# Global variation in grip strength: a systematic review and meta-analysis of normative data

|  |  |
| --- | --- |
| Author | Affiliation(s) |
| Dr Richard M Dodds PhD | 1,2 |
| Dr Holly E Syddall PhD | 1 |
| Dr Rachel Cooper PhD | 3 |
| Prof Diana Kuh FMedSci | 3 |
| Prof Cyrus Cooper FMedSci | 1,4,5 |
| Prof Avan Aihie Sayer PhD | 1,2,4,6,7 |

## Affiliations

1. Medical Research Council Lifecourse Epidemiology Unit, University of Southampton
2. Academic Geriatric Medicine, Faculty of Medicine, University of Southampton
3. Medical Research Council Unit for Lifelong Health and Ageing at UCL
4. National Institute for Health Research Southampton Biomedical Research Centre, University of Southampton and University Hospital Southampton NHS Foundation Trust
5. National Institute for Health Research Musculoskeletal Biomedical Research Unit, University of Oxford
6. National Institute for Health Research Collaboration for Leadership in Applied Health Research and Care: Wessex
7. Newcastle University Institute for Ageing and Institute of Health & Society, Newcastle University

## Corresponding author:

Dr Richard M Dodds. MRC Lifecourse Epidemiology Unit, University of Southampton, Southampton General Hospital, Southampton, SO16 6YD, UK. Tel 0044 2380 777624. Fax 0044 2380 704021. Email rd@mrc.soton.ac.uk

Word count: approx. 2,746

PLEASE NOTE: The very long list of references supporting this review has meant that only the most important are listed here and are represented by bold type throughout the text. The full list of references is available on the journal website <http://www.ageing.oxfordjournals.org/> as Appendix 1.

# Abstract

## **Background**

Weak grip strength is a key component of sarcopenia and is associated with subsequent disability and mortality. We have recently established life course normative data for grip strength in Great Britain, but it is unclear whether the cut points we derived for weak grip strength are suitable for use in other settings. Our objective was to investigate differences in grip strength by world region using our data as a reference standard.

## **Methods**

We searched MEDLINE and EMBASE for reporting age- and gender-stratified normative data for grip strength. We extracted each item of normative data and converted it on to a Z-score scale relative to our British centiles. We performed metaregression to pool the Z-scores and compare them by world region.

## **Findings**

Our search returned 806 abstracts. Sixty papers met inclusion criteria and reported on 63 different samples. Seven UN regions were represented although most samples (n=44) were based in developed regions. We extracted 726 normative data items relating to 96,537 grip strength observations. Normative data from developed regions were broadly similar to our British centiles, with a pooled Z-score 0.12 SDs (95% CI: 0.07, 0.17) above the corresponding British centiles. By comparison, normative data from developing regions were clearly lower, with a pooled Z-score of -0.85 SDs (95% CI: -0.94, -0.76).

## **Interpretation**

Our findings support the use of our British grip strength centiles and their associated cut points in consensus definitions for sarcopenia and frailty across developed regions, but highlight the need for different cut points in developing regions.

# Introduction

Weak grip strength is linked to a range of health outcomes including higher all-cause mortality rates [1–3] and morbidity [4,5], as well as forming a key part of sarcopenia [6] and frailty [7] phenotypes. As such there is growing interest in its assessment in clinical settings. We have recently established life course normative data for grip strength from 12 British studies, allowing an individual’s strength to be assessed in terms of what would be expected for their gender and age [8]. Cut points for weak grip strength allow healthcare workers to easily identify older people who may benefit from further assessment: using a T-score approach with our normative data, we proposed cut points of 16kg in females and 27kg in males. These values are similar to those from the FNIH Sarcopenia Project (16kg and 26kg) based on the presence of mobility impairment in a sample combining several US and European cohorts [9]. This raises the question of whether our normative data are also applicable in US and European settings, as well as in other world regions. There exists a growing literature of normative data studies for grip strength covering different stages of the life course in different countries [10–15]. The objective of this paper was therefore to use a systematic review and meta-analysis to investigate differences in grip strength by world region, using our recently published life course normative data as a reference.

# Methods

## Literature search

We carried out a systematic review following the guidance in the PRISMA statement [16]. We searched the databases MEDLINE (including in-process citations) and EMBASE for English language publications up to August 2014 (for full search strategy see Appendix 2). Eligible studies were those published from 1980 onwards reporting normative data for grip strength. We included studies based on samples of the general population and excluded those based on specific occupational or illness groups. We required studies to have reported their normative data in tabular form stratified by gender and age (across at most 15-year age bands), and to have included a mean and a standard error (or values from which one could be calculated) for each stratum.

## Data extraction

We extracted information about each study. In terms of the sample used, this included the country, level (national, regional, local or based in a single facility), the sample size and whether a sampling frame or a convenience sampling approach was used. We assumed a convenience sample had been used when the sample type was not described. In terms of the protocol used to measure grip strength, this included the dynamometer, measurement position (seated or standing), the hand(s) tested and the number of trials along with the summary value reported (mean or maximum).

For each age and gender stratum, we extracted the mean value for grip strength along with its standard error, or equivalent values from which one could be calculated (the formulae used for these calculations are shown in Appendix 3a). We extracted the maximum value from both hands if this was reported; otherwise we extracted the maximum or mean for the right or dominant side, as available in the paper. We converted grip strength values in pounds force and Newtons to kilograms force [17].

## Statistical analyses

We produced summary charts of the extracted normative data for males and females. As described in the results section, these data typically followed the same overall pattern across the life course as our British normative values. We therefore chose to use our British values as a reference, and converted the normative data items that we extracted from existing studies to mean Z-scores prior to further analyses. To do this, we calculated the difference between the mean from each normative data item and the mean from our British values for an equivalent age range, divided by the SD from our British values. Where a normative data item referred to a range of ages, we calculated the equivalent pooled mean and standard deviation [18]across the same age range in our British values and used these as the basis for Z-scores.

We used random effects metaregression in Stata version 13 [19] to pool the grip strength z-scores and to investigate the associations with world region and aspects of measurement protocol. We assumed a coefficient of variation (the SD / mean) for grip strength of 0.25 (as seen in our British normative data) such that a difference of 0.4 on the Z-score scale is equivalent to a 10% difference in grip strength mean values (see Appendix 3b).We classified countries into those in developed and developing regions using groupings provided by the United Nations Statistics Division [20]. In terms of measurement protocol, we classified type of dynamometer as either hydraulic (divided into the commonly used Jamar hydraulic dynamometer [21] or other hydraulic dynamometers), electronic or not specified. We also compared results from studies which had measured grip in the seated or standing positions, those which had reported values from one or both hands, and those which showed the maximum or mean value from repeated trials.

## Declaration of sources of funding

This work was supported by the Wellcome Trust (Fellowship to RD, grant number WT099055AIA); and the UK Medical Research Council (DK and RC, programme code MC\_UU\_12019/4). The funders had no role in the design, execution, analysis and interpretation of data, or writing of the study.

# Results

## Study selection and characteristics

We screened 806 abstracts and assessed 96 papers for eligibility (for flow diagram see Appendix 4). Sixty papers met inclusion criteria [10,11,13–15,22–76]. Two papers included results for two samples [42,62] and one paper provided results for two dynamometers [46], hence the total number of samples for analysis was 63. A summary of their characteristics is shown in Table 1 and a full list of included papers is provided in Appendix 5. The samples were based across 27 countries in seven UN regions, with a majority in developed regions (n=44) as shown in Figure 1. The normative data covered childhood, adolescence and adulthood in four regions (Africa, Asia excluding Japan, Europe and Northern America). The data in the other three regions (Americas excluding Northern America, Australia and Japan) only covered adulthood. There were no samples from New Zealand (normally grouped with Australia in the UN classification).

## The relationship between world region and grip strength

We extracted 726 normative data items relating to 96,537 grip strength observations. We excluded eight normative data items outside the age range of our British normative data (younger than 4 years or older than 90 years), leaving 718 for analyses. As shown in Figure 2, we saw a similar pattern of mean grip strength across the life course in both males and females to that from our British normative values: an increase to peak in early adult life, broad maintenance through to midlife and decline from midlife onwards. There was separation between data items from developed and developing regions. Data items from developed regions were typically similar to those in Britain, with a pooled Z-score 0.12 SDs (95% CI: 0.07, 0.17) above the equivalent British centiles. Data items from developing regions were typically lower, with a pooled Z-score of -0.85 SDs (95% CI: -0.94, -0.76). To illustrate these values, at age 30 in British males we previously found mean grip strength to be 51.6 (9.6) kg. At this age, the pooled Z-scores from developed and developing regions would equate to mean grip strengths of 52.8kg and 43.4kg, respectively. The pooled results within each of the seven UN regions were consistent with this pattern, although the number of samples contributing to three regions (Africa, Australia and Japan) was low.

## Measurement protocol and reporting of normative data

The protocol used to measure grip strength and the reporting of normative data varied between the included papers. The majority had used the Jamar hydraulic (n=31) or other types of hydraulic dynamometer (n=18), with measurement in the seated position (n=42). Most studies (n=54) presented grip strength normative data for each hand separately (and we extracted data for either the right or dominant hand in such cases). The summary of repeated trials varied: either the maximum (n=33), mean (n=19) or not specified (n=11). Meta-regression analyses (results not shown) did not find evidence of a difference in mean grip strength Z-scores in terms of these protocol and reporting factors.

# Discussion

## Main findings

We carried out a systematic literature review of published normative data for grip strength. We saw that the normative data followed the same pattern across the life course as our previous British normative data, with an increase across childhood to peak in early adult life, broad maintenance through to midlife and decline from midlife onwards. There was clear evidence that average grip strength measurements are substantially lower in developing compared with developed world regions. Our findings are important since they highlight how consensus definitions of sarcopenia and frailty may need different cut points for grip strength for different geographical regions.

## Comparison with other studies

There are several possible explanations for the difference in normative data for grip strength between regions, including differences in body size and composition including mean height and weight. We were not able to test this as the studies did not present age and gender stratified height and weights alongside those for grip strength. Koopman et al. [77] compared grip strength between samples in Ghana and the Netherlands across ages 50-80 years: those in the Netherlands were stronger on average than those in Ghana, but they were also taller and had higher BMI. To take account of these differences in body size the authors used linear regression to predict age- and gender specific grip strength in the Ghanaian sample assuming they had the same mean height and BMI as their Dutch counterparts. This showed that differences in body size largely explained the differences in grip strength that had been observed. Clearly these differences in height and weight between Ghana and the Netherlands are likely to be explained by a wide range of factors including early growth, nutrition and genetic factors, many of which may also account for the differences seen in grip strength.

We are not aware of other studies that have compared normative data for grip strength between world regions. Two of the papers from our literature search provided normative values from two samples: Kaur et al. [42] from rural and urban Haryana in North India, and Rodrigues-Barbosa et al. [62] from Barbados and Cuba. In neither paper had the authors tested for differences between the two samples. We found no evidence of a marked or statistically significant difference when we did this by pooling the Z-scores from each sample (results not shown). Bohannon et al. [12] combined normative data for grip strength from 12 studies from countries in developed regions: the USA, Canada, UK, Sweden and Australia in order to produce normative data for the Jamar dynamometer for ages 20-75. They did not find evidence of heterogeneity between the 12 studies that they combined. This is in keeping with our results of similar pooled Z-scores from developed regions.

We are also not aware of other studies that have compared sets of normative data for grip strength collected with different measurement protocols. We previously found that 12 British studies using a range of dynamometers in the seated and standing positions produced acceptably similar normative data [8], and our present finding of no marked difference in the pooled Z-scores of other normative data papers by protocol factors is consistent with this. Several studies have examined whether values from repeat measurements of grip strength using different dynamometers [78–80] or a change of position [81–83] are consistent. The findings have varied although overall these studies support using a consistent protocol for repeat measurements of an individual’s grip strength where possible. We also again highlight the importance of recent calls for standardisation in future data collections [21,84].

## Clinical relevance of findings

As consensus definitions for sarcopenia and frailty are implemented in clinical practice, the question of whether a single set of normative data and cut points for grip strength can be applied across a range of different countries is an important one. For example, we previously used a T-score approach [85] to produce cut points from our British normative data of 27 kg in males and 16 kg in females, and we estimated that approximately 25% of individuals aged 80 were at or below these levels [8]. If the same cut-offs were applied to a hypothetical population with a mean grip strength 0.85 SDs lower than our British norms, as seen in our pooled results for developing regions, then the prevalence at age 80 would increase to approximately 60%. This suggests that the cut points from our British normative data may not be specific enough in developing regions. Indeed the potential need for specific cut points for the Asia region, as well as the need to consider heterogeneity between countries in this region, have recently been recognised [86,87]; a situation analogous to the use of region-specific BMD thresholds for fracture risk prediction in osteoporosis. It would be helpful to investigate prospective associations between grip strength and outcomes in a region-specific fashion [2], in order to determine optimum cut points for use in clinical practice.

A related question is whether normative data and cut points need to be stratified by height and ethnicity, and whether these factors would explain the regional differences that we observed. As described earlier, differences in height (and BMI) appeared to account for differences in grip strength between samples from Ghana and the Netherlands [75]. Other studies in the US and the Netherlands have examined differences in grip strength by ethnicity [88–90]. The combination of data from cohorts based in different regions would allow the independent contributions of height, ethnicity and region to the global variation in grip strength to be examined.

We searched for papers containing normative data on grip strength from samples of the general population. The results of this review demonstrate that the measurement of grip strength has been undertaken in such samples in many countries, suggesting that it is acceptable for research participants and data collection teams. There is growing interest in the assessment of grip strength of individuals in hospitals and care homes [91–95], although to date there are few examples of age and gender stratified normative data in this diverse range of settings.

## Strengths and limitations

The systematic literature review had some limitations. In terms of the literature search, it is possible that there are other examples of normative data for grip strength in journals not indexed by MEDLINE or EMBASE, or those not published in medical journals, such as in government reports. We also found 12 papers with data not presented in the correct form. It is possible that contacting the authors of these papers would have allowed us to include them. However we do not believe that the inclusion of additional papers would substantially alter our results. Also many of the included papers were based on small convenience samples of the local area or one facility. This may have led to pooled estimates for some countries which were not representative of the population as a whole, although we did use random effects metaregression which anticipated variance between estimates and weighted them according to their standard errors. Finally as stated above we have not been able to explore to what extent factors such as height and ethnic group account for the differences in grip strength between regions.

This review also had many strengths. We undertook a comprehensive literature search which yielded papers on grip strength from all world regions. There was considerable variation in how papers reported their normative data, such as the age ranges and descriptive statistics used. We undertook necessary data management and then used our British norms as a reference to generate Z-scores for inclusion in metaregression analyses. As far as we are aware, such an approach has not been used before for grip strength.

## Conclusions

There is an urgent need for widely applicable thresholds for grip strength in men and women. This systematic review found that normative data from developed regions were similar to those described in our recent British centiles, whereas those from developing regions were clearly lower. This supports the use of our cut points (or those from the FNIH Sarcopenia project) in consensus definitions for sarcopenia and frailty across Europe, Northern America, Australia and Japan. In Asia, the rest of the Americas and Africa, consideration will need to be given to region-specific cut points.

# References

1. Sayer AA, Kirkwood TBL. Grip strength and mortality: a biomarker of ageing? Lancet. 2015;386(9990):226–7.

2. Leong DP, Teo KK, Rangarajan S, *et al.* Prognostic value of grip strength: findings from the Prospective Urban Rural Epidemiology (PURE) study. Lancet. 2015;386(9990):266–73.

3. Cooper R, Kuh D, Hardy R, Mortality Review Group. Objectively measured physical capability levels and mortality: systematic review and meta-analysis. BMJ. 2010;341:c4467.

4. Cooper R, Kuh D, Cooper C, *et al.* Objective measures of physical capability and subsequent health: a systematic review. Age Ageing. 2011;40(1):14–23.

5. Cheung C-L, Nguyen U-SDT, Au E, Tan KCB, Kung AWC. Association of handgrip strength with chronic diseases and multimorbidity. Age (Omaha). 2013;35(3):929–941.

6. Aihie Sayer A, Robinson SM, Patel HP, Shavlakadze T, Cooper C, Grounds MD. New horizons in the pathogenesis, diagnosis and management of sarcopenia. Age Ageing. 2013;42(2):145–50.

7. Fried LP, Tangen CM, Walston J, *et al.* Frailty in older adults: evidence for a phenotype. J Gerontol A Biol Sci Med Sci. 2001;56A(3):M146–M156.

8. Dodds RM, Syddall HE, Cooper R, *et al.* Grip strength across the life course: normative data from twelve British studies. PLoS One. 2014;9(12):e113637.

9. Alley DE, Shardell MD, Peters KW, *et al.* Grip strength cutpoints for the identification of clinically relevant weakness. J Gerontol A Biol Sci Med Sci. 2014;69(5):559–66.

10. Häger-Ross C, Rösblad B. Norms for grip strength in children aged 4-16 years. Acta Paediatr. 2002;91(6):617–25.

11. Almuzaini KS. Muscle function in Saudi children and adolescents: relationship to anthropometric characteristics during growth. Pediatr Exerc Sci. 2007;19(3):319–33.

12. Bohannon RW, Peolsson A, Massy-Westropp N, Desrosiers J, Bear-Lehman J. Reference values for adult grip strength measured with a Jamar dynamometer: a descriptive meta-analysis. Physiother. 2006;92(1):11–15.

13. Adedoyin RA, Ogundapo FA, Mbada CE, *et al.* Reference values for handgrip strength among healthy adults in Nigeria. Hong Kong Physiother J. 2009;27(1):21–29.

14. Frederiksen H, Hjelmborg J, Mortensen J, McGue M, Vaupel JW, Christensen K. Age trajectories of grip strength: cross-sectional and longitudinal data among 8,342 Danes aged 46 to 102. Ann Epidemiol. 2006;16(7):554–62.

15. Spruit MA, Sillen MJH, Groenen MTJ, Wouters EFM, Franssen FME. New normative values for handgrip strength: results from the UK Biobank. JAMDA. 2013;14(10):775.e5–11.

16. Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. Ann Intern Med. 2009;151(4):264–269.

17. Engineering Department University of Cambridge. Unit conversion tables. Available at: http://www3.eng.cam.ac.uk/DesignOffice/cad/proewild3/usascii/proe/promec/getstart/units/reference/units\_conv.htm. Accessed February 26, 2015.

18. Burton DA. Composite standard deviations. Available at: http://www.burtonsys.com/climate/composite\_standard\_deviations.html. Accessed December 11, 2014.

19. StataCorp. Stata statistical software: release 13. 2014.

20. United Nations Statistics Division. Composition of macro geographical (continental) regions, geographical sub-regions, and selected economic and other groupings. 2013. Available at: http://unstats.un.org/unsd/methods/m49/m49regin.htm. Accessed December 9, 2014.

21. Roberts HC, Denison HJ, Martin HJ, *et al.* A review of the measurement of grip strength in clinical and epidemiological studies: towards a standardised approach. Age Ageing. 2011;40(4):423–9.

22. Aadahl M, Beyer N, Linneberg A, Thuesen BH, Jørgensen T. Grip strength and lower limb extension power in 19-72-year-old Danish men and women: the Health2006 study. BMJ Open. 2011;1(2):e000192.

23. Ahn R, Yoo C-I, Lee H, *et al.* Normative data for neuromuscular assessment of the hand-arm vibration syndrome and its retrospective applications in Korean male workers. Int. Arch. Occup. Environ. Health. 2013;86(7):837–44.

24. Backman E, Johansson V, Hager B, Sjoblom P, Henriksson KG. Isometric muscle strength and muscular endurance in normal persons aged between 17 and 70 years. Scand J Rehab Med. 1995;27:109–117.

25. Balogun JA, Adenlola SA, Akinloye AA. Grip strength normative data for the Harpenden dynamometer. J Orthop Sport. Phys Ther. 1991;14(4):155–60.

26. Bear-Lehman J, Kafko M, Mah L, Mosquera L, Reilly B. An exploratory look at hand strength and hand size among preschoolers. J. Hand Ther. 15(4):340–6.

27. Brennan P, Bohannon R, Pescatello L, Marschke L, Hanson S, Murphy M. Grip strength norms for elderly women. Percept Mot. Ski. 2004;99:899–902.

28. Budziareck MB, Pureza Duarte RR, Barbosa-Silva MCG. Reference values and determinants for handgrip strength in healthy subjects. Clin Nutr. 2008;27(3):357–62.

29. Chatterjee S, Chowdhuri BJ. Comparison of grip strength and isometric endurance between the right and left hands of men and their relationship with age and other physical parameters. J Hum. Ergol. 1991;20:41–50.

30. Chuang MC, You M, Cai D, Chen CC. Isometric muscle strength of Chinese young males in Taiwan. Ergonomics. 1997;40(5):576–90.

31. Cohen DD, Voss C, Taylor MJD, Stasinopoulos DM, Delextrat A, Sandercock GRH. Handgrip strength in English schoolchildren. Acta Paediatr. 2010;99(7):1065–72.

32. Corish CA, Kennedy NP. Anthropometric measurements from a cross-sectional survey of Irish free-living elderly subjects with smoothed centile curves. Br. J. Nutr. 2003;89(1):137–45.

33. De Smet L, Vercammen A. Grip strength in children. J Pedr Ortho B. 2001;10:352–4.

34. Desrosiers J, Bravo G, Hébert R, Dutil É. Normative data for grip strength of elderly men and women. Am J Occ Ther. 1995;49(7):637–44.

35. Gunther CM, Burger A, Rickert M, Crispin A, Schulz C. Grip strength in healthy caucasian adults: reference values. J Hand Surg Am. 2008;33(4):558–65.

36. Hanten WP, Chen W-Y, Austin AA, *et al.* Maximum grip strength in normal subjects from 20 to 64 years of age. J. Hand Ther. 1999;12(3):193–200.

37. Harkonen R, Piirtomaa M, Alaranta H. Grip strength and hand position of the dynamometer in 204 Finnish adults. J Hand Surg [Eur]. 1993;18B:129–32.

38. Holm I, Fredriksen P, Fosdahl M, Vøllestad N. A normative sample of isotonic and isokinetic muscle strength measurements in children 7 to 12 years of age. Acta Paediatr. 2008;97(5):602–7.

39. Horowitz BP, Tollin R, Cassidy G. Grip Strength : Collection of Normative Data with Community Dwelling Elders. Phys Occ Ther Ger. 1997;15(1):53–64.

40. Jansen CWS, Niebuhr BR, Coussirat DJ, Hawthorne D, Moreno L, Phillip M. Hand force of men and women over 65 years of age as measured by maximum pinch and grip force. J. Aging Phys. Act. 2008;16(1):24–41.

41. Kallman D, Plato C, Tobin J. The role of muscle loss in the age-related decline of grip strength: cross-sectional and longitudinal perspectives. J Gerontol. 1990;45(3):M82–8.

42. Kaur M. Age-related changes in hand grip strength among rural and urban Haryanvi Jat females. Homo. 2009;60(5):441–50.

43. Kenny RA, Coen RF, Frewen J, Donoghue OA, Cronin H, Savva GM. Normative values of cognitive and physical function in older adults: findings from the Irish Longitudinal Study on Ageing. J Am Geriatr Soc. 2013;61 S2:S279–90.

44. Lang I, Busche P, Rakhimi N, Rawer R, Martin DD. Mechanography in childhood: References for grip force, multiple one-leg hopping force and whole body stiffness. J Musculoskelet Neuronal Interact. 2013;13(2):227–35.

45. Luna-Heredia E, Martín-Peña G, Ruiz-Galiana J. Handgrip dynamometry in healthy adults. Clin Nutr. 2005;24(2):250–8.

46. Massy-Westropp N, Rankin W, Ahern M, Krishan J, Hearn TC. Measuring grip strength in normal adults: reference ranges and a comparison of electronic and hydraulic instruments. J Hand Surg Am. 2004;29(3):514–9.

47. Massy-Westropp NM, Gill TK, Taylor AW, Bohannon RW, Hill CL. Hand Grip Strength: age and gender stratified normative data in a population-based study. BMC Res Notes. 2011;4(1):127.

48. Mathiowetz V, Kashman N, Volland G, Weber K, Dowe M, Rogers S. Grip and pinch strength: normative data for adults. Arch Phys Med Rehabil. 1985;66:69–74.

49. Mathiowetz V, Wiemer DM, Federman SM. Grip and Pinch Strength: Norms for 6- to 19-Year-Olds. Am J Occ Ther. 1986;40(10):705–11.

50. Molenaar HMT, Selles RW, Zuidam JM, Willemsen SP, Stam HJ, Hovius SER. Growth diagrams for grip strength in children. Clin. Orthop. Relat. Res. 2010;468(1):217–23.

51. Montalcini T, Migliaccio V, Yvelise F, *et al.* Reference values for handgrip strength in young people of both sexes. Endocrine. 2013;43:342–45.

52. Mullerpatan RP, Karnik G, John R. Grip and pinch strength: Normative data for healthy Indian adults. Hand Ther. 2013;18(1):11–16.

53. Nevill AM, Holder RL. Modelling handgrip strength in the presence of confounding variables: results from the Allied Dunbar National Fitness Survey. Ergonomics. 2000;43(10):1547–58.

54. Nilsen T, Hermann M, Eriksen CS, Dagfinrud H, Mowinckel P, Kjeken I. Grip force and pinch grip in an adult population: reference values and factors associated with grip force. Scand J Occ Ther. 2012;19(3):288–96.

55. Pearl A, Robinson D, Hale A. Fitness in a U.K. screening sample - a comparison with the Canadian Population. Meth Inf. Med. 1993;32:203–5.

56. Peolsson A, Hedlund R, Oberg B. Intra- and inter-tester reliability and reference values for hand strength. J Rehab Med. 2001;33:36–41.

57. Peters MJH, van Nes SI, Vanhoutte EK, *et al.* Revised normative values for grip strength with the Jamar dynamometer. J. Peripher. Nerv. Syst. 2011;16(1):47–50.

58. Ploegmakers JJW, Hepping AM, Geertzen JHB, Bulstra SK, Stevens M. Grip strength is strongly associated with height, weight and gender in childhood: a cross sectional study of 2241 children and adolescents providing reference values. J. Physiother. 2013;59(4):255–61.

59. Puh U. Age-related and sex-related differences in hand and pinch grip strength in adults. Int J Rehab Res. 2010;33:4–11.

60. Rauch F, Neu CM, Wassmer G, *et al.* Muscle analysis by measurement of maximal isometric grip force: new reference data and clinical applications in pediatrics. Pediatr. Res. 2002;51(4):505–10.

61. Ribom EL, Mellström D, Ljunggren Ö, Karlsson MK. Population-based reference values of handgrip strength and functional tests of muscle strength and balance in men aged 70-80 years. Arch Gerontol Ger. 2011;53(2):e114–7.

62. Rodrigues-Barbosa A, Miranda LM De, Vieira-Guimaraes A, Xavier-Corseuil H, Weber-Corseuil M. Age and gender differences regarding physical performance in the elderly from Barbados and Cuba. Rev salud pública. 2011;13(1):54–66.

63. Schlüssel MM, dos Anjos LA, de Vasconcellos MTL, Kac G. Reference values of handgrip dynamometry of healthy adults: a population-based study. Clin Nutr. 2008;27(4):601–7.

64. Seino S, Shinkai S, Fujiwara Y, *et al.* Reference values and age and sex differences in physical performance measures for community-dwelling older Japanese: a pooled analysis of six cohort studies. PLoS One. 2014;9(6):e99487.

65. Sella GE. The hand grip : gender , dominance and age considerations. Eur Med Phys. 2001;37(3):161–170.

66. Semproli S, Brasili P, Toselli S, Ventrella A, Jurimae J, Jurimae T. The influence of anthropometric characteristics to the handgrip and pinch strength in 6-10-year old children. Anthr. Anz. 2007;65(3):293–302.

67. Shim JH, Roh SY, Kim JS, *et al.* Normative measurements of grip and pinch strengths of 21st century Korean population. Arch. Plast. Surg. 2013;40(1):52–6.

68. Skelton DA, Greig CA, Davies JM, Young A. Strength, Power and Related Functional Ability of Healthy People Aged 65–89 Years. Age Ageing. 1994;23(5):371–377.

69. Tsang RCC. Reference Values for 6-Minute Walk Test and Hand-Grip Strength in Healthy Hong Kong Chinese Adults. Hong Kong Physiother. J. 2005;23(1):6–12.

70. Tveter AT, Dagfinrud H, Moseng T, Holm I. Health-related physical fitness measures: reference values and reference equations for use in clinical practice. Arch. Phys. Med. Rehabil. 2014;95(7):1366–73.

71. Vianna LC, Oliveira R, Araujo CGS. Age-related decline in handgrip strength differs according to gender. J Strength Cond Res. 2007;21(4):1310–14.

72. Wang C-Y. Hand dominance and grip strength of older Asian adults. Percept Mot. Ski. 2010;110:897–900.

73. Werle S, Goldhahn J, Drerup S, Simmen BR, Sprott H, Herren DB. Age- and gender-specific normative data of grip and pinch strength in a healthy adult Swiss population. J Hand Surg [Eur]. 2009;34(1):76–84.

74. Wu S-W, Wu S-F, Liang H-W, Wu Z-T, Huang S. Measuring factors affecting grip strength in a Taiwan Chinese population and a comparison with consolidated norms. Appl. Ergon. 2009;40(4):811–5.

75. Yim SY, Cho JR, Lee IY. Normative data and developmental characteristics of hand function for elementary school children in Suwon area of Korea: grip, pinch and dexterity study. J Korean Med Sci. 2003;18(4):552–8.

76. Yoshimura N, Oka H, Muraki S, *et al.* Reference values for hand grip strength, muscle mass, walking time, and one-leg standing time as indices for locomotive syndrome and associated disability: the second survey of the ROAD study. J Orthopaed Sci. 2011;16(6):768–77.

77. Koopman JJE, van Bodegom D, van Heemst D, Westendorp RGJ. Handgrip strength, ageing and mortality in rural Africa. Age Ageing. 2015;44(3):465–470.

78. Svantesson U, Nordé M, Svensson S, Brodin E. A comparative study of the Jamar® and the Grippit® for measuring handgrip strength in clinical practice. Isokinet. Exerc Sci. 2009;17:85–91.

79. Amaral JF, Mancini M, Novo Júnior JM. Comparison of three hand dynamometers in relation to the accuracy and precision of the measurements. Rev. Bras. Fisioter. 2012;16(3):216–24.

80. Guerra RS, Amaral TF. Comparison of hand dynamometers in elderly people. J Nutr Heal. Ageing. 2009;13(10):907–12.

81. Shechtman O, Mackinnon L, Locklear C. Using the BTE Primus to measure grip and wrist flexion strength in physically active wheelchair users: an exploratory study. Am J Occup Ther. 2001;55(4):393–400.

82. Balogun J, Akomolafe C, Amusa L. Grip strength: effects of testing posture and elbow position. Arch Phys Med Rehabil. 1991;72(5):280–3.

83. Liao W-C, Wang C-H, Yu S-Y, Chen L-Y, Wang C-Y. Grip strength measurement in older adults: A comparison of three testing positions. Austr J Ageing. 2014;33(4):278–82.

84. Reuben DB, Magasi S, McCreath HE, *et al.* Motor assessment using the NIH Toolbox. Neurology. 2013;80:S65–75.

85. Bohannon RW, Magasi S. Identification of dynapenia in older adults through the use of grip strength *t* -scores. Muscle Nerve. 2015;51(1):102–105.

86. Woo J, Arai H, Ng TP, *et al.* Ethnic and geographic variations in muscle mass, muscle strength and physical performance measures. Eur. Geriatr. Med. 2014;5(3):155–164.

87. Chen LK, Liu LK, Woo J, *et al.* Sarcopenia in Asia: Consensus report of the Asian working group for sarcopenia. J. Am. Med. Dir. Assoc. 2014;15(2):95–101.

88. Haas S a, Krueger PM, Rohlfsen L. Race / Ethnic and Nativity Disparities in Later Life Physical Performance : The Role of Health and Socioeconomic Status Over the Life Course. Journals Gerontol. Ser. B Psychol. Sci. Soc. Sci. 2012;67:238–248.

89. Van der Kooi A-LLF, Snijder MB, Peters RJG, van Valkengoed IGM. The Association of Handgrip Strength and Type 2 Diabetes Mellitus in Six Ethnic Groups: An Analysis of the HELIUS Study. PLoS One. 2015;10(9):e0137739.

90. Araujo AB, Chiu GR, Kupelian V, *et al.* Lean mass, muscle strength, and physical function in a diverse population of men: a population-based cross-sectional study. BMC Public Health. 2010;10:508.

91. Kerr A, Syddall HE, Cooper C, Turner GF, Briggs RS, Aihie Sayer A. Does admission grip strength predict length of stay in hospitalised older patients? Age Ageing. 2006;35(1):82–4.

92. García-Peña C, García-Fabela LC, Gutiérrez-Robledo LM, García-González JJ, Arango-Lopera VE, Pérez-Zepeda MU. Handgrip strength predicts functional decline at discharge in hospitalized male elderly: a hospital cohort study. PLoS One. 2013;8(7):e69849.

93. Guerra RS, Fonseca I, Pichel F, Restivo MT, Amaral TF. Handgrip strength and associated factors in hospitalized patients. J. Parenter. Enter. Nutr. 2015;39(3):322–30.

94. Keevil VL, Mazzuin Razali R, Chin AV, Jameson K, Aihie Sayer A, Roberts H. Grip strength in a cohort of older medical inpatients in Malaysia: A pilot study to describe the range, determinants and association with length of hospital stay. Arch Gerontol Ger. 2013;56:155–159.

95. Roberts HC, Syddall HE, Sparkes J, *et al.* Grip strength and its determinants among older people in different healthcare settings. Age Ageing. 2014;43(2):241–6.

# Figures and Tables

## Figure 1. Country setting of included samples, by UN region



The chart shows the country setting of the 63 included samples, grouped by UN region.

## Figure 2. Grip strength mean values from included samples, by region

U:\__existing_analysis\region\Output 10 Jun 2015 plot 2.emf

Each point represents the mean value of grip strength for each item of normative data, plotted against the mid-point of the age range it relates to. Values from the same sample are connected.

Data from developing and developed regions are shown with triangles and circles, respectively.

For comparison, the grey line shows the mean values from our normative data for 12 British studies.

## Table 1. Characteristics of included samples, by developed status of region

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | **Developed status n (%)\*** | | | | | |
| **Characteristic** |  | **Developing**  **N=19** | | **Developed**  **N=44** | | **Both**  **N=63** | |
| Year of  publication | 1985 – 1994 | 2 | (11) | 6 | (14) | 8 | (13) |
| 1995 – 2004 | 2 | (11) | 15 | (34) | 17 | (27) |
| 2005 – 2014 | 15 | (79) | 23 | (52) | 38 | (60) |
| Sample  level | National | 1 | (5) | 6 | (14) | 7 | (11) |
| Regional | 3 | (16) | 10 | (23) | 13 | (21) |
| Local / facility / NS | 15 | (79) | 28 | (64) | 43 | (68) |
| Sample  type | Sampling frame | 3 | (16) | 14 | (32) | 17 | (27) |
| Convenience / NS | 16 | (84) | 30 | (68) | 46 | (73) |
| Sample size† | Median (IQR) | 435 | (120, 1005) | 514 | (270, 1479) | 498 | (225, 1119) |
| Stage of life  course | Child / adol. ≤ 18 y | 3 | (16) | 11 | (25) | 14 | (22) |
| Adults all < 50 y | 3‡ | (16) | 2 | (5) | 5 | (8) |
| Adults all ≥ 50 y | 3 | (16) | 9 | (20) | 12 | (19) |
| Adults, both ages | 8 | (42) | 20§ | (45) | 28 | (44) |
| All stages above | 2 | (11) | 2 | (5) | 4 | (6) |
| Dynamometer | Jamar hydraulic | 8 | (42) | 23 | (52) | 31 | (49) |
|  | Other - hydraulic | 6 | (32) | 12 | (27) | 18 | (29) |
|  | Electronic | 3 | (16) | 6 | (14) | 9 | (14) |
|  | NS | 2 | (11) | 3 | (7) | 5 | (8) |
| Position | Seated | 10 | (53) | 32 | (73) | 42 | (67) |
|  | Standing | 6 | (32) | 7 | (16) | 13 | (21) |
|  | NS | 3 | (16) | 5 | (11) | 8 | (13) |
| Hand(s) described in extracted data | Right / dominant | 18 | (95) | 32 | (72) | 50 | (79) |
| Non-dominant | 0 | (0) | 4 | (9) | 4 | (6) |
| Both | 1 | (5) | 8 | (18) | 9 | (14) |
| Summary of trials | Maximum | 11 | (58) | 22 | (50) | 33 | (52) |
| Mean | 6 | (32) | 13 | (30) | 19 | (30) |
| NS | 2 | (11) | 9 | (20) | 11 | (17) |

NS, not specified.

\*­ Unless otherwise specified. Please note all percentages are rounded to the nearest whole percentage point, and hence the total for each group may not equal 100.

† This refers to the sample size for the age ranges extracted from each paper. This value is smaller than the sample size provided in papers which had included open-ended age ranges such as 75+ years.

‡ The paper by Chatterjee et al.[29] had an age range of 10-49 years and for the purpose of this table we classed this as a young adult paper.

§ The paper by Backman et al.[24] had an age range of 17-70 years and we classed this as adults, both ages.

## Table 2. Pooled Z-scores by region status and individual regions

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Classification | N \* | Pooled  Z-score † | (95% CI) | Adjusted R2 § |
| Overall | 63 | -0.09 | (-0.14, -0.04) | - |
|  |  |  |  |  |
| **UN region status** |  |  |  | 34.1% |
| Developing | 19 | -0.85 | (-0.94, -0.76) |  |
| Developed | 44 | 0.12 | ( 0.07, 0.17) |  |
|  |  |  |  |  |
| **UN world region  (with references shown)** |  |  |  | 36.3% |
|  |  |  |  |  |
| *Developing regions* |  |  |  |  |
| Africa  [13,25] | 2 | -1.34 | (-1.57, -1.11) |  |
| Americas excluding N America  [28,62,63,71] | 5 | -0.80 | (-0.97, -0.63) |  |
| Asia excluding Japan  [11,23,29,30,42,67,69,72,74,75] | 12 | -0.74 | (-0.86, -0.62) |  |
|  |  |  |  |  |
| *Developed regions* |  |  |  |  |
| Australia  [46,47] | 3 | -0.01 | (-0.20, 0.18) |  |
| Europe  [10,14,15,22,24,31–33,35,37,38,43–45,50,51,53–61,66,68,70,73] | 29 | 0.13 | ( 0.07, 0.19) |  |
| Japan  [64,76] | 2 | -0.13 | (-0.40, 0.14) |  |
| Northern America  [26,27,34,36,39–41,48,49,65] | 10 | 0.16 | ( 0.04, 0.28) |  |

Results shown are from separate metaregression models of all 718 normative data items, with model term(s) those for each classification shown.

\* N, number of samples contributing to each subgroup.

† The Z-score scale is the number of SDs above the equivalent values from our British centiles. Each pooled Z-score (and 95% CI) is from a metaregression model combining the Z-scores for all the normative data items from the subgroup shown.

§ The adjusted R2 is the proportion of variance between each item of normative data explained by each of the two classifications.

# Supplementary material

## Appendix 1. Full list of references

## Appendix 2. Search strategy used

Search run on 11th August 2014 using databases MEDLINE (including in-process citations) and EMBASE.

|  |  |  |
| --- | --- | --- |
| **Step** | **Search string** | **Abstracts returned** |
| 1 | (Hand Strength/ or Muscle Strength Dynamometer/ or "grip strength".ti,ab or "hand strength".ti,ab or "handgrip strength".ti,ab or "grip dynamometer".ti,ab) | 26480 |
| 2 | Reference Values/ or "reference values".ti,ab. or "normative".ti,ab. or (association\* adj2 age).ab. or (relationship adj2 age).ab. or "age related".ti. or "age-related".ti. or "normal values".ti,ab | 334730 |
| 3 | 1 and 2 | 1167 |
| 4 | remove duplicates from 3  (with preference towards MEDLINE) | 860 |
| 5 | (4 and humans/) or (4 not (humans/ or animals/)) | 840 |
| 6 | limit 5 to english language | 811 |
| 7 | limit 6 to yr="1980 -Current" | 806 |

## Appendix 3. Statistical appendix

**a. Formulae used to calculate standard errors**

Calculation of standard error of the sample mean, from standard deviation, and sample size, :

Calculation of standard deviation, , when alternatives provided as shown:

|  |  |
| --- | --- |
| Lower 95 % CI, for mean |  |
| Interquartile range\* and  (based on the N(0,1) distribution, and are 0.674 SDs either side of the mean, so the difference between them represents 1.348 SDs). |  |
| Fifth centile  (as above, is 1.645 SDs below the mean) |  |

\* From our earlier work on normative data, we considered it reasonable to assume that grip strength was normally distributed and indeed on inspection of the data that we extracted from studies reporting a median and interquartile range for grip strength, there was very little evidence of skew.

**b. Interpretation of differences in grip strength on the Z-score scale**

In our paper on British normative data for grip strength, we tested if the results from sensitivity analyses were acceptably similar to our main grip strength centiles using a range of 10% either side of the main findings [8]. We took a similar approach in the current work when testing differences between our British normative data and the results of our systematic literature search, both in terms of world region and aspects of measurement protocol.

To do this, we assumed that the coefficient of variation (the ratio of the standard deviation to the mean) for grip strength was 0.25. This was based on our British normative data, where we saw a mean coefficient of variation across the life course of 0.22. The average coefficient of variation across the 730 normative data items in the present study was similar at 0.21.

Following our assumption, a 1 SD difference in mean grip strength is equivalent to a 25% difference in mean grip strength (kg). It therefore follows that a 10% difference in mean grip strength (kg) is equivalent a 0.4 SD difference in mean grip strength Z-score.

## Appendix 4. Flow diagram for systematic review

**n = 806 abstracts screened**

**n = 96 papers retrieved for further assessment**

**n = 60 papers included in the review**

n = 702 not considered relevant

n = 3 seen to be duplicates

n = 4 conference abstracts (no paper found)

n = 709 abstracts excluded:

n = 18 not a normative data study of grip strength

n = 36 papers excluded:

n = 4 specific illness / occupational groups

n = 12 normative data not in correct form\*

n = 1 potentially relevant paper not available

n = 2 same data as an earlier study

\* Reasons for normative data not being in the correct form included not presenting data in the form of a table, including a mean but no measure of spread such as standard deviation, and using an age range for each item of normative data wider than 15 years.

## Appendix 5. Full list of included studies

Studies ordered by first author and then by year. C, convenience sample. NS, not specified. Sf, sampling frame used.

\* The age range shown is that for the normative data items that we extracted from each paper. We excluded open-ended age ranges, such as 70+ years.

† N, the number of individuals with grip strength measurements in the age range specified. These are notably lower than the figures in the published papers by Frederiksen et al. and Spruit et al., since in these two studies we chose to extract details for a single height group only.

‡ In the paper by Frederiksen et al., sample sizes for individual normative data items were not provided. Rather the sample size shown is approximated based on the standard deviation and standard error of the sample mean, which were provided for each item.

| **Author, year**  **Ref** | **Type** | **Country** | **Level** | **Sample description** | **Dynamometer** | **Age range (y)\*** | **N†** |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Aadahl, 2011  [22] | Sf | Denmark | Regional | Participants recruited through the Danish Civil Registration office across in 11 municipalities in the western area of the Capital Region of Denmark. | Jamar hydraulic | 19 - 72 | 3453 |
| Adedoyin, 2009  [13] | C | Nigeria | Facility | Participants recruited by advertisement and invitations from Obafemi Awolowo University, Ile-Ife. | Takei TKK 84466 | 20 - 69 | 745 |
| Ahn, 2013  [23] | C | Korea, Republic of | Facility | Recruited from healthy participants visiting the Occupational and Environmental Health Center over a 2 month period. | Camry Electronic | 30 - 59 | 120 |
| Almuzaini, 2007  [11] | C | Saudi Arabia | Local | Drawn from three local schools. | NS | 11 - 19 | 44 |
| Backman, 1995  [24] | Sf | Sweden | NS | Two sources mentioned in paper; appears approached all healthy adults in a small area of Linköping. | Rank Stanley Cox strain gauge | 17 - 70 | 128 |
| Balogun, 1991  [25] | C | Nigeria | Local | Participants were recruited from community residential quarters, shopping centers, churches, and schools. | Harpenden | 7 - 69 | 840 |
| Bear-Lehman, 2002  [26] | C | United States | Local | From 4 preschools in New York City. | Jamar hydraulic | 3 - 5 | 81 |
| Brennan, 2004  [27] | C | United States | Local | Noninstitutionalised women who participated in health screenings at one of five community senior centers in the state of Connecticut. | Jamar hydraulic | 60 - 89 | 104 |
| Budziareck, 2008  [28] | C | Brazil | Local | Three locations: a hospital, centre for older people and a local city square. | Jamar hydraulic | 18 - 30 | 100 |
| Chatterjee, 1991  [29] | NS | India | NS | Normal healthy male subjects. | Simple handgrip dynamometer -INCO made in India | 10 - 49 | 81 |
| Chuang, 1997  [30] | C | Taiwan, Province of China | Facility | From one junior college; participants paid NT$ 50 (approx 2 US $) for every hour attending session. | Takei TKK Muscular Power Measuring Device with digital dynamometer | 16 - 20 | 120 |
| Cohen, 2010  [31] | Sf | United Kingdom | Regional | 23 state primary and secondary schools in East of England Healthy Hearts study. | Takei T.K.K.5001 Grip A | 10 - 15 | 6683 |
| Corish, 2003  [32] | C | Ireland | Local | Recruited from interest groups for the active retired. | Takei | 65 - 85 | 874 |
| De Smet, 2001  [33] | NS | Belgium | NS | No sample details provided. | Jamar hydraulic | 5 - 15 | 419 |
| Desrosiers, 1995  [34] | Sf | Canada | Local | Random sampling (with replacement) from the electoral list | Jamar hydraulic | 60 - 79 | 240 |
| Frederiksen, 2006  [14] | Sf | Denmark | National | Participants of three nationwide population-based surveys. | Smedley | 45 - 94 | 2926‡ |
| Gunther, 2008  [35] | C | Germany | Regional | Volunteers randomly chosen from different locations including hospitals, public recreations areas and homes for the elderly. | Baseline digital hydraulic dynamometer | 20 - 95 | 769 |
| Hager-Ross, 2002  [10] | C | Sweden | Local | From 20 randomly chosen day care centres and schools in the municipality of Umea. | Grippit | 4 - 16 | 530 |
| Hanten, 1999  [36] | C | United States | NS | NS. | Jamar hydraulic | 20 - 64 | 1182 |
| Harkonen, 1993  [37] | NS | Finland | NS | Volunteers working in the food and medicine industries. | Jamar hydraulic | 30 - 49 | 115 |
| Holm, 2008  [38] | C | Norway | Local | Schools in the Oslo area up to 4-5km from hospital where study based. | Jamar hydraulic | 7 - 29 | 376 |
| Horowitz, 1997  [39] | C | United States | Local | Two Suffolk County, Long Island senior citizen community organisations. | Jamar hydraulic | 70 - 74 | 47 |
| Jansen, 2008  [40] | C | United States | Local | Recruited from local health fairs, a geriatric primary-care clinic and senior-citizen community events. | Jamar hydraulic | 65 - 84 | 196 |
| Kallman, 1990  [41] | Sf | United States | Regional | Baltimore Longitudinal Study of Ageing | Smedley | 20 - 89 | 842 |
| Kaur (rural), 2009  [42] | NS | India | Regional | Samples of rural Jat (the most prominent caste) females from Haryana, North India. | NS | 40 - 70 | 300 |
| Kaur (urban), 2009  [42] | NS | India | Regional | Samples of urban Jat (the most prominent caste) females from Haryana, North India. | NS | 40 - 70 | 300 |
| Kenny, 2013  [43] | Sf | Ireland | National | Nationally representative sample of adults. | Baseline | 50 - 85 | 5819 |
| Lang, 2013  [44] | NS | Germany | Facility | All participants from Tuebingen Waldorf School | Jamar hydraulic | 3 - 19 | 869 |
| Luna-Heredia, 2005  [45] | C | Spain | Local | Workers of the Móstoles Hospital, Madrid, relatives of patients visiting the hospital and elderly subjects from senior residences in two cities near Madrid. | Baseline and Grip-D (two devices used, considered exchangeable) | 30 - 84 | 473 |
| Massy-Westropp (Grippit), 2004  [46] | C | Australia | Local | From several sources including a large teaching hospital, a high pedestrian-traffic area of a Medical Centre and community centres. | Grippit | 18 - 74 | 362 |
| Massy-Westropp (Jamar), 2004  [46] | C | Australia | Local | From several sources including a large teaching hospital, a high pedestrian-traffic area of a Medical Centre and community centres. | Jamar hydraulic | 18 - 74 | 359 |
| Massy-Westropp, 2011  [47] | Sf | Australia | Regional | Data obtained from the North West Adelaide Health Study - random sampling using telephone directory. NB Sample size not divided into males and females, so total divided by two and split equally across age groups. | Jamar hydraulic | 20 - 69 | 2629 |
| Mathiowetz, 1985  [48] | C | United States | Regional | Recruited from shopping centers, fairs, senior citizen centers, a rehabiliation center (staff) and a university. | Jamar hydraulic | 20 - 74 | 577 |
| Mathiowetz, 1986  [49] | C | United States | Regional | Participants from schools in the seven-county Milwaukee area. | Jamar hydraulic | 6 - 19 | 471 |
| Molenaar, 2010  [50] | C | Netherlands | Facility | Children from a local primary school. | Lode | 4 - 12 | 225 |
| Montalcini, 2013  [51] | C | Italy | Facility | Healthy university students. | Hersteller | 19 - 25 | 335 |
| Mullerpatan, 2013  [52] | C | India | Facility | Students and staff members of (presumed) a single hospital. | Jamar hydraulic | 18 – 30 | 1005 |
| Nevill, 2000  [53] | Sf | United Kingdom | National | Random sample of English population with subsample having physical appraisal. | Nottingham electronic | 16 - 74 | 2632 |
| Nilsen, 2012  [54] | C | Norway | Local | Several settings including shopping malls, workplaces and community centres for the elderly in the region of Oslo. | Grippit | 20 - 79 | 498 |
| Pearl, 1993  [55] | C | United Kingdom | Facility | Subject attending BUPA Health Screening Centre, London. Of those over 50, only those who exercised regularly completed grip strength assessment. | NS | 20 - 69 | 16980 |
| Peolsson, 2001  [56] | Sf | Sweden | Facility | Age stratified sample of hospital staff. | Jamar hydraulic | 25 - 65 | 101 |
| Peters, 2011  [57] | C | Netherlands | Local | University, hospital and secondary school personnel, homes for the elderly and sports clubs. | Jamar hydraulic | 20 - 79 | 614 |
| Ploegmakers, 2013  [58] | C | Netherlands | Regional | Schools approached in the four northern provinces of The Netherlands. | Jamar hydraulic | 4 - 14 | 2241 |
| Puh, 2010  [59] | C | Slovenia | NS | Recruited at locations including shopping centres, fairs and nursing homes. | Baseline | 20 - 79 | 199 |
| Rauch, 2002  [60] | NS | Germany | Regional | Participants in the Dortmund Nutritional and Anthropometric Longitudinally Designed study. | Jamar hydraulic | 7 - 18 | 305 |
| Ribom, 2011  [61] | Sf | Sweden | Regional | MrOS (osteoporotic fractures in men) Sweden cohort in Uppsala. | Jamar hydraulic | 70 - 75 | 548 |
| Rodrigues-Barbosa (Barbados), 2011  [62] | Sf | Barbados | Local | Data taken from SABE (Survey on Health, Aging and Well Being in Latin America and the Caribbean), specifically Bridgetown. | Takei TK 1201 | 60 - 79 | 1119 |
| Rodrigues-Barbosa (Cuba), 2011  [62] | Sf | Cuba | Local | Data taken from SABE (Survey on Health, Aging and Well Being in Latin America and the Caribbean), specifically Havana. | Takei TK 1201 | 60 - 79 | 1425 |
| Schlussel, 2008  [63] | Sf | Brazil | Local | Three stage sampling procedure in the city of Niterói. | Jamar hydraulic | 20 - 69 | 2802 |
| Seino, 2014  [64] | Sf | Japan | National | Six cohort studies participating in TMIG-LISA (Tokyo Metropolitan Institute of Gerontology-Longitudinal Interdisciplinary Study on Aging). | Smedley-like | 65 - 84 | 4443 |
| Sella, 2001  [65] | C | United States | Facility | Retrospective analysis of data collected from an occupational physician's patients (none had upper limb pathology). | Jamar hydraulic | 10 - 69 | 860 |
| Semproli, 2007  [66] | C | Estonia | Local | Several schools in Tartu. | Takei TKK 5001 | 6 - 10 | 461 |
| Shim, 2013  [67] | C | Korea, Republic of | Facility | Patients visiting a hospital for normal health screening visits. | Jamar hydraulic | 10 - 79 | 336 |
| Skelton, 1994  [68] | C | United Kingdom | Local | Volunteers recruited through local and national newspapers to attend Human Performance Laboratory in Hampstead, London. | Takei Kiki Kogyo Handgrip mechanical dynamometer | 65 - 89 | 100 |
| Spruit, 2013  [15] | C | United Kingdom | National | Recruitment via centrally  coordinated identification and invitation from population-based registers (such as those held by the NHS) of potentially eligible people living within a reasonable travelling distance of an assessment centre. | Jamar hydraulic | 45 - 64 | 18735 |
| Tsang, 2005  [69] | C | China | Regional | Healthy subjects from 22 hospitals and clinics of the Hospital Authority in Hong Kong. | Jamar hydraulic | 21 - 70 | 544 |
| Tveter, 2014  [70] | C | Norway | Local | Volunteers recruited from a range of work sites, schools, community centres for older adults. | Baseline | 18 - 90 | 370 |
| Vianna, 2007  [71] | C | Brazil | Facility | Those attending a private exercise medicine clinic. | Takei Digital Grip Dynamometer | 18 - 75 | 2477 |
| Wang, 2010  [72] | NS | Taiwan, Province of China | NS | Volunteers but source(s) NS. | Jamar hydraulic | 60 - 89 | 176 |
| Werle, 2009  [73] | C | Switzerland | Local | Shopping centres and malls, secondary schools, senior sports groups and senior residences. | Jamar hydraulic | 18 - 84 | 922 |
| Wu, 2009  [74] | C | Taiwan, Province of China | National | The research team visited universities, mountain villages, public parks, markets, community halls, churches and temples. Access to volunteers was gained through community gatekeepers, district nurses, priests, and local community leaders. | Jamar hydraulic | 20 - 74 | 435 |
| Yim, 2003  [75] | C | Korea, Republic of | Facility | Students in an elementary school in Suwon city, Korea | Jamar hydraulic | 7 - 12 | 712 |
| Yoshimura, 2011  [76] | Sf | Japan | National | Second wave of a large-scale population cohort study: the ROAD study (research on osteoarthritis / osteopororis against disability) | Toei Light handgrip dynamometer | 40 - 79 | 1776 |