiency and feasibility of HGS because the dominant hand is recorded, and multiple measures of HGS are performed on each hand in most HGS test protocols.

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RM conceived and designed the study, participated in analyses, interpreted the results, and wrote the manuscript; BMV designed the study, participated in analyses, interpreted the results, and revised the manuscript; DAJ designed the study, interpreted the results, and revised the manuscript; KJH designed the study, interpreted the results, and revised the manuscript; GRT designed the study interpreted the results, and revised the manuscript; LJD interpreted the results; BCC designed the study, interpreted the results, and revised the manuscript.

Conflicts of Interest

None.

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FIGURE LEGEND

Figure 1. Histogram for the Differences in Handgrip Strength between the Dominant and Non-Dominant Hands.

Figure 2. Results for the Associations of A) Any Handgrip Strength Asymmetry and Weakness and B) Handgrip Strength Asymmetry Dominance and Weakness on Future Activities of Daily Living Disability.

Note: the symmetric handgrip strength and not-weak group was the reference (n=8,486).

Table 1. Participant Breakdown for Wave in Which Handgrip Strength and Future Activities of Daily Living Disability Status Were Measured.

A)

		Outcome Assessed				
		2008 wave	**2010 wave**	**2012 wave**	**2014 wave**	**2016 wave**
First HGS Measured	**2006 wave**	6,140	70	16	7	1
	2008 wave	-	5,405	79	27	4
	2010 wave	-	-	2,873	51	14
	2012 wave	-	-	-	2,844	74
	2014 wave	-	-	-	-	863

B)

		Outcome Assessed				
		2008 wave	**2010 wave**	**2012 wave**	**2014 wave**	**2016 wave**
HGS Measured	**2006 wave**	6,140	70	16	7	1
	2008 wave	-	5,405	79	27	4
	2010 wave	-	-	7,021	82	15
	2012 wave	-	-	-	6,502	106
	2014 wave	-	-	-	-	5,985

Note: A) first HGS measured and subsequent functional outcomes assessed; B) all waves where HGS was measured and subsequent functional outcomes were assessed. HGS=handgrip strength.

Table 2. Baseline Descriptive Characteristics of the Participants.

	Overall Sample (n=18,468)	**Symmetric HGS (n=8,920)**	**Asymmetric Dominant HGS (n=7,983)**	**Asymmetric Non-Dominant HGS (n=1,565)**
Weak (n (%))	990 (5.4)	434 (4.9)	379 (4.8)	177 (11.3)
Handgrip Strength (kilograms)	32.7±11.3	33.3±11.5	32.4±11.0	29.9±11.5
Handgrip Strength Ratio	0.93±0.17	0.98±0.05	0.81±0.08	1.26±0.30
Right Hand Dominant (n (%))	16,856 (91.3)	7,977 (89.4)	7,632 (95.6)	1,247 (79.7)
Age (years)	65.0±10.2	64.4±10.0	65.3±10.3	66.5±10.6
Male (n (%))	7,825 (42.4)	4,160 (46.6)	2,997 (37.5)	668 (42.7)
White Race (n (%))	13,743 (74.4)	6,769 (75.9)	5,823 (72.9)	1,151 (73.6)
Health Conditions	1.9±1.4	1.8±1.4	1.9±1.4	2.2±1.5
Obesity (n (%))	6,488 (35.1)	3,102 (34.8)	2,813 (35.2)	573 (36.6)
Previous Smoker (n (%))	7,549 (40.9)	3,707 (41.6)	3,194 (40.0)	648 (41.4)
Current Smoker (n (%))	2,883 (15.6)	1,396 (15.7)	1,235 (15.5)	252 (16.1)
Educational Achievement (n (%))				
Not a HS Graduate	3,388 (18.4)	1,565 (17.5)	1,455 (18.2)	368 (23.5)
HS Graduate or Passing HS Equivalent Exam, Some College	10,919 (59.1)	5,303 (59.5)	4,685 (58.7)	931 (59.5)

College Graduate or Above	4,161 (22.5)	2,052 (23.0)	1,843 (23.1)	266 (17.0)
Social Engagement	1.5±0.9	1.6±0.9	1.5±0.9	1.3±0.9
Depression (n (%))	3,849 (20.8)	1,771 (19.9)	1,661 (20.8)	417 (26.7)
Moderate-to-Vigorous Physical Activity Participation (n (%))	11,009 (59.6)	5,498 (61.6)	4,631 (58.0)	880 (56.2)
Self-Rated Health (n (%))				
Excellent	2,098 (11.4)	1,121 (12.6)	850 (10.6)	127 (8.1)
Very Good	5,665 (30.7)	2,830 (31.7)	2,435 (30.5)	400 (25.5)
Good	5,875 (31.8)	2,810 (31.5)	2,583 (32.4)	482 (30.8)
Fair	3,700 (20.0)	1,673 (18.8)	1,616 (20.2)	411 (26.3)
Poor	1,130 (6.1)	486 (5.4)	499 (6.3)	145 (9.3)
Cognitive Impairment (n (%))	1,935 (10.5)	946 (10.6)	796 (10.0)	193 (12.3)
Time Between Waves (years)	2.1±0.6	2.1±0.6	2.1±0.6	2.1±0.5
Activities of Daily Living Disability at Current Wave (n (%))	2,602 (14.1)	1,093 (12.3)	1,166 (14.6)	343 (21.9)
Activities of Daily Living Disability at Next Wave (n (%))	3,054 (16.5)	1,269 (14.2)	1,390 (17.4)	395 (25.2)

Note: HGS=handgrip strength; HS=high school.

Table 3. Results for the Lagged Associations of Any Handgrip Strength Asymmetry and Weakness on Future Functional Disability.

	Odds Ratio	95% Confidence Interval
Model 1		
Weakness Only (n=990)†	1.55	1.35, 1.77
Model 2		
Asymmetric Handgrip Strength Only (n=9,548)‡	1.12	1.04, 1.21
Model 3		
Weakness Only (n=990)†	1.54	1.35, 1.76
Asymmetric Handgrip Strength Only (n=9,548)‡	1.12	1.04, 1.21

†Reference: not-weak (n=17,478); ‡Reference: symmetric handgrip strength (n=8,920).

Note: each generalized estimating equation was adjusted for activities of daily living disability at current wave, age, sex, race and ethnicity, hand dominance, obesity, morbidities, moderate-to-vigorous physical activity participation, educational achievement, smoking history, current smoking status, self-rated health, social engagement, depression, cognitive functioning, and time between waves.

Table 4. Results for the Lagged Associations of Handgrip Strength Asymmetry Dominance and Weakness on Future Activities of Daily Living Disability.

	Odds Ratio	95% Confidence Interval
Model 1		
Weakness Only (n=990)†	1.55	1.35, 1.77
Model 2		
Asymmetric Dominant Handgrip Strength Only (n=7,983)‡	1.08	1.01, 1.17
Asymmetric Non-Dominant Handgrip Strength Only (n=1,565)‡	1.31	1.16, 1.50
Model 3		
Weakness Only (n=990)†	1.52	1.33, 1.74
Asymmetric Dominant Handgrip Strength Only (n=7,983)‡	1.09	1.01, 1.18
Asymmetric Non-Dominant Handgrip Strength Only (n=1,565)‡	1.28	1.12, 1.45

†Reference: not-weak (n=17,478); ‡Reference: symmetric handgrip strength (n=8,920).

Note: each generalized estimating equation was adjusted for activities of daily living disability at current wave, age, sex, race and ethnicity, hand dominance, obesity, morbidities, moderate-to-vigorous physical activity participation, educational achievement, smoking history, current smoking status, self-rated health, social engagement, depression, cognitive functioning, and time between waves.

Figure 1

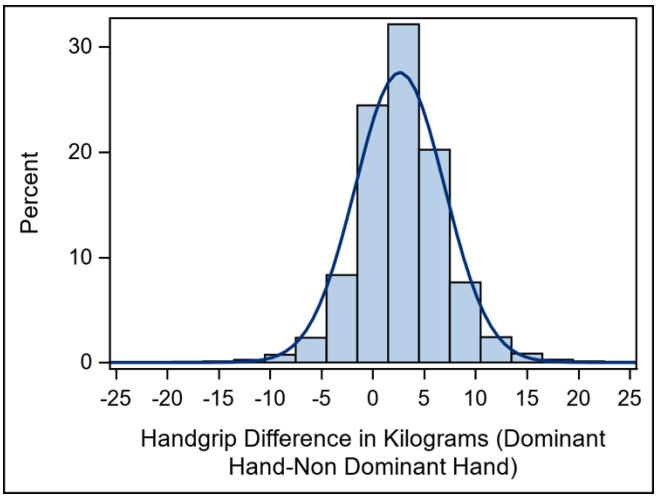

Percent
30
20
10
0
-25
-20
-15
-10
-5
0
5
10
15
20
25
Handgrip Difference in Kilograms (Dominant Hand-Non Dominant Hand)

Figure 2A

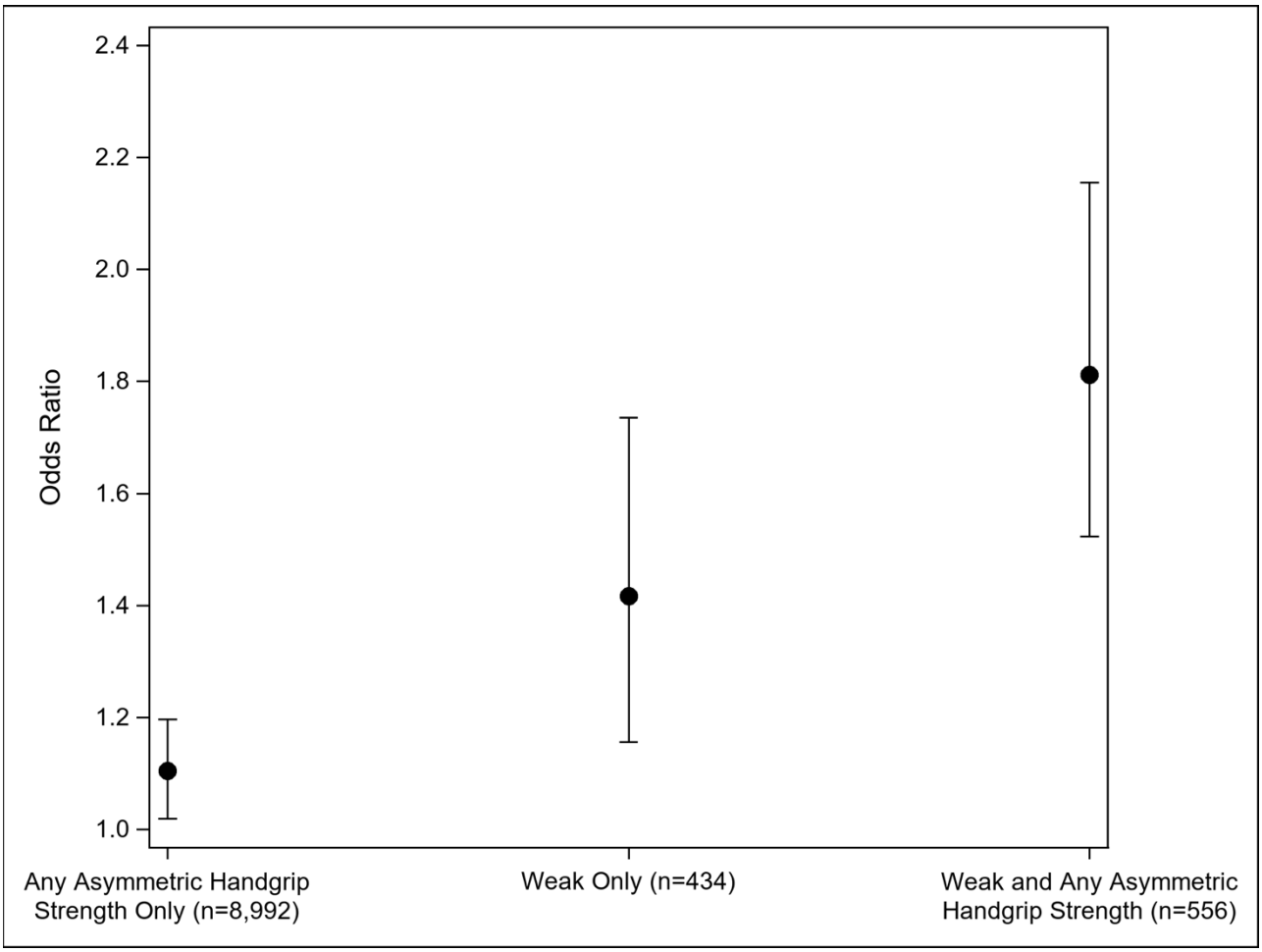
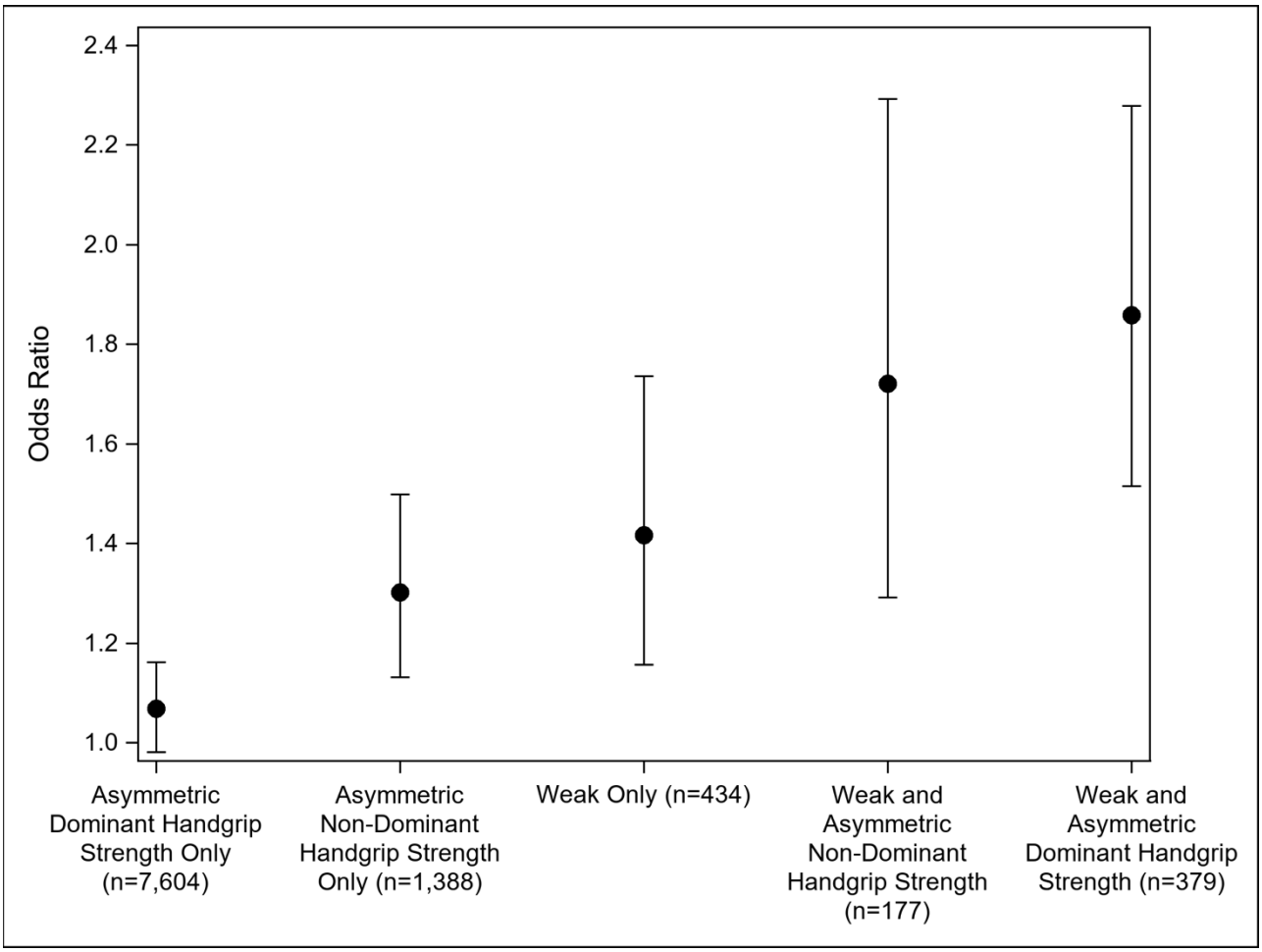

2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
Odds Ratio
Any Asymmetric Handgrip Strength Only (n=8,992)
Weak Only (n=434)
Weak and Any Asymmetric Handgrip Strength (n=556)

Figure 2B


Odds Ratio
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
Asymmetric Dominant Handgrip Strength Only (n=7,604)
Asymmetric Non-Dominant Handgrip Strength Only (n=1,388)
Weak Only (n=434)
Weak and Asymmetric Non-Dominant Handgrip Strength (n=177)
Weak and Asymmetric Dominant Handgrip Strength (n=379)