7-31-2017

Hand Grip Strength and Gender: Allometric Normalization in Older Adults and Implications for the NIOSH Lifting Equation

Trish Gail Sevene
California State University, Monterey Bay

Joseph Berning
New Mexico State University

Chad Harris
Metropolitan State University of Denver

Mike Climstein
The University of Sydney

Kent Jason Adams
California State University, Monterey Bay

See next page for additional authors

Original Article

Vol. 7, No. 2, 63-68
https://doi.org/10.15280/jlm.2017.7.2.63

Journal of Lifestyle Medicine

Hand Grip Strength and Gender: Allometric Normalization in Older Adults and Implications for the NIOSH Lifting Equation

Trish Gail Sevene[1], Joseph Berning[2], Chad Harris[3], Mike Climstein[4], Kent Jason Adams[1], Mark DeBeliso[5,]*

[1]Kinesiology Department, California State University Monterey Bay, Seaside, CA, [2]Department of Kinesiology and Dance, New Mexico State University, Las Cruces, NM, [3]College of Professional Studies, Metropolitan State University of Denver, Denver, CO, USA, [4]The University of Sydney, Exercise, Health & Performance Faculty Research Group, Sydney, Australia, [5]Department of Kinesiology and Outdoor Recreation, Southern Utah University, Cedar City, UT, USA

Background: Many countries are experiencing an aging workforce with women workers making up a growing proportion. Workplaces often require employees to complete lifting tasks that require the ability of the hand to grasp an implement (coupling). The National Institute for Occupational Safety and Health (NIOSH) has developed an equation for manual lifting tasks hoping to minimize the potential for a workplace back-injury related to a lifting task. The NIOSH lifting equation relies upon stress variables including a coupling factor. However, little is known regarding grip strength as related to the NIOSH lifting equation coupling factor. The purpose of this study was to investigate differences in grip strength due to gender in older adults.

Methods: The participant's (68-88 years) maximal grip (MG) strength measures were collected for each hand with a hand grip dynamometer (kg). MG scores were converted to Newtons (N), normalized to body mass, and allometrically scaled. Measures of MG were than compared between genders with an independent t-test.

Results: The hand grip measures of MG (kg) [male: 30.3 ± 5.6, female: 10.6 ± 3.3], MG (kg) / body mass (kg) [male: 0.35 ± 0.06, female: 0.16 ± 0.04], MG (N) / $(\text{body mass (kg)})^{0.67}$ [male: 15.1 ± 2.5, female: 6.2 ± 1.7], and MG (N) / $(\text{body height (m)})^{1.84}$ [male: 103.6 ± 18.6, female: 42.6 ± 10.6] were all significantly lower ($p < 0.0001$) for women than men. Regardless of how grip strength was reported, there is a strong difference in grip strength between genders in this sample. The NIOSH lifting equation does not account for varying grip strength due to aging and gender differences.

Conclusions: It is recommended that grip strength variability be accounted for in the coupling factor of the NIOSH lifting equation.

Key Words: NIOSH, Jamar, Older adult, Coupling

INTRODUCTION

The world population continues to grow older and it is projected that by 2050 there will be 1.6 billion people aged 65 years or older [1]. The increase in the aging population is not uniform across the planet and many countries in Europe and North America are geographic areas experiencing the aging population phenomena [1]. In the United States the increase in the aging population is being accompanied by an aging workforce [2]. Projections in workforce

Received: March 25, 2017, Accepted: June 13, 2017

*Corresponding author: Mark DeBeliso
Department of Kinesiology and Outdoor Recreation, Southern Utah University, 351 West University Blvd, Cedar City, UT 84720, USA
Tel: 1-435-586-7812, Fax: 1-435-865-8057
E-mail: markdebeliso@suu.edu

participation for the period of 2012-2022 indicate that the population of workers 55 years and older will increase by 28.8% and by 85.2% for workers 75 years and older [2]. Of particular interest for same period, women workers 55 years and older will increase by 33.0% and by 104.6% for workers 75 years and older [2].

It is likely that the aging workforce will be accompanied by musculoskeletal disorders including areas of the back and spine. It is estimated that 60-70% of the work force will experience at least one serious incidence of sciatica or back strain during their lifetime [3,4]. The US Bureau of Statistics reported 182,270 cases involving injuries to the back in year 2011 [5]. The US National Center for Health Statistics reported that 18% of all work place injuries are spine or back related [6].

The Revised NIOSH lifting equation [7] for the design and evaluation of manual lifting tasks was developed with the goal of minimizing the potential for a workplace back-injury related to a lifting task (NIOSH-National Institute for Occupational Safety and Health). The NIOSH lifting equation is based on three general stress related variables: physiologic, biomechanical, and psycho-physical. One specific variable included in the NIOSH lifting equation is referred to as the coupling factor. The coupling factor is an estimate of how well the hand is coupling with a tool or workplace implement. The better the grip between the hand and the tool or workplace implement, the more effective the coupling and hence higher coupling factor.

When considering the concept of a coupling factor it would seem prudent to include the issue of varying grip strength due to age and/or gender. Prior research suggests that there are age and gender related differences in grip strength [8]. However, the published data sets do not reflect grip strength allometrically scaled. Allometric scaling is based upon the theory that humans have relatively the same shape however vary in size and that the relationship between strength and body mass is curvilinear [9]. Jaric and colleagues [10] suggested that to allometrically scale strength that the strength measure should be divided by $(\text{body mass})^{0.67}$. Most recently Maranhao Netoa and colleagues [11] suggested that hand grip strength should be allometrically scaled to body height $(\text{meters})^{1.84}$. When strength measures are allometrically scaled, strength comparisons between genders that are relative to body mass can be more precisely made.

Given the advancing age of the workforce the use of the NIOSH lifting equation for the design of manual lifting tasks is essential for minimizing the potential of a workplace back-injury. However, grip strength as related to the NIOSH lifting equation coupling factor is not well understood. While previous research has examined the effects of varied coupling on lifting tasks [12-15], and the relationship of grip strength to overall body strength and function in older adults [16,17], to our knowledge no studies have taken age and gender into account in relation to both grip strength and coupling. Examining raw grip strength and allometrically scaled grip strength measures of older adults could provide insight into how the NIOSH equation coupling factor might be more precisely manipulated based on age and gender.

With that said, the purpose of this study was to collect hand grip strength measures of older adults and determine if there is a difference in grip strength between genders based on allometric scaling. It was hypothesized that there would be differences in grip strength as related to gender following the allometric scaling of the grip strength measures.

MATERIALS AND METHODS

1. Participants

The participants in this study included healthy males (n = 16) and females (n = 12) in either their 7^{th}, 8^{th}, or 9^{th} decade of life. Recruitment strategies included public announcements, flyers, and word of mouth. The volunteers were independent and community-dwelling with no previous background in resistance training. Participants were cleared for participation in the study by their personal physician. Prior to the execution of the study, all participants were verbally informed of the details of the study, read and signed an informed consent document approved by an Institutional Review Board for the use of Human Subjects.

2. Hand grip strength assessment

Maximal grip strength (MG) was assessed with a Jamar hand dynamometer. Participants completed two trials of MG with both the dominant and non-dominant hand. Participants were seated with the shoulder at 0° abduction and flexion with the elbow at 90° flexion, as recommended by American Society of Hand Therapists [18]. Participants were instructed to familiarize themselves with the hand-grip dynamometer (Fig. 1) by holding and squeezing the device prior to performing the MG trials. Participants were then instructed to grip and squeeze the device with a maximal effort for 3 seconds. The trials were separated by approximately a 1 min rest period. The greatest MG from the two trials was used for analysis.

The Jamar handgrip dynamometer has been demonstrated to be among the most accurate instruments for grip strength measurement [19]. Grip strength measurement has been demonstrated to be reliable with coefficients of 0.80 or higher [19].

3. Allometric normalization of hand grip strength

Recorded MG was assessed in kilograms (kg) and was subsequently converted to Newtons (MG kg × 9.81 m/s^2). In order to allometrically scale the MG scores the following equations were used as suggested by Jaric et al. [10] and Maranhao Netoa and colleagues [11].

$$MG_{allometrically\ scaled} = MG\ (N)\ /\ (body\ mass\ (kgs))^{0.67}$$

$$MG_{allometrically\ scaled} = MG\ (N)\ /\ (body\ height\ (meters))^{1.84}$$

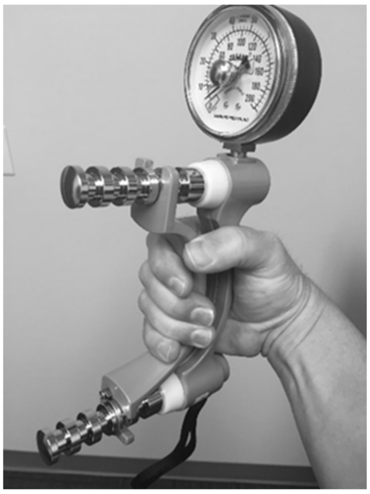

Fig. 1. Jamar dynamometer.

4. Statistical analysis

Independent t-tests were used to determine if statistical differences existed between genders for the variables explored. Likewise, means and standard deviations were calculated to establish the central tendency and dispersion of the variables collected. For the purpose of this study, only the dominant hand strength scores were analyzed. Significance for the study was set *a priori* at $\alpha < 0.05$.

RESULTS

All but one of the participants was able to complete the MG trials. One male was unable to complete the left-handed MG assessments and he was subsequently eliminated from the study. Table 1 provides the subject descriptive statistics for age, body mass, and height (mean ± standard deviation).

Table 2 provides the MG scores for kilograms (kg) and as converted to Newtons (N). MG is also reported as normalized to body mass (kg). Allometric MG scores likewise are provided. Male MG was significantly ($p < 0.0001$)

Table 1. Participant descriptive characteristics

Participants	N	Age (year)	Body height (m)
Female	12	71.2 ± 3.8	1.62 ± 0.07
Male	16	72.9 ± 4.7	1.77 ± 0.06

Table 2. Maximal grip scores

Measure	Male (N = 15)	Female (N = 12)	p-value
MG (kg)	30.3 ± 5.6	10.6 ± 3.3	p < 0.0001
MG (N)	296.8 ± 54.6	103.8 ± 32.3	p < 0.0001
MG (kg)/body mass (kg)	0.35 ± 0.06	0.16 ± 0.04	p < 0.0001
MG Allometric scaled (N/kg)	15.1 ± 2.5	6.2 ± 1.7	p < 0.0001
MG Allometric scaled (N/m) Body Height$^{1.84}$	103.6 ± 18.6	42.6 ± 10.6	p < 0.0001

N: Newtons.

greater than female MG for all measures.

DISCUSSION

The purpose of this study was to examine hand grip strength measures of older adults (range 65-86 years) and determine if there is a difference in grip strength between genders based upon allometric scaling (as well as traditional measures). It was presumed that differences in grip strength as related to gender would persist following the allometric scaling. MG scores were assessed and converted to Newtons, normalized to body mass, and allometrically scaled (body mass$^{0.67}$ and body height$^{1.84}$). In each case, MG strength was significantly ($p < 0.0001$) greater for males than for females.

The effect size (SD) for the differences in MG scores between genders was: 3.5 MG, 3.2 MG/body mass, 3.6 MG allometrically scaled to body mass$^{0.67}$ and 3.3 MG allometrically scaled to body height$^{1.84}$. The effect sizes between the male and female grip strength scores were comparative for the four measures of grip strength. Effect sizes of magnitude >2.0 are considered “large” in untrained individuals [9].

The MG scores in the current study for males were approximately 60$^{th\%ile}$ for adult males 60-69 [8]. Likewise, the MG scores for the females were just below 20$^{th\%ile}$ for women 70 and older [8]. We suspect that the large effect sizes mentioned in the previous paragraph were due in part to the deviation in percentile rank of the MG scores and not completely due to differences related to gender.

The allometric values (body mass$^{0.67}$) in the current study were well below those reported by Sağiroğlu and colleagues [20] of 21.3 ± 2.5 and 26.3 ± 3.8 (N/kg) for women and men respectively. It should be noted that the participants in the Sağiroğlu et al. study were 21 ± 2.0 years of age which could explain the much larger MG scores observed. We suspect that the similarity between the allometrically scaled MG scores between the men and women in the Sağiroğlu et al. study was due to MG (kg) scores being closer in magnitude than in our study. Specifically, the ratio of the non-scaled MG female to MG male strength scores in the Sağiroğlu et al. study was 33.0/47.0 or 0.81; whereas in our study the ratio of the non-scaled MG female to MG male strength scores was 10.6/30.3 or 0.35. It should also be noted that the MG scores reported in the Sağiroğlu et al. study were beyond 80$^{th\%ile}$ normative scores for both the males and females in their respective age groups [8].

Another study examining hand grip strength [21] of young adults (20-21 years) using allometrically scaling scores reported comparable results to the Sağiroğlu et al. study. Dopsaj and colleagues reported MG allometrically scaled scores of 33.6 N/kg and 24.02 N/kg for males and females respectively (right hand). The similarity in hand grip allometric scores (body mass$^{0.67}$) between the Dopsaj et al. and Sağiroğlu et al. study is likely due to the similar age range of the participants and that MG values were collected with very similar devices (digital hand grip dynamometer, Takei Scientific Instruments Co. Japan) and testing protocol (standing with arm alongside of trunk, elbow fully extended). Noting that the current study used the Jamar hang grip dynamometer and tested the participants in a differing anatomical position (seated with the shoulder at 0° abduction and flexion with the elbow at 90° flexion) then the Sağiroğlu et al. and Dopsaj et al. study protocols.

While the results of the current study do not necessarily compare directly with the results of the Sağiroğlu et al. and Dopsaj et al. studies, the results of the current study do confirm that gender differences in grip strength exist after allometric scaling (body mass$^{0.67}$). Additionally, the gender differences in grip strength appear to persist with advancing age.

In a recent study by Maranhao Netoa and colleagues [11] grip strength of older adults (n = 263, 60-87 years) was allometrically scaled to fat free mass, body mass, and height. The results of their study indicated that the optimal method of allometrically scaling MG was associated with body height, specifically, MG divided by body height (meters)$^{1.84}$. Their allometrically scaled MG scores were not specifically reported, further the MG scores were not reported as converted to force in Newtons as in the current study. However, the MG scores reported in kgs were 35.3 ± 7.3 and 21.2 ± 5.6 for men and women respectively which were higher than those reported in the current study. In an attempt to compare the allometrically scaled scores (body height$^{1.84}$) eluded to in the Maranhao Netoa with the current study, we used the participant mean scores for MG (kgs) and height (m) reported in their study to calculate their presumed allometrically scaled scores (body height$^{1.84}$). First, we multiplied the mean MG (kgs) scores by 9.81 m/sec to convert strength scores to Newtons (as reported in the current study), hence 35.3*9.81 and 21.2*9.81 for men and women respectively. Second, we divided the MG (N) scores by mean body height$^{1.84}$, yielding allometrically scaled MG scores (body height$^{1.84}$) of 127.8 and 89.6 (N/m) for men and women respectively. While Maranhao Netoa allometrically scaled MG scores (body height$^{1.84}$) are greater than those reported in the current study, they are consistent with our study in that there is a large difference in the grip strength scores between genders after allometrically scaling to body height$^{1.84}$.

1. NIOSH lifting equation considerations

An aged workforce (≥55 years) likely possesses lower muscle strength compared to a younger workforce (20-55 years) and as such may be more susceptible to a workplace injury during a lifting task. As such, there is an increased focus on the use of the NIOSH lifting equation (revised) for the design of manual lifting tasks with the goal of minimizing the potential for a workplace back-injury. The coupling factor is a multiplier used in the calculation of the recommended weight limit of a given lifting task (see Waters et al., 1993 for a detailed explanation of the lifting equation). However, the coupling factor varies by only 10% (in gradients of 5%) which is based upon the vertical height a load is lifted in conjunction with a qualitative rating of the coupling of the hand with the work implement (good, fair, poor).

The ability of the hand to couple with an object is far more complex than the NIOSH coupling factor suggests. Successful coupling of the hand with a workplace implement depends on the size, geometry and texture of the object to be grasped during the lifting task. Further, the type of grip action involved in the lifting task is important. Specifically, crush grip strength is a concentric muscle action whereas break away grip strength is an eccentric muscle action, noting that eccentric muscle strength is greater than concentric muscle strength. Finally, as noted in this current research effort, grip strength decreases with age and according to our findings (and others) is gender dependent. The coupling factor used in the NIOSH lifting equation does not account for the aforementioned issues surrounding the ability of the hand to successfully grasp a workplace implement while conducting a lifting task, most specifically maximal grip strength and its variability as related to age and gender. As mentioned above, the NIOSH lifting equation coupling factor varies by only 10%, yet in the current study the allometric MG strength scores between genders varied by well over 100%. MG strength for females age 20-29 and ≥70 years are 59.5 and 43.2 kgs respectively (28% reduction) [8]. MG strength for males age 20-29 and ≥70 years are 95.5 and 69.9 kgs respectively (27% reduction) [8]. The reduction in percent MG strength for both genders as related to aging is 27-28%. In our opinion the variability of MG strength due to aging and gender differences needs to be incorporated into the NIOSH lifting equation's coupling factor in order to account for the aging workforce.

CONCLUSIONS

Within the parameters of this study, it is concluded:

- Maximal hand grip strength scores are lower for women than for men regardless of the manner of reporting [MG, MG / Body Mass, MG / (Body Mass)$^{0.67}$, MG / (Body Height)$^{1.84}$]
- The NIOSH lifting equation coupling factor does not reflect grip strength variability with regards to age and gender,
- Gender differences in maximal hand grip strength scores appear to persist across the life span, and
- Given the aging workforce, differences in maximal hand grip strength scores due to gender and age should be taken into account when considering workplace lifting tasks.

REFERENCES

1. He W, Goodkind D, Kowal P. An Aging World: 2015 US Census Bureau, International Population Reports. US Government Publishing Office; Washington, DC. 2016.
2. Toossi M. Labor force projections to 2022: The labor force participation rate continues to fall. Monthly Lab Rev [Internet]. 2013;136:1. Table 4. [cited 2017 Mar 13]

Available from: https://www.bls.gov/opub/mlr/2013/article/labor-force-projections-to-2022-the-labor-force-participation-rate-continues-to-fall.htm#top.
3. Andersson GB. Epidemiologic aspects on low-back pain in industry. *Spine* 1981;6:53-60.
4. Pope MH, Andersson GB, Frymoyer JW, Chaffin DB. Occupational low back pain: Assessment, treatment and prevention. Mosby-Year Book Inc; St. Louis, MO. 1991.
5. United States Department of Labor, Bureau of Labor Statistics: Injuries, Illnesses, and Fatalities (IIF) Program [Internet]. Washington DC: US Bureau of Labor Statistics. [cited 2017 Mar 13]. Available from: http://www.bls.gov/iif/home.htm.
6. Chen LH, Warner M, Fingerhut L, Makuc D. Injury episodes and circumstances: National Health Interview Survey, 1997-2007. Vital and health statistics. Series 10, Data from the *National Health Survey*. 2009;241:1-55.
7. Waters TR, Putz-Anderson V, Garg A, Fine LJ. Revised NIOSH equation for the design and evaluation of manual lifting tasks. *Ergonomics* 1993;36:749-76.
8. Perna FM, Coa K, Troiano RP, Lawman HG, Wang CY, Li Y, Moser RP, Ciccolo JT, Comstock BA, Kraemer WJ. Muscular grip strength estimates of the US population from the National Health and Nutrition Examination Survey 2011-2012. *J Strength Cond Res* 2016;30:867-74.
9. Rhea MR, Peterson MD. Tests, data analysis, and conclusions. In: Miller T, editor. NSCA's guide to tests and assessments. Human Kinetics; Champaign, IL. 2012. pp.11.
10. Jaric S, Mirkov D, Markovic G. Normalizing physical performance tests for body size: a proposal for standardization. *J Strength Cond Res* 2005;19:467-74.
11. Maranhao Netoa GA, Oliveira AJ. de Melo Pedreiro RC, Pereira-Junior PP, Machado S, Neto SM. Farinatti PT. Normalizing handgrip strength in older adults: An allometric approach. *Arch Gerontol Geriatr* 2017; 70:230-234.
12. Sevene TG, DeBeliso M, Harris C, Berning JM, Leininger L, Adams KJ. Metabolic and psychophysical comparison of a one-handed lifting task with different coupling factors. *Int J Sci Eng Inv* 2015;4:26-30.
13. Sevene TG, DeBeliso M, Harris C, Berning JM, Climstein M, Adams KJ. Metabolic response to repetitive lifting tasks: predetermined vs. self-selected pace. *Int J Sci Eng Inv* 2013;2:68-71.
14. Sevene TG, DeBeliso M, Berning JM, Harris C, Adams KJ. Physiological and psychophysical comparison between a one and two-handed identical lifting task. *Int J Sci Eng Inv* 2012;1:86-9.
15. Adams KJ, DeBeliso M, Sevene-Adams PG, Berning JM, Miller T, Tollerud DJ. Physiological and psychophysical comparison between a lifting task with identical weight but different coupling factors. *J Strength Cond Res* 2010;24:307-12.
16. DeBeliso M, Boham M, Harris C, Carson C, Berning JM, Sevene T, Adams KJ. Grip and body strength measures in the mature adult: A Brief Report. *Int J Sci Eng Inv* 2015;4:83-6.
17. DeBeliso M, Boham M, Harris C, Carson C, Berning JM, Sevene T, Adams KJ, Climstein M. Grip strength and functional measures in the mature Adult: Brief report II. *Int J Sci Eng Inv* 2015;4:1-4.
18. Fess, E.E. Grip strength. In: Casanova JS, editor. Clinical assessment recommendations. (2nd ed). American Society of Hand Therapists; Chicago, IL. 1992. pp.41-5.
19. Mathiowetz V, Weber K, Volland G, Kashman N. Reliability and validity of grip and pinch strength evaluations. *J Hand Surg* 1984;9:222-6.
20. Sağiroğlu İ, Kurt C, Ömürlü İK, Çatikkaş F. Does hand grip strength change with gender? The traditional method vs. the allometric normalization method. *Euro J Phys Edu Sport Sci* 2016;2:84-92.
21. Dopsaj M, Koropanovski N, Vučković G, Blagojević M, Marinković B, Miljuš D. Maximal isometric hand grip force in well-trained university students in Serbia: Descriptive, functional and sexual dimorphic model. *Serbian J Sport Sci* 2007;1:138-47.