Muscle mass, strength, and physical performance predicting activities of daily living: a meta-analysis

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Abstract

Background
Activities of daily living (ADLs) and instrumental activities of daily living (IADLs) are essential for independent living and are predictors of morbidity and mortality in older populations. Older adults who are dependent in ADLs and IADLs are also more likely to have poor muscle measures defined as low muscle mass, muscle strength, and physical performance, which further limit their ability to perform activities. The aim of this systematic review and meta-analysis was to determine if muscle measures are predictive of ADL and IADL in older populations.

Methods
A systematic search was conducted using four databases (MEDLINE, EMBASE, Cochrane, and CINAHL) from date of inception to 7 June 2018. Longitudinal cohorts were included that reported baseline muscle measures defined by muscle mass, muscle strength, and physical performance in conjunction with prospective ADL or IADL in participants aged 65 years and older at follow-up. Meta-analyses were conducted using a random effect model.

Results
Of the 7760 articles screened, 83 articles were included for the systematic review and involved a total of 108 428 (54.8% female) participants with a follow-up duration ranging from 11 days to 25 years. Low muscle mass was positively associated with ADL dependency in 5/9 articles and 5/5 for IADL dependency. Low muscle strength was associated with ADL dependency in 22/34 articles and IADL dependency in 8/9 articles. Low physical performance was associated with ADL dependency in 37/49 articles and with IADL dependency in 9/11 articles. Forty-five articles were pooled into the meta-analyses, 36 reported ADL, 11 reported IADL, and 2 reported ADL and IADL as a composite outcome. Low muscle mass was associated with worsening ADL (pooled odds ratio (95% confidence interval) 3.19 (1.29–7.92)) and worsening IADL (1.28 (1.02–1.61)). Low handgrip strength was associated with both worsening ADL and IADL (1.51 (1.34–1.70); 1.59 (1.04–2.31) respectively). Low scores on the short physical performance battery and gait speed were associated with worsening ADL (3.49 (2.47–4.92); 2.33 (1.58–3.44) respectively) and IADL (3.09 (1.06–8.98); 1.93 (1.69–2.21) respectively). Low one leg balance (2.74 (1.31–5.72)), timed up and go (3.41 (1.86–6.28)), and chair stand test time (1.90 (1.63–2.21)) were associated with worsening ADL.

Conclusions
Muscle measures at baseline are predictors of future ADL and IADL dependence in the older adult population.

Keywords
Muscle mass; Muscle strength; Handgrip strength; Physical performance; Activities of daily living; Aged
Introduction

Dependence in activities of daily living (ADLs), the basic tasks required of an individual to maintain their independence at home, is associated with increased risk of morbidity and mortality.\(^1\) Individuals that are dependent in ADL are also likely to be dependent in instrumental activities of daily living (IADLs), the tasks required of an individual to maintain their independence in the community.\(^2\) The prevalence of ADL and IADL disability for at least one activity is 34.6% and 53.5%, respectively, in adults aged 65 years and older,\(^3\) and this prevalence increases with age.\(^4\) Those with lower muscle measures, defined by muscle mass, muscle strength, and physical performance,\(^5\) are more likely to be dependent in ADL and/or IADL.\(^6\) The more difficult tasks are for an individual, the more effort and demand they require relative to their muscle’s maximum capacity.\(^7\)

Older adults that develop ADL dependence are less likely to recover function, stressing the need for strategies that can prevent or delay the onset of ADL dependence.\(^8\) Higher muscle strength is protective against declining below the threshold where dependence in ADL and IADL occurs.\(^9\) In community-dwelling older adults, physical performance measured by gait speed has been shown to be a strong predictor of ADL disability.\(^10\)\(^11\) Similarly, low muscle mass, muscle strength, and gait speed have all been associated with an impaired ability to perform ADL and IADL.\(^12\)\(^13\) Currently, there are no systematic review and/or meta-analyses that quantifies the association between muscle mass, muscle strength, and physical performance as predictors of ADL and IADL dependence. By determining which muscle measures are predictive of ADL and IADL dependence allows for the identification of individuals at high risk of decline as well as the development and implementation of strategies that can prevent or delay the onset of dependence.

The aim of this systematic review and meta-analysis was to determine if muscle mass, muscle strength, or physical performance are predictors of ADL and/or IADL at follow-up in older populations.

Methods

Search strategy

This systematic review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-analyses and registered with the PROSPERO International Prospective Register of Systematic Reviews (CRD42019125666).\(^14\) The following four electronic databases were screened for potential relevance from date of inception to 7 June 2018: MEDLINE, EMBASE, Cochrane Central Register of Controlled Trials, and Cumulative Index of Nursing and Allied Health Literature. The search strategy was developed in consultation with a senior tertiary librarian from The University of Melbourne, with expertise in research and search strategies. The following terms were used in the search strategy: ‘muscle mass’, ‘fat free mass’, ‘lean mass’, ‘muscle loss/atrophy’, ‘muscle strength’, ‘physical performance/mobility/fittness/endurance’, ‘activities of daily living’, ‘functional decline/disability, and aged/elderly/older. The full search strategy can be found in Supporting Information, Table S1.

Eligibility criteria

Inclusion criteria consisted of prospective longitudinal cohorts of older adults with a reported mean/median age of 65 years and older at follow-up and reporting at least one of the following measurements: muscle mass, muscle strength, or physical performance in conjunction with a follow-up outcome of ADL or IADL.

Exclusion criteria included cross-sectional and case-control studies; anthropometric measurements as measures of muscle mass such as body mass index, hip-waist ratio, waist or calf circumference measurements, and skin-fold thickness; populations that suffered from cancer, muscular dystrophy, genetically inherited diseases, and HIV/AIDS; cohorts that received an intervention other than usual care or placebo; and non-English articles. Articles including participants of the same cohort more than once were excluded in a hierarchical manner: (i) if there was no statistical analysis conducted regarding odds ratio (OR), hazards ratio, or relative risk and lacking data to calculate the OR; (ii) if their primary research question was not exploring the association between muscle measures with ADL or IADL; or (iii) an article had a smaller sample size.

Article selection

Articles obtained through the search strategy had their title and abstract screened followed by full-text screening for eligibility independently by two authors (D. W., Y. Z., or J. Y.) using Covidence (Covidence Systematic Review Software, Veritas Health Innovation, Melbourne, Australia). The decision made by authors was compared, and conflicts were settled by a third reviewer (E. M. R.).

Data extraction and quality assessment

Data extraction was performed by two authors (D. W., Y. Z., or J. Y.). The following data were extracted from included articles: author, year, study/cohort, setting, country/region, demographic information [sample size, age (mean/median), and sex (% female)], and follow-up duration. Muscle mass, muscle strength, physical performance, ADL, and IADL were extracted based on the measurement method, unit, and cut-offs applied in analyses. Effect sizes were extracted from text, tables, or figures if not described elsewhere.

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The quality of the included articles was assessed by a modified version of the Newcastle–Ottawa Scale (NOS) for cohort studies. Quality assessment was performed based on the following categories: selection, comparability, and outcome. Articles were deemed to be high quality with the following criteria: (i) the population was representative of the 65 years and older at follow-up; (ii) in the case of a dichotomized sarcopenic cohort (low muscle mass, muscle strength, and physical performance), both cohorts were recruited from the same population; (iii) the technique used to measure muscle mass, muscle strength, or physical performance; (iv) the analysis was controlled for age and/or sex, as well as other factors; (v) ADL or IADL was measured with a validated method or a study designed questionnaire or survey; (vi) follow-up duration was ≥3 months; and (vii) subjects were all followed up, accounted for or the number lost to follow-up was unlikely to introduce bias (≤20%). The adapted version of the NOS can be found in Supporting Information, Supplementary Material 2. Studies above the median score (7/7 and 8/8) were the cut-off point for articles of high quality.

Data synthesis and analysis

Effect sizes were extracted and reported where associations were made between baseline muscle measures and follow-up ADL and/or IADL. Inclusion into the meta-analysis required articles to report an OR, hazards ratio, relative risk, or if the article provided sufficient information to calculate an OR for the association between baseline muscle measures and follow-up ADL and/or IADL. Forest plots were generated for the graphical representation of the meta-analysis. A random effect model was adopted to account for differences between articles. Articles were presented in order from the shortest to longest follow-up duration to determine if follow-up duration impacts effect size, i.e. longer follow-up duration showing

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**Figure 1** Preferred Reporting Items for Systematic Reviews and Meta-analyses flow chart for the study selection process.
Table 1 Characteristics of included studies and measured activities of daily living and instrumental activities of daily living

| Study characteristics | Participants | FU | ADL | IADL |
|-----------------------|--------------|----|-----|------|
| First author (year) [ref] | Cohort name | Setting | Country | N | Age (years) | F (%) | Measure | Cut-offs | Measure | Cut-offs |
| — | — | — | — | 907 | 81.3 ± 6.5 | 56.7 | 2 y | Katz | ≥1 loss | — | — |
| Al snih (2004) | HEPESE | CD | USA | 2493 | 72.4 ± 6.2 | 57.9 | 7 y | M Katz | ≥1 loss | — | — |
| Albert (2015) | SITE | CD | USA | 375 | 78.9 ± 5.8 | 68.9 | 2 y | — | — | — | — |
| Alexandre (2012) | SABE | CD | BRA | 1634 | 68.6 ± 0.4 | 57.1 | 6 y | M Katz | ≥1 loss | — | — |
| Amigues (2013) | EPIDOS | CD | FRA | 975 | 79.9 ± 3.5 | 100.0 | 4 y | — | — | — | — |
| Amal (2016) | OP | ESP | 252 | 81.7 ± 4.6 | 58.7 | 1 y | BI | — | — | — | — |
| Artaud (2015) | 3C | CD | FRA | 3814 | 73.2 ± 4.6 | 60.9 | 11 y | M Katz | ≥1 loss | — | — |
| Basic (2017) | — | IP | AUS | 1693 | 81.9 ± 7.5 | 61.5 | 11 d | — | — | — | — |
| Baumgartner (2004) | NMAPS | CD | USA | 451 | 72.7 ± 6.3 | — | — | Own Q | ≥1 loss | — | — |
| Beauchamp (2015) | Boston RISE | PB | USA | 360 | 76.6 ± 0.4 | 57.1 | 6 y | LLFDI-FC | Cont | — | — |
| Belosesky (2009) | — | OP | ISR | 93 | 81.2 ± 7.2 | 53.5 | 9 y | — | — | — | — |
| Bianchi (2015) | InCHIANTI | CD | ITA | 538 | 77.1 ± 5.5 | 69.5 | 6 m | Own Q | Cont | — | — |
| Broadin (2001) | — | CD | USA | 1051 | 70.7 | 60.3 | 4 y | Own Q | — | — | — |
| Carriere (2015) | EPI DOS | CD | FRA | 545 | 79 (76–81) | 100 | 7 y | — | — | — | — |
| Cesari (2015) | InCHIANTI | CD | ITA | 991 | 73.9 ± 6.7 | 57.0 | 9 y | — | — | — | — |
| Chan (2014) | ISCOPE | CD | USA | 764 | 83 (79–87) | 68.2 | 1 y | — | — | — | — |
| Chaudhry (2010) | CHS | CD | USA | 5888 | 72.4 | 57.6 | 7 y | — | — | — | — |
| Chu (2006) | — | CD | HKG | 1419 | 73.1 ± 6.2 | 49.5 | 1 y | M BI | — | — | — |
| Cooper (2011) | LASA | CD | NLD | 1532 | 70.0 ± 8.5 | 54.8 | 3 y | Own Q | — | — | — |
| Corsonello (2012) | PVC | IT | 506 | 80.1 ± 5.9 | 54.3 | 1 y | M Katz | — | — | — | — |
| Costanzo (2018) | InCHIANTI | CD | ITA | 709 | 73.4 ± 6.5 | 56.3 | 6 y | Katz | — | — | — |
| Den Ouden (2013) | PROFIEL | CD | NLD | 625 | 62.3 ± 8.9 | 49.0 | 10 y | M Katz | — | — | — |
| Denkiger (2010) | IRIE | CD | DEU | 161 | 82 (58–93) | 77.3 | 8 y | — | — | — | — |
| Di Monaco (2015) | — | CD | HKG | 193 | 80.0 ± 7.7 | 100 | 6 m | — | — | — | — |
| Donoghue (2014) | TILDA | CD | IRL | 1819 | 72.8 ± 6.1 | 52.6 | 2 y | Own Q | — | — | — |
| Duchowny (2018) | HRS | CD | USA | 8467 | 74.6 ± 7.0 | 57.0 | 2 y | Own Q | — | — | — |
| Fantin (2007) | — | CD | ITA | 159 | 71.4 ± 2.3 | 61.0 | 6 y | Own Q | — | — | — |
| Femia (1997) | OCTO Project | CD | SWE | 95 | 86.8 ± 2.3 | 74.0 | 4 y | Own Q | — | — | — |
| Fujita (2016) | TMG-LISA | CD | JPN | 981 | 71.5 ± 5.2 | 58.1 | 8 y | Own Q | — | — | — |
| Giampaoli (1999) | FIN | CD | USA | 140 | 76.5 ± 3.4 | 0 | 4 y | WHO scale | — | — | — |
| Gill (1996) | PS | CD | USA | 775 | 79.1 ± 5.0 | 74 | 3 y | — | — | — | — |
| Gill (2009) | PEP | CD | USA | 722 | 78.4 ± 5.2 | 62.4 | 11 y | Own Q | — | — | — |
| Guralnik (2000) | EPESE | CD | USA | 2478 | — | — | 6 y | Own Q | — | — | — |
| Hansen (1999) | — | PB | USA | 73 | 80.4 ± 7.0 | 66.0 | 1 m | Katz | — | — | — |
| Heiland (2016) | SNAC-K | CD | SWE | 3060 | 73.7 ± 10.8 | 63.7 | 6 y | — | — | — | — |
| Hirani (2015) | CHAMP | CD | AUS | 1819 | 77.3 ± 5.8 | 0 | 5 y | M Katz | — | — | — |
| Hirani (2017) | CHAMP | CD | AUS | 1685 | 76.9 ± 5.5 | 0 | 5 y | M Katz | — | — | — |
| Hoeymans (1996) | Zitphen Elderly | CD | NLD | 303 | 75.8 ± 5.4 | 0 | 3 y | M WHO | — | — | — |
| Hong (2016) | — | CD | KOR | 8000 | 72.5 ± 5.5 | 59.4 | 3 y | — | — | — | — |

(Continues)
| First author (year) | Cohort name | Setting | Country | N | Age (years) | F (%) | Measure | Cut-offs | Measure | Cut-offs |
|---------------------|-------------|---------|---------|---|-------------|------|--------|----------|--------|----------|
| Idland (2013) 63 | CD NOR | 113 | 79.4 ± 2.9 | 100 | 9 y | M A PADL-H scale | ≥ 1 loss | — | — |
| Ishizaki (2000) 64 | CD JPN | 583 | 70.9 ± 4.9 | 55.9 | 3 y | Own Q | ≥ 1 loss | TMIG IC | ≥ 1 loss |
| Janssen (2006) 65 | CD USA | 3694 | 73.5± | 53.2 | 8 y | Own Q | ≥ 1 loss | — | — |
| Jonkman (2018) 16 | InCHIANTI, LASA CD ITA, NLD | 798 | 67.5 ± 2.1 | 53.8 | 9 y | Own Q | ≥ 1 loss | Own Q | ≥ 1 loss |
| Kempen (1998) 66 | GLAS CD NLD | 557 | 72.4 ± 7.7 | 74.7 | 2 y | GARS | Cont | — | — |
| Kozicka (2016) 67 | — | 41 | 69.8 ± 9.0 | 41.5 | 1 y | Katz | Cont | LB | Cont |
| Kwon (2012) 68 | — | 204 | 71.1 ± 5.3 | 57.8 | 1 y | HAQ | ≥ 1 loss | — | — |
| Legrand (2014) 69 | — | 431 | 84.4 ± 3.5 | 63.0 | 34 m | Own Q | ≥ 1 loss | — | — |
| Lopez-Terros (2014) 70 | — | 133 | 75.5 ± 4.7 | 53.4 | 1 y | Own Q | ≥ 1 loss | — | — |
| McGrath (2018) 71 | — | 758 | 78.7 ± 8.0 | 100 | 3 y | Own Q | ≥ 1 loss | OARS and RB | ≥ 1 loss |
| Minnedi (2015) 72 | — | 562 | 72.9 ± 7.1 | 57.6 | 3 y | Own Q | ≥ 1 loss | — | — |
| Moe (2018) 73 | — | 115 | 86.0 ± 5.9 | 55.0 | 3 w | Nor BI | Cont | — | — |
| Onder (2005) 74 | — | 884 | 78.7 ± 8.0 | 100 | 3 y | Own Q | ≥ 1 loss | — | — |
| Ostir (1998) 75 | — | 1342 | 73.5 | 53.0 | 2 y | Own Q | Cont | — | — |
| Pellers (2014) 76 | — | 351 | 79.0 ± 8.8 | 65.8 | 6 m | interRAC HC | Cont | — | — |
| Purser (2005) 78 | — | 1388 | 74 ± 6.0 | 2.0 | 1 y | Katz | Cont | LB | Cont |
| Rajan (2012) 79 | — | 5317 | 73.2 ± 6.4 | 61.0 | 8 y | Katz | ≥ 1 loss | — | — |
| Rantanen (1999) 80 | — | 6089 | 54.0 ± 5.5 | 100 | 25 y | Own Q | ≥ 1 loss | — | — |
| Rantanen (2002) 81 | — | 567 | 75+ | 60.0 | 5 y | Own Q | ≥ 1 loss | — | — |
| Rodriguez-Pascual (2017) 82 | — | 497 | 85.2 ± 7.3 | 61.0 | 1 y | Katz | Cont | — | — |
| Rothman (2008) 83 | — | 754 | 78.4 ± 5.3 | 64.6 | 8 y | Own Q | ≥ 1 loss | — | — |
| Sakamoto (2016) 84 | — | 188 | 80.2 ± 3.9 | 65.4 | 2 y | Own Q | ≥ 1 loss | — | — |
| Sanchez-Martinez (2016) 85 | — | 607 | 77.0 ± 7.6 | 50.9 | 4 y | Own Q | ≥ 1 loss | — | — |
| Sanchez-Rodriguez (2014) 86 | — | 99 | 84.6 ± 6.6 | 61.6 | 3 m | BL | Cont | — | — |
| Sarkissian (2000) 87 | — | 6632 | 73.0 ± 4.9 | 100 | 4 y | Own Q | ≥ 1 loss | — | — |
| Sarkissian (2001) 88 | — | 89 | 72.4 ± 4.5 | 100 | 4 y | NHIS | ≥ 1 loss | — | — |
| Seidel (2011) 89 | — | 119 | 83.4 ± 4.6 | 55.5 | 6 m | Katz | Cont | — | — |
| Shimada (2010) 91 | — | 436 | 79.2 ± 6.8 | 72.5 | 1 y | Katz | ≥ 1 loss | — | — |
| Shimada (2015) 92 | — | 4081 | 71.7 ± 5.3 | 51.6 | 2 y | LTIC | ≥ 1 loss | — | — |
| Shinkai (2000) 93 | — | 748 | NR | 6 y | Own Q | ≥ 1 loss | — | — |
| Shinkai (2003) 94 | — | 601 | 73.0 ± 5.3 | 65 | 4 y | Own Q | ≥ 1 loss | — | — |
| Sourlet (2012) 95 | — | 632 | 77.5 ± 5.0 | 72.2 | 2 y | Katz | ≥ 0.5 loss | — | — |
| Stenholm (2014) 96 | — | 724 | 67.1 ± 15.0 | 54.3 | 9 y | Own Q | ≥ 1 loss | — | — |
| Taekema (2010) 97 | — | 555 | NR | 65.0 | NR | GARS | 1 loss | GARS | ≥ 1 loss |
| Takuhiro (2017) 98 | — | 104 | 69.3 ± 3.0 | 100 | 9 y | Composite | ≥ 3 loss | — | — |
| Tanimoto (2013) 99 | — | 716 | 73.2 ± 6.1 | 65.8 | 2 y | MKatz | 1 loss | — | — |
| Terhorst (2017) 99 | — | 256 | 78.9 ± 5.1 | 100 | 6 m | PASS | 1 loss | PASS | ≥ 1 loss |

(Continues)
Table 1 (continued)

| Study characteristics | Participants | FU | ADL | IADL |
|-----------------------|--------------|----|-----|------|
|                       | First author (year) [ref] | Cohort name | Setting | Country | N | Age (years) F (%) | Measure | Cut-offs | Measure | Cut-offs |
| Tinetti (2005) 100     | PEP, PS        | CD | USA | 1471 | 78.8 ± 5.2 $^a$ | 70.8 | 3 y | — | — | LB | ≥1 loss |
| Volpato (2011) 101     | —              | IP | ITA | 87  | 77.4 ± 6.5 $^a$ | 49.0 | 3 m | Own Q | Cont | M LB | Cont |
| Wennie Huang (2010) 102| —              | CD | USA | 110 | 80.3 ± 7.0 | 70.9 | 18 m | NHIS | ≥1 loss | — | — |
| Zhang (2013) 103       | InCHIANTI      | CD | ITA | 562 | 71.4 ± 5.7 | 47.9 | 3 y | Own Q | 1 loss | Own Q | ≥1 loss |
| Zoico (2007) 104       | —              | CD | ITA | 145 | 71.7 ± 2.3 $^a$ | 58.6 | 2 y | Composite | — | — | — |

Cohort: 3C, Three City Study; BFc80+, BELFRAIL; Boston RISE, Boston Rehabilitative Impairment Study of the Elderly; CHAMP, The Concord Health and Ageing in Men Project; CHS, Cardiovascular Health Study; CNDS, Chicago Neighbourhood and Disability Study; Coyoacan, Mexico Study of Nutritional and Psychosocial Markers of Frailty among Community-dwelling Elderly; EPESE, Established Populations for the Epidemiological Study for the Elderly; EPIDOS, epidemiology of osteoporosis; E-SAS project, Elderly Status Assessment Set; FINE, Finland, Italy, Netherlands Elderly, GLAS, Groningen Longitudinal Aging Study; HAAS, Honolulu Asia Aging Study; HEPF, Hispanic Established Populations for the Epidemiological Study for the Elderly; HPP, Honolulu Heart Program; HRS, Health and Retirement Study; ICARE Dicomano, Insuffisenza Cardiaca negi Anziani Residenti a Dicomano; InCHIANTI, Invecchiare in Chi- anti; ISCOPE, Integrated Systematic Care for Older People; LASA, Longitudinal Aging Study Amsterdam; NMAPS, New Mexico Aging Process Study; NORA75, Nordic Research on Aging 75 study; OSHPE, Obu Study of Health Promotion for the Elderly; PEP, Precipitating Events Project; PS, Project Safety; PVC, PharmacosurVeillance in the elderly Care; REAL.FR, Reseau sur la maladie Alzheimer Francais; SABE, Saude, Bem-Estar e Envelhecimento; SITE, Sources of Independence in the Elderly; SHARE, The Survey of Health, Ageing and Retirement in Europe; SNACK-1, Swedish National study on Aging and Care in Kungsholmen; SOF, Study of Osteoporotic Fractures; TILDA, The Irish Longitudinal Study of Ageing; USA, Longitudinal Interdisciplinary Study on Aging; TIAS, Tosa Longitudinal Aging Study; TMIG-LISA, Tokyo Metropolitan Institute of Gerontology Longitudinal Interdisciplinary Study on Ageing; VA, Department of Veterans Affairs; WHAS, Women’s Health and Aging Study. Setting: AD, Alzheimer’s disease; CD, community-dwelling; OP, outpatients; IP, inpatients; TAVI, transcatheter aortic valve implantation; TCP, transitional care program; PB, population based; PD, post-discharge; HF, heart failure. Country: AUS, Australia; BEL, Belgium; BRA, Brazil; CHE, Switzerland; DEU, Germany; DNK, Denmark; ESP, Spain; EU, Europe; FIN, Finland; FRA, France; HKG, Hong Kong; IRL, Ireland; ISR, Israel; ITA, Italy; JPN, Japan; KOR, Korea; MEX, Mexico; NLD, Netherlands; NOR, Norway; POL, Poland; SWE, Sweden; USA, United States. Age: presented as mean ± SD or median (range) or (IQR); range, percentage; —, not applicable or reported; F, female; FU, follow-up duration; D, day(s); M, month(s); Y, year(s). ADL: —, not applicable or reported; BI, Barthel Index; Cont, continuous; GARS, Groningen Activities Restriction Scale; HAQ, Stanford Health Assessment Questionnaire; interRAC HC, interRAC Home Care; Nor BI, Norwegian Barthel Index; M A PDL-H scale, modified Avlund Physical ADL-H scale; M Katz, modified Katz Index; M BI, modified Barthel Index; M WHO, modified World Health Organization scale; LLFDI-FC, Functional Component of the Late-Life Function and Disability Instrument; LTCI, long-term care insurance system; PASS, Performance Assessment of Self-Care Skills; WHO, World Health Organization; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index. IADL: —, not applicable or reported; AMPS, assessment of motor and process skills; GARS, Groningen Activities Restriction Scale; KADL, Korean IADL; LB, Lawton and Brody; M LB, modified Lawton and Brody; M WHO, modified WHO scale; NHIS, National Health Interview Survey; OARS, Older Americans Resources and Services; RB, Rosow-Breslau scale; TMIG-IC, Tokyo Metropolitan Institute of Gerontology Index of Competence.

$^a$Calculated mean ± SD or mean from information provided.
greater effect size. Articles that reported sex-stratified results or ADL and IADL were entered in the meta-analysis separately. The least adjusted statistical model consisting of age and sex was used in the meta-analysis, followed by the next least adjusted model then the unadjusted model. Heterogeneity was measured using the I-squared ($I^2$) test. Low heterogeneity was defined as an $I^2 \leq 25\%$, moderate as $25\%$–$75\%$, and high as $\geq75\%$. The $P$-value for significance was set at $<0.05$, and the $P$-value for a trend was set at $0.05 < P < 0.01$. Meta-analyses were performed separately according to the unit of gait speed, ADL, and IADL. The meta-analysis was performed using Comprehensive Meta-analysis (version 3.3; Biostat Inc., Englewood, NJ).

## Results

Figure 1 presents the Preferred Reporting Items for Systematic Reviews and Meta-analyses flow diagram of selected articles. The four databases yielded 12 950 potential articles to which an additional 13 were added by snowballing. After removing duplicate articles, 7760 progressed to title and abstract screening. Of these, 7535 articles were excluded resulting in 225 articles for full-text screening. Ultimately, 83 articles were included in the systematic review and 45 articles in the meta-analysis.

### Characteristics of included articles

Table 1 presents the study characteristics of included articles. The majority of the articles were conducted on community-dwelling participants ($n = 65/83$). The mean or median age of the study ranged from 54 to 86 years at baseline. The number of participants in each study ranged from 41 to 8000 and included a total of 108 428 (54.8% female) participants. Follow-up duration ranged from 11 days to 25 years. ADL was measured in 73 articles that examined physical motor tasks, 30 of which had developed an adapted questionnaire to assess the motor component of ADL (Supporting Information, Table S3) and 21 articles using the Katz Index or a modified version. Of the articles reporting ADL, 63 articles used a dichotomous cut-off reporting a worsening ADL score ($\geq$1 points loss, i.e. more dependency) at follow-up compared with using a continuous ADL score ($n = 11$). IADL was measured in 35 articles with the Lawton–Brody IADL scale being used in 14 articles, three of which were modified. A total of 26 articles included measures of both ADL and IADL.

### Qualitative analysis

Muscle mass was reported in 13 articles, six using dual-energy X-ray absorptiometry, five using bioelectrical impedance analysis, one using computed tomography, and one did not report the measurement method (Table 2). Low muscle mass was positively associated with worsening ADL in 5/9 articles and IADL in 5/5 at follow-up.

Muscle strength was investigated in 41 articles as a predictor of ADL and IADL (Table 3). Handgrip strength was used as a measure of muscle strength in 40 articles, five using quadriceps or knee strength and each of the following were used in single articles: shoulder strength, ankle and

## Table 2  Muscle mass as predictor of activities of daily living or instrumental activities of daily living

| First author (year) [ref] | $N$ | Tool | Measure | Units | Cut-offs | AM | MA |
|---------------------------|-----|------|---------|-------|----------|----|----|
| Amigues (2013) 28          | 975 | DXA  | SMI     | kg/m$^2$ | SD (NR) | A  | Y  |
|                           | 975 | DXA  | LM      | kg     | Quartile$^4$ | A  | N  |
|                           |     |      |         |        |          |    |    |
| Baumgartner (2004) 32      | 451 | DXA  | SMI     | kg/m$^2$ | M: 7.26. F: 5.45 | A  | N  |
|                           | 538 | BIA  | SMI     | kg/m$^2$ | M: 8.87. F: 6.42 | A  | Y  |
|                           | 1051| BIA  | FFM     | %      | Quintile$^5$ | A  | N  |
| Cariere (2005) 37          | 545 | —    | LM/BM   |        | <0.54, 0.54–0.63, ≥0.63 | A  | N  |
| Cesari (2015) 38           | 991 | CT   | Muscle density | mg/cm$^3$ | SD (M: 3.32: F: 3.60) | A  | N  |
| Fantin (2007) 50           | 159 | DXA  | FFM     | kg     | Continuous | U  | N  |
| Hirani (2015) 59           | 1819| DXA  | ALM     | kg     | <19.75   | A  | N  |
| Hirani (2017) 50           | 1685| DXA  | ALM/BMI |        | <0.789   | A  | Y  |
| Janssen (2006) 65          | 3694| BIA  | MM      | kg     | Quartile (NR) | A  | N  |
| Sanchez-Rodriguez (2014) 86| 3694| BIA  | SMI     | kg/m$^2$ | M: <10.75. F: <6.75 | A  | Y  |
|                           | 99  | BIA  | FFM     | kg     | Continuous | A  | N  |
|                           | 99  | BIA  | LBM     | kg     | Continuous | A  | N  |
| Tanimoto (2013) 98         | 716 | BIA  | AMI     | kg/m$^2$ | M: <7.0. F: <5.8 | U  | Y  |
| Zoico (2007) 104           | 145 | DXA  | AMI     | kg/m$^2$ | <7.6     | A  | N  |

**Measure:** —, not applicable or reported; ALM, appendicular lean mass; AMI, appendicular mass index; BIA, bioelectrical impedance analysis; BM, body mass; CT, computed tomography; DXA, dual-energy X-ray absorptiometry; FFM, fat free mass; LBM, lean body mass; LM, lean mass; MM, muscle mass; SMI, skeletal muscle index. **Cut-off:** NR, not reported; SD, standard deviation. Expressed as either dichotomous, ranges for specific tertiles, quartiles, quintiles, or categories or per unit or score. **AM**, adjustment model denotes whether the model in the meta-analysis was: A, adjusted; or U, unadjusted. **MA**, meta-analysis; **N**, no; **Y**, yes.

$^4$M: 35.5–75.6, 75.7–78.0, 78.1–80.2, 80.3–82.8, 82.9–93.0. F: 45.6–67.0, 67.1–69.4, 69.5–71.8, 71.9–74.7, 74.8–88.0.
Table 3  Muscle strength as predictor of activities of daily living or instrumental activities of daily living

| First author (year) [ref] | N     | Measure | Units    | Cut-offs | AM | MA |
|---------------------------|-------|---------|----------|----------|----|----|
| Abete (2017)              | 907   | HGS     | NR       | Dich (NR) | A  | Y  |
| Al snih (2004)            | 2493  | HGS     | kg       | Continuous | U  | Y  |
| Alexandre (2012)          | 1634  | HGS     | kg       | Continuous | A  | Y  |
| Amigues (2013)            | 975   | HGS     | kPa      | SD (NR)   | A  | N  |
| Beloosesky (2009)         | 93    | HGS     | kg       | Continuous | U  | N  |
| Bianchi (2015)            | 538   | HGS     | kg       | BMI specific | A  | N  |
| Carriero (2005)           | 545   | HGS     | kPa      | <47       | A  | Y  |
| Cesari (2015)             | 991   | HGS     | kg       | SD (M: 9.79. F: 8.35) | A  | N  |
| Chan (2014)               | 570   | HGS     | kg       | Continuous | A  | N  |
| Chaudhry (2010)           | 5888  | HGS     | kg       | Lowest quintile for sex and BMI (NR) | A  | Y  |
| Costanzo (2018)           | 625   | HGS     | kg       | Per 10    | A  | N  |
| Den Ouden (2013)          | 625   | QS      | Nm       | Per 10    | A  | N  |
| Di Monaco (2015)          | 193   | HGS     | kg       | SD (5.7)  | A  | N  |
| Duchowey (2018)           | 8467  | HGS     | kg       | WM: <35, BM: <40, WW: <22, BW: <31 | A  | Y  |
| Femia (1997)              | 95    | HGS     | kPa      | Continuous | U  | N  |
| Giampaoli (1999)          | 140   | HGS     | kg       | Continuous | A  | N  |
| Gill (2009)               | 722   | HGS     | kg       | BMI specific | A  | N  |
| Hirani (2015)             | 1819  | HGS     | kg       | <26       | A  | N  |
| Ishizaki (2000)           | 468   | HGS     | kg       | Continuous | A  | Y  |
| Kozicka (2016)            | 41    | HGS     | kg       | Continuous | U  | N  |
| Kwon (2012)               | 204   | HGS     | kg       | BMI specific | A  | N  |
| Legrand (2014)            | 309   | HGS     | kg       | Tertile   | A  | Y  |
| Lopez-Teros (2014)        | 133   | HGS     | kg       | Continuous | A  | N  |
| McGrath (2018)            | 672   | HGS     | kg       | Continuous | A  | N  |
| Minneci (2015)            | 453   | HGS     | kg       | Continuous | A  | Y  |
| Moen (2018)               | 115   | HGS     | kg       | Continuous | A  | N  |
| Onder (2005)              | 458   | HGS     | kg       | SD (5.9)  | A  | N  |
| Pisters (2012)            | 216   | KE      | N/kg     | SD (0.6)  | A  | N  |
| Rantanen (1999)           | 6089  | HGS     | kg       | Tertile   | A  | N  |
| Rantanen (2002)           | 553   | HGS     | N        | M: <392, F: <225 | U  | Y  |
| Rodriguez-Pascual (2017)  | 277   | HGS     | kg       | Lowest quintile for sex and BMI (NR) | A  | Y  |
| Rothman (2008)            | 754   | HGS     | kg       | BMI specific | A  | Y  |
| Sanchez-Rodriguez (2014)  | 99    | HGS     | kg       | Continuous | U  | N  |
| Sarkissian (2000)         | 6632  | HGS     | kg       | Lowest Quintile (NR) | A  | Y  |
| Sarkissian (2001)         | 89    | HGS     | kg       | Decile (NR) | A  | N  |
| Seidel (2011)             | 6670  | HGS     | kg       | <26       | U  | Y  |
| Shinkai (2000)            | 133   | HGS     | kg       | Age specific | U  | Y  |
| Shinkai (2003)            | 601   | HGS     | kg       | Quartile decrease | A  | Y  |
| Taekema (2010)            | 555   | HGS     | kg       | Continuous | A  | N  |
| Tanimoto (2013)           | 716   | HGS     | kg       | Lowest quartile (NR) | U  | N  |
| Wennie Huang (2010)       | 65    | HGS     | kg       | Continuous | A  | Y  |

Measure: ---: not applicable or reported; AE, ankle extension; AF, arm flexion; BMI, body mass index; HGS, handgrip strength; KE, knee extension; QS, quadriceps strength; SS, shoulder strength; TE, trunk extension; TF, trunk flexion. Cut-offs: NR, not reported; SD, standard deviation. Expressed as either dichotomous, ranges for specific tertiles, quartiles, quintiles, or categories or per unit or score. AM, adjustment model denotes whether the model in the meta-analysis was: A, adjusted; or U, unadjusted. MA, meta-analysis; N, no; Y, yes.

* M: <22.00, 21.01–30.00, 30.01–35.00, ≥35.01. F: <14.00, 14.01–18.20, 18.21–22.50, ≥22.51.
* M ≤24: ≤29, 24.1–28 ≤30, >30: ≤32: F ≤23: ≤17, 23.1–26: ≥17.3, 26.1–29: ≤21.
* M ≤24: ≤29, 24.1–26: ≤30, 26.1–28: >30, >28: ≤32: F ≤23: ≤17, 23.1–26: ≥17.3, 26.1–29: <18, >29: ≤21.
* M ≤25.0–29.9: 30.0–39.9, >40: F ≤15, 15.0–19.9, 20.0–24.9, >25.
* M ≤25.3, 25.4–33.2, >33.3: F ≤15.0, 15.1–20.0, >20.1.
* ≤37.0, 37.0–42.0, ≥42.0.
* M ≤24: ≤29, 24.1–26: ≤30, 26.1–28: >30, >28: ≤32: F ≤23: ≤17, 23.1–26: ≥17.3, 26.1–29: ≤18, >29: ≤21.
* M ≤65–74: ≤37, >75: ≤30. F: 65–74: ≤22, >75: ≤20.

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| First author (year) [ref] | N   | Measure          | Units | Cut-offs         | AM | MA |
|--------------------------|-----|------------------|-------|------------------|----|----|
| Albert (2015) 26         | 347 | Gait             | m/s   | Quartile⁴        | A  | N  |
| Alexandre (2012) 27      | 1634| OLB              | s     | Continuous       | A  | N  |
| Amigues (2013) 28        | 974 | Gait             | m/s   | SD (0.22)        | A  | N  |
| Arnau (2016) 29          | 252 | SPPB             | points| <7               | U  | Y  |
| Artaud (2015) 30         | 3814| Fast Gait        | m/s   | SD (0.22)        | A  | N  |
| Basic (2017) 31          | 1693| TUG              | s     | Continuous       | U  | N  |
| Beauchamp (2015) 33      | 430 | SPPB             | points| Continuous       | U  | N  |
| Bianchi (2015) 35        | 538 | Gait             | m/s   | <0.8             | A  | N  |
| Carriere (2005) 37       | 545 | Gait             | m/s   | <0.78            | A  | Y  |
| Cesar (2015) 38          | 991 | Gait             | m/s   | SD (0.24, F: 0.23)| A  | Y  |
| Chaudhry (2010) 40       | 5888| Gait             | m/s   | Lowest quintile  | A  | N  |
| Chu (2006) 41            | 1338| Gait             | m/s   | <0.65 m/s        | A  | Y  |
| Cooper (2011) 42         | 1425| Timed walk test  |       | Continuous       | A  | N  |
| Corsonello (2012) 43     | 506 | SPPB             | points| Continuous       | A  | Y  |
| Costanzo (2018) 44       | 709 | Gait             | m/s   | Lowest quintile  | U  | Y  |
| Don Ouden (2013) 45      | 625 | SPPB             | points| Continuous       | A  | Y  |
| Denkinger (2010) 46      | 161 | Change in gait   | m/s   | Continuous       | A  | N  |
| Donoghue (2014) 48       | 1391| Gait             | m/s   | Continuous       | U  | N  |
| Duchowey (2018) 49       | 1391| TUG              | s     | Continuous       | U  | N  |
| Fujisawa (2016) 52       | 981 | Gait             | m/s   | Tertile         | A  | Y  |
| Gill (1996) 54           | 775 | Own test         |       | Quartile (25%)  | U  | N  |
| Gill (2009) 55           | 722 | SPPB             | points| Continuous       | A  | Y  |
| Guralnik (2000) 56       | 722 | RGT              | s     | ≤10              | U  | N  |
| Hans (1999) 57           | 722 | Gait and balance | points| Continuous       | U  | N  |
| Heiland (2016) 58        | 1971| Gait             | m/s   | <0.8             | A  | Y  |
| Hirani (2015) 59         | 1819| Gait             | m/s   | ≤0.8             | A  | N  |
| Hoeymans (1996) 61       | 303 | Gait             | m/s   | <0.73            | U  | N  |
| Hong (2016) 62           | 8000| Gait             | m/s   | ≤17.2            | A  | Y  |
| Idland (2013) 63         | 113 | Gait             | m/s   | <0.6             | A  | Y  |
| Jonkman (2018) 16        | 113 | Step climb test  | cm    | Per 10           | A  | N  |
| Kempen (1998) 66         | 978 | Tandem stand     | s     | ≤10 s            | A  | N  |
| Legrand (2014) 69        | 957 | Jacket           | s     | Cont             | A  | N  |
| Lopez-Teros (2014) 71    | 204 | Gait             | m/s   | Quartile         | A  | N  |
| McGrath (2018) 71        | 204 | Balance          | s     | FT10, FT1-9, ST10, STs10| A  | N  |
| Minnece (2015) 72        | 308 | SPPB             | points| Continuous       | A  | Y  |
| Muscar (2017) 73         | 133 | Gait             | m/s   | Continuous       | A  | N  |
| Noda (2013) 74           | 672 | Gait             | m/s   | Lowest quintile  | A  | Y  |
| Ohta (2017) 75           | 453 | Gait             | m/s   | Continuous       | A  | Y  |

(Continues)
Table 4 (continued)

| First author (year) [ref] | N  | Measure | Units | Cut-offs | AM | MA |
|---------------------------|----|---------|-------|----------|----|----|
| Moen (2018) 73            | 453| 6MWT    | m     | Continuous | A  | N  |
| Onder (2005) 74           | 458| Balance | s     | SD (10.2) | A  | N  |
| 458                       | CST| s       | SD (8.4) | A  | N  |
| 458                       | Gait| m/s   | SD (0.31) | A  | Y  |
| 458                       | LE comp | —     | SD (0.69) | A  | N  |
| 458                       | Blouse| s      | SD (72) | A  | N  |
| 458                       | Purdue| s     | SD (10.5) | A  | N  |
| 458                       | UE comp | —     | SD (0.49) | A  | N  |
| Ostr (1998) 75            | 1342| SPPB points | <9 | U  | Y  |
| 1328                      | Gait| m/s   | <0.8  | U  | Y  |
| 1342                      | CST| s     | <10.9 | U  | Y  |
| 1006                      | Balance| s | FT10, FT2-10, StS10 | U  | N  |
| Peel (2014) 76            | 280| Gait m/s | Continuous | (0.1) | A  | Y  |
| Purser (2005) 78          | 1388| Gait m/s | Continuous | (0.1) | A  | N  |
| Rajan (2012) 79           | 5317| M SPPB points | Continuous | A  | Y  |
| Rodriguez-Pascual (2017) 82| 218| Gait m/s | Lowest quintile for sex (NR) | A  | Y  |
| Rothman (2008) 83         | 188| TUG s   | <0.3  | A  | N  |
| Sakamoto (2016) 84        | 188| FRT cm  | <20   | A  | N  |
| Sanchez-Martinez (2016) 85| 607| SPPB points | <8 | A  | N  |
| Sarkissian (2000) 87      | 6632| Gait m/s | Lowest quintile (NR) | A  | N  |
| Schoenemberg (2013) 89    | 119| TUG s   | <20 s | U  | Y  |
| Seidel (2011) 90          | 1804| Gait m/s | <0.4  | U  | Y  |
| Shimada (2015) 92         | 4081| Gait —   | <1.0  | A  | N  |
| Shimada (2000) 93         | 513| UWS m/s  | Tertilec | U  | Y  |
| Shinkai (2003) 94         | 601| Gait m/s | Quartile lower | A  | N  |
| Sourdert (2012) 95        | 583| OLB s   | <5    | A  | N  |
| Stenholm (2014) 96        | 727| Gait m/s | Continuous | (0.1) | A  | Y  |
| Takuhiro (2017) 97        | 104| RWS m/s  | SD (0.24) | A  | Y  |
| Tanimoto (2013) 98        | 716| Gait m/s | Lowest quartile (NR) | U  | N  |
| Terhorst (2017) 99        | 256| Balance — | NR | U  | N  |
| Tinetti (2005) 100        | 1042| CST s   | Tertilem | U  | N  |
| Volpato (2011) 101        | 74| SPPB points | <8 | U  | Y  |
| Wennie Huang (2010) 102   | 65| SPPB points | Continuous | A  | Y  |
| 65                       | Gait | m/s | Continuous | (1) | A  | Y  |
| 65                       | BBS| points | Continuous | A  | N  |
| 65                       | TUG| s     | Continuous | A  | Y  |
| Zhang (2013) 103          | 504| CST s   | <11.2 | A  | Y  |

*Physical Performance:* —, not applicable or reported; 6MWT, 6 min walk test; BBS, Berg Balance Scale; CST, chair stand test; OLB, one leg balance; FRT, functional reach test; FT, full tandem; MWS, maximum walking speed; POMA, performance oriented mobility assessment; PPT, physical performance test; RGT, rapid gait test; RWS, regular walking speed; SPPB, short physical performance battery; ST, semi tandem; StS, side to side; TUG, timed up and go; UWS, usual walking speed; WS, walking speed. *Cut-offs:* NR, not reported; SD, standard deviation. Expressed as either dichotomous, ranges for specific tertiles, quartiles, quintiles, or categories or per unit or score unless otherwise stated in brackets. AM, adjustment model denotes whether the model in the meta-analysis was: A, adjusted; or U, unadjusted. MA, meta-analysis; N, no; Y, yes.

a≥1, 0.74–0.99, 0.57–0.73, <0.57.
b<2, 3–9, ≥10.
cFull tandem, semi tandem, side to side.
d<21.8, 21.8–24.3, 24.4–27.5, ≥27.6.
e<8.8, 8.8–10.3, 10.4–12.4, ≥12.5.
f<20, 20–40, ≥40.
g15–27, 28–38, 39–41.
hM: ≥4.5, 4.0–4.5, 3.0–3.9, <3. F: >5, 4.0–5.0, 3.0–3.9, <3.
iM: >20, 17.0–19.0, 11–16.9. F: >21, 18.0–20.9, 12.0–17.9, <12.
jM: ≥1.08, ≥75: ≥0.82. F: <0.9, ≥75: <0.69.
kM: 65–74: ≤1.81, 1.82–2.10, 2.11–2.36, ≥2.37. ≥75: ≤1.34, 1.35–1.64, 1.65–1.99, ≥2.00. F: 65–75: ≤1.45, 1.46–1.70, 1.71–1.98, ≥1.97.

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Table 5  Quality assessment of included studies using a modified Newcastle–Ottawa Scale (NOS)

| First author (year) [ref] | Selection | Comp | Outcome | Total score |
|---------------------------|-----------|------|---------|-------------|
| Abete (2017) 24           |           | Q1   | Q2      | Q3          | Q1         | Q1 | Q2 | Q3 | Score |
| Al snih (2004) 25         |           | Q1   | Q2      | Q3          | Q1         | Q1 | Q2 | Q3 | Score |
| Albert (2015) 26          |           | Q1   | Q2      | Q3          | Q1         | Q1 | Q2 | Q3 | Score |
| Alexandre (2012) 27       |           | Q1   | Q2      | Q3          | Q1         | Q1 | Q2 | Q3 | Score |
| Amigues (2013) 28         |           | Q1   | Q2      | Q3          | Q1         | Q1 | Q2 | Q3 | Score |
| Arnau (2016) 29           |           | Q1   | Q2      | Q3          | Q1         | Q1 | Q2 | Q3 | Score |
| Artaud (2015) 30          |           | Q1   | Q2      | Q3          | Q1         | Q1 | Q2 | Q3 | Score |
| Basic (2017) 31           |           | Q1   | Q2      | Q3          | Q1         | Q1 | Q2 | Q3 | Score |
| Baumgartner (2004) 32     |           | Q1   | Q2      | Q3          | Q1         | Q1 | Q2 | Q3 | Score |
| Beauchamp (2015) 33       |           | Q1   | Q2      | Q3          | Q1         | Q1 | Q2 | Q3 | Score |
| Beloosesky (2009) 34      |           | Q1   | Q2      | Q3          | Q1         | Q1 | Q2 | Q3 | Score |
| Bianchi (2015) 35         |           | Q1   | Q2      | Q3          | Q1         | Q1 | Q2 | Q3 | Score |
| Broadwin (2001) 36        |           | Q1   | Q2      | Q3          | Q1         | Q1 | Q2 | Q3 | Score |
| Carriere (2005) 37        |           | Q1   | Q2      | Q3          | Q1         | Q1 | Q2 | Q3 | Score |
| Cesari (2015) 38          |           | Q1   | Q2      | Q3          | Q1         | Q1 | Q2 | Q3 | Score |
| Chan (2014) 39            |           | Q1   | Q2      | Q3          | Q1         | Q1 | Q2 | Q3 | Score |
| Chaudhry (2010) 40        |           | Q1   | Q2      | Q3          | Q1         | Q1 | Q2 | Q3 | Score |
| Chu (2006) 41             |           | Q1   | Q2      | Q3          | Q1         | Q1 | Q2 | Q3 | Score |
| Cooper (2011) 42          |           | Q1   | Q2      | Q3          | Q1         | Q1 | Q2 | Q3 | Score |
| Corsonello (2012) 43      |           | Q1   | Q2      | Q3          | Q1         | Q1 | Q2 | Q3 | Score |
| Costanzo (2018) 44        |           | Q1   | Q2      | Q3          | Q1         | Q1 | Q2 | Q3 | Score |
| Den Oudin (2013) 45       |           | Q1   | Q2      | Q3          | Q1         | Q1 | Q2 | Q3 | Score |
| Denkinger (2010) 46       |           | Q1   | Q2      | Q3          | Q1         | Q1 | Q2 | Q3 | Score |
| Di Monaco (2015) 47       |           | Q1   | Q2      | Q3          | Q1         | Q1 | Q2 | Q3 | Score |
| Donoghue (2014) 48        |           | Q1   | Q2      | Q3          | Q1         | Q1 | Q2 | Q3 | Score |
| Duchowny (2018) 49        |           | Q1   | Q2      | Q3          | Q1         | Q1 | Q2 | Q3 | Score |
| Fantin (2007) 50          |           | Q1   | Q2      | Q3          | Q1         | Q1 | Q2 | Q3 | Score |
| Femia (1997) 51           |           | Q1   | Q2      | Q3          | Q1         | Q1 | Q2 | Q3 | Score |
| Fujiwara (2016) 52        |           | Q1   | Q2      | Q3          | Q1         | Q1 | Q2 | Q3 | Score |
| Giampaoli (1999) 53       |           | Q1   | Q2      | Q3          | Q1         | Q1 | Q2 | Q3 | Score |
| Gill (1996) 54            |           | Q1   | Q2      | Q3          | Q1         | Q1 | Q2 | Q3 | Score |
| Gill (2009) 55            |           | Q1   | Q2      | Q3          | Q1         | Q1 | Q2 | Q3 | Score |
| Guralnik (2000) 56        |           | Q1   | Q2      | Q3          | Q1         | Q1 | Q2 | Q3 | Score |
| Hansen (1999) 57          |           | Q1   | Q2      | Q3          | Q1         | Q1 | Q2 | Q3 | Score |
| Heiland (2016) 58         |           | Q1   | Q2      | Q3          | Q1         | Q1 | Q2 | Q3 | Score |
| Hirani (2015) 59          |           | Q1   | Q2      | Q3          | Q1         | Q1 | Q2 | Q3 | Score |
| Hirani (2017) 60          |           | Q1   | Q2      | Q3          | Q1         | Q1 | Q2 | Q3 | Score |
| Hoeymans (1996) 61        |           | Q1   | Q2      | Q3          | Q1         | Q1 | Q2 | Q3 | Score |
| Hong (2016) 62            |           | Q1   | Q2      | Q3          | Q1         | Q1 | Q2 | Q3 | Score |
| Idland (2013) 63          |           | Q1   | Q2      | Q3          | Q1         | Q1 | Q2 | Q3 | Score |
| Ishizaki (2000) 64        |           | Q1   | Q2      | Q3          | Q1         | Q1 | Q2 | Q3 | Score |
| Janssen (2006) 65         |           | Q1   | Q2      | Q3          | Q1         | Q1 | Q2 | Q3 | Score |
| Jonkman (2018) 66         |           | Q1   | Q2      | Q3          | Q1         | Q1 | Q2 | Q3 | Score |
| Kempen (1998) 66          |           | Q1   | Q2      | Q3          | Q1         | Q1 | Q2 | Q3 | Score |
| Kozicka (2016) 67         |           | Q1   | Q2      | Q3          | Q1         | Q1 | Q2 | Q3 | Score |
| Kwon (2012) 68            |           | Q1   | Q2      | Q3          | Q1         | Q1 | Q2 | Q3 | Score |
| Legrand (2014) 69         |           | Q1   | Q2      | Q3          | Q1         | Q1 | Q2 | Q3 | Score |
| Lopez-Teros (2014) 70     |           | Q1   | Q2      | Q3          | Q1         | Q1 | Q2 | Q3 | Score |
| McGrath (2018) 71         |           | Q1   | Q2      | Q3          | Q1         | Q1 | Q2 | Q3 | Score |
| Minneci (2015) 72         |           | Q1   | Q2      | Q3          | Q1         | Q1 | Q2 | Q3 | Score |
| Moen (2018) 73            |           | Q1   | Q2      | Q3          | Q1         | Q1 | Q2 | Q3 | Score |
| Onder (2005) 74           |           | Q1   | Q2      | Q3          | Q1         | Q1 | Q2 | Q3 | Score |
| Ostir (1998) 75           |           | Q1   | Q2      | Q3          | Q1         | Q1 | Q2 | Q3 | Score |
| Peel (2014) 76            |           | Q1   | Q2      | Q3          | Q1         | Q1 | Q2 | Q3 | Score |
| Pisters (2012) 77         |           | Q1   | Q2      | Q3          | Q1         | Q1 | Q2 | Q3 | Score |
| Purser (2005) 78          |           | Q1   | Q2      | Q3          | Q1         | Q1 | Q2 | Q3 | Score |
| Rajan (2012) 79           |           | Q1   | Q2      | Q3          | Q1         | Q1 | Q2 | Q3 | Score |
| Rantanen (1999) 80        |           | Q1   | Q2      | Q3          | Q1         | Q1 | Q2 | Q3 | Score |
| Rantanen (2002) 81        |           | Q1   | Q2      | Q3          | Q1         | Q1 | Q2 | Q3 | Score |
| Rodriguez-Pascual (2017) 82|           | Q1   | Q2      | Q3          | Q1         | Q1 | Q2 | Q3 | Score |
| Rothman (2008) 83         |           | Q1   | Q2      | Q3          | Q1         | Q1 | Q2 | Q3 | Score |
| Sakamoto (2016) 84        |           | Q1   | Q2      | Q3          | Q1         | Q1 | Q2 | Q3 | Score |
| Sanchez-Martinez (2016) 85|           | Q1   | Q2      | Q3          | Q1         | Q1 | Q2 | Q3 | Score |
| Sanchez-Rodriguez (2014) 86|         | Q1   | Q2      | Q3          | Q1         | Q1 | Q2 | Q3 | Score |
| Sarkissian (2000) 87      |           | Q1   | Q2      | Q3          | Q1         | Q1 | Q2 | Q3 | Score |

(Continues)
torso flexion, and extension. Low muscle strength was positively associated with worsening ADL in 22/34 and IADL in 8/9 at follow-up.

A total of 62 articles reported physical performance as a predictor of ADL and IADL (Table 4). Gait speed was the most reported measure, with a total of 37 articles, followed by the composite test short physical performance battery (SPPB), which was reported in 14 articles. Other measures of physical performance included a variety of balance (n = 15), chair stand (n = 10), timed up and go (n = 8), and functional reach tests (n = 2) as well as tests that involve multiple assessments (n = 3). Poor physical performance was positively associated with worsening ADL in 37/49 articles and IADL in 9/11 at follow-up: SPPB (10/13, 2/2), gait speed (27/33, 7/8), one leg balance (3/4, 0/0), and chair stand test (4/9, 0/1).

Quality assessment

A complete breakdown of the NOS can be found in Table 5. The majority of the articles were of high quality (46/83).

Meta-analysis

Muscle mass

Two articles evaluating muscle mass (low vs. high) and its association with ADL were included in the meta-analysis. Low muscle mass was associated with worsening ADL

| First author (year) [ref] | Selection | Comp | Outcome | Total score |
|---------------------------|-----------|------|---------|-------------|
| Sarkissian (2001) 88      | Q1 Q2 a   | Q3   | Q1 Q1 Q2 Q3 | 7/7 |
| Schoenenberg (2013) 89   | 0         | 1    | 1 1 1 | 4/7 |
| Seidel (2011) 100         | 1         | 1    | 2 1 1 1 1 | 7/7 |
| Shimada (2010) 91         | 1         | 1    | 2 1 1 | 7/7 |
| Shimada (2015) 92         | 1         | 1    | 2 1 1 | 0 6/7 |
| Shinkai (2000) 93         | 1         | 1    | 2 1 1 1 | 7/7 |
| Shinkai (2003) 94         | 1         | 1    | 2 1 1 1 | 7/7 |
| Sourdet (2012) 95         | 0         | 1    | 1 1 | 6/7 |
| Stenholm (2014) 96        | 1         | 1    | 2 1 1 | 7/7 |
| Taekema (2010) 18         | 1         | 1    | 1 1 1 | 6/7 |
| Takehiro (2017) 97        | 1         | 1    | 0 1 1 1 | 5/7 |
| Tanimoto (2013) 98        | 1         | 1    | 2 1 1 1 | 8/8 |
| Terhorst (2017) 99        | 1         | 1    | 0 1 1 1 | 5/7 |
| Tinetti (2005) 100        | 1         | 1    | 0 1 1 1 | 5/7 |
| Volpato (2011) 101        | 0         | 1    | 1 1 | 4/7 |
| Wennie Huang (2010) 102   | 1         | 1    | 2 1 1 1 | 0 6/7 |
| Zhang (2013) 103          | 1         | 1    | 2 1 1 1 | 7/7 |
| Zoico (2007) 104          | 1         | 1    | 2 1 1 1 | 0 6/7 |

Comp, comparability.

*aOnly applied to studies that dichotomized sarcopenic cohorts.

Figure 2 Forest plot showing the association between baseline muscle mass (low vs. high) with activity of daily living (ADL) and instrumental activity of daily living (IADL) at follow-up. Heterogeneity (I²): ADL = 68.8. IADL = 75.8. M, male; F, female. Articles that reported both ADL and IADL were denoted a and b.
[OR = 3.19, 95% confidence interval (CI): 1.29–7.92, $I^2 = 68.8$.] Four articles were pooled into a meta-analysis exploring the effect of muscle mass (low vs. high), which favoured worsening IADL (OR = 1.28, 95% CI: 1.02–1.61, $I^2 = 75.8$) (Figure 2).

Muscle strength

Six articles evaluating the association between handgrip strength (per 1 kg lower) and ADL were pooled, favoured worsening ADL (OR = 1.09, 95% CI: 1.05–1.13, $I^2 = 87.5$) (Figure 3A). Ten articles were pooled into meta-analysis demonstrating the association between low vs. high handgrip strength with ADL (OR = 1.12, 95% CI: 1.07–1.18, $I^2 = 91.8$) (Figure 3A). The pooled result again favoured worsening ADL (OR = 1.19, 95% CI: 1.04–2.41, $I^2 = 94.7$) (Figure 3B).

Physical performance

Seven articles evaluating the association between SPPB and ADL were pooled, which demonstrated that a lower SPPB score (per one point) is associated with worsening ADL (OR = 1.12, 95% CI: 1.07–1.18, $I^2 = 63.3$). Two articles combined ADL and IADL and showed that SPPB score (low vs. high) favoured a worsening of the combined ADL and IADL measure (OR = 3.09, 95% CI: 1.06–8.98, $I^2 = 57.6$) (Figure 4B).

Seven articles were pooled in a meta-analysis demonstrating the association of gait speed (per unit increase) with ADL (Figure 5A). After subgrouping for a lower unit (per 0.1 m/s, per 1 m/s and per SD) in gait speed, a lower gait speed of 0.1 m/s was not associated with worsening ADL (OR = 1.64, 95% CI: 0.80–3.38, $I^2 = 85.0$) while a lower gait speed of 1.0 m/s was associated with worsening ADL (OR = 4.39, 95% CI: 2.47–7.92, $I^2 = 87.5$).

Figure 3 Forest plot showing the association between baseline handgrip strength with activity of daily living (ADL) and instrumental activity of daily living (IADL) at follow-up. (A) Handgrip strength (per 1 kg lower), heterogeneity ($I^2$) = 72.8. (B) Handgrip strength (low vs. high), heterogeneity ($I^2$): ADL = 50.0. IADL: 94.7. M, male; F, female.

A

| Group by Outcome | First author | FU (ys) | N | Statistics for each study | Odds ratio | Lower limit | Upper limit | p-Value | Odds ratio and 95% CI | Relative weight |
|-----------------|--------------|---------|---|---------------------------|------------|-------------|------------|---------|-----------------------|----------------|
| ADL             | Wenjie Huang (2010) | 2        | 65 | 1.004 | 0.970 | 1.034 | 0.142 |       |                       | 5.40 |
| ADL             | Alessandro (2012) F | 2       | 1634 | 1.009 | 1.052 | 1.146 | 0.000 |       |                       | 18.72 |
| ADL             | Minervi (2015)   | 3       | 433 | 1.176 | 1.070 | 1.283 | 0.001 |       |                       | 7.47 |
| ADL             | Ishizaki (2003)  | 3       | 408 | 1.110 | 1.042 | 1.182 | 0.001 |       |                       | 13.32 |
| ADL             | Al sinh (2004) M | 7       | 1050 | 1.031 | 1.015 | 1.047 | 0.000 |       |                       | 28.15 |
| ADL             | Al sinh (2004) F | 7       | 1443 | 1.053 | 1.031 | 1.075 | 0.000 |       |                       | 26.54 |
| ADL             |               |        | 1.074 | 1.041 | 1.108 | 0.000 |       |       |                       | 0.50 |

No change or improvement | 1 | 2

B

| Group by Outcome | First author | FU (ys) | N | Statistics for each study | Odds ratio | Lower limit | Upper limit | p-Value | Odds ratio and 95% CI | Relative weight |
|-----------------|--------------|---------|---|---------------------------|------------|-------------|------------|---------|-----------------------|----------------|
| ADL             | Abele (2017)  | 2       | 907 | 1.000 | 1.038 | 2.345 | 0.032 |       |                       | 6.06 |
| ADL             | Duchowny (2019) | 2       | 8467 | 1.540 | 1.535 | 1.545 | 0.000 |       |                       | 26.54 |
| ADL             | Legrand (2014) | 3       | 369 | 1.009 | 1.032 | 1.471 | 0.026 |       |                       | 10.77 |
| ADL             | Robilane (2017) | 5       | 583 | 1.000 | 1.009 | 1.352 | 0.071 |       |                       | 3.69 |
| ADL             | Shriket (2003) | 3       | 513 | 2.170 | 1.294 | 3.640 | 0.033 |       |                       | 5.50 |
| ADL             | Costanzo (2010) | 6       | 788 | 2.940 | 1.809 | 4.778 | 0.000 |       |                       | 4.99 |
| ADL             | Al sinh (2004) M | 7       | 1050 | 1.790 | 1.972 | 3.257 | 0.002 |       |                       | 3.89 |
| ADL             | Al sinh (2004) F | 7       | 1443 | 1.009 | 0.776 | 1.961 | 0.070 |       |                       | 6.83 |
| ADL             | Chaudhry (2010) | 7       | 8888 | 1.350 | 1.119 | 1.629 | 0.002 |       |                       | 16.14 |
| ADL             | Rothman (2009) | 8       | 754 | 1.500 | 1.225 | 1.837 | 0.000 |       |                       | 15.14 |
| ADL             | Rodriguez-F occas (2017) | 11 | 277 | 1.870 | 0.738 | 4.576 | 0.199 |       |                       | 1.96 |
| ADL             |               |        | 1.506 | 1.335 | 1.699 | 0.000 |       |       |                       | 0.10 |
| IADL            | Seidel (2011) | 2       | 2690 | 2.470 | 2.123 | 2.802 | 0.000 |       |                       | 26.94 |
| IADL            | Shriek (2003) | 3       | 601 | 1.220 | 1.070 | 1.381 | 0.033 |       |                       | 27.14 |
| IADL            | Saini (2003) | 4       | 6632 | 1.210 | 0.986 | 1.494 | 0.038 |       |                       | 28.14 |
| IADL            | Carriero (2006) | 7       | 565 | 1.710 | 1.072 | 2.966 | 0.026 |       |                       | 19.78 |

No change or improvement | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10
worsening ADL (OR = 4.40, 95% CI: 1.34–14.48, $I^2 = 52.1$; OR = 1.85, 95% CI: 1.44–2.36, $I^2 = 62.8$). Six articles\cite{41,49,52,58,75,93} pooling gait speed (low vs. high) with ADL favoured worsening in ADL (OR = 2.33, 95% CI: 1.58–3.44, $I^2 = 94.2$) (Figure 5B). Four articles\cite{37,41,62,90} evaluating the association between gait speed (low vs. high) with IADL demonstrated worsening in IADL (OR = 1.93, 95% CI: 1.69–2.21, $I^2 = 0.0$) (Figure 5B). Five articles\cite{40,44,71,82,87} were pooled comparing the lowest quintile for gait speed with the upper four quintiles with ADL demonstrated an association in worsening ADL (OR = 3.08, 95% CI: 2.13–4.46, $I^2 = 75.7$) (Figure 5C).

Three articles\cite{58,93,95} were pooled demonstrating a strong association between one leg balance (low vs. high) and a decline in ADL (OR = 2.74, 95% CI: 1.31–5.72, $I^2 = 88.5$) (Figure 6A). Two articles\cite{84,89} reported timed up and go (slow vs. fast) with ADL (Figure 6B). Slow timed up and go favoured worsening in ADL (OR = 3.41, 95% CI: 1.86–6.28, $I^2 = 41.6$). Three articles\cite{55,75,103} explored the effect of chair stand test time (slow vs. fast) with ADL (Figure 6B). Slow chair stand test favoured worsening in ADL (OR = 1.90, 95% CI: 1.63–2.21, $I^2 = 0.0$). Two articles\cite{37,103} were pooled exploring the effect of chair stand test time (slow vs. fast) was not associated with worsening IADL (OR = 2.10, 95% CI: 0.80–5.48, $I^2 = 74.8$) (Figure 6C).

All meta-analyses were ordered by study follow-up duration from shortest to longest. No pattern was present based on follow-up duration in all meta-analyses.

### Discussion

Muscle mass was associated with the development of IADL dependence. Muscle strength and physical performance were associated with the development of ADL and IADL dependence at follow-up in older adults.

#### Muscle mass

Surprisingly, muscle mass was associated with the development of new IADL dependence, but not ADL dependence at follow-up in this meta-analysis. While the association between muscle mass and ADL was not statistically significant, perhaps because of only two studies being included, a trend suggested that it was a clinically significant predictor of worsening ADL. The Concord Health and Ageing in Men Project reported that low muscle mass and sarcopenic obesity were
significantly associated with worsening ADL and IADL. Additionally, a prospective study reported that low fat free mass was associated with functional disability. It has been previously hypothesized that muscle mass plays an important role in the loss of ADL with increasing age. Loss of muscle mass could be explained by a variety of different factors including the loss of innervation from alpha-motor neurons, reduced dietary protein intake, and less physical activity.

Individuals with lower muscle mass have more difficulty in performing ADL and IADL. Furthermore, it has been suggested that the infiltration of fat into the muscle is a risk factor for low muscle mass, which is associated with worsening ADL and IADL. Prior studies exploring the effect of training on muscle mass demonstrate its effectiveness in increasing performance and preservation of ADL and IADL.
response to resistance exercise training and nutritional interventions, even in frail populations.109,113,115–117

**Muscle strength**

The predictive ability of muscle strength at baseline of ADL and IADL decline is consistent with a previous study consisting of 6089 participants, which suggested that having higher muscle strength was protective against the onset of future disability.80 However, the discrepancies in measures and cut-offs and thus a lack of consensus in measuring muscle strength. Handgrip strength has been used as a measure of upper limb strength in older populations.80 However handgrip strength should not be used as an approximation of overall muscle strength in older adults because of the variation between individuals and the variation in muscle groups within the same individual.119. Although a strong association between muscle mass and muscle strength exists120–122, muscle strength may better predict worsening ADL and IADL as muscle mass can also be influenced by factors like disease, muscle use, and muscle morphology.123

It has previously been hypothesized that there is a minimal amount of muscle strength required to complete ADL124. Handgrip strength declines by 0.06 kg per year up to the age of 50 with an even steeper decline of 0.37 kg per year after the age of 50 years.125 In healthy older adults, large changes in muscle strength have little effect on ADL while small changes in a frail population have a more profound effect124. This suggests that the completion of ADL and IADL requires a minimum threshold of strength and that higher muscle strength provides individuals with a protective

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### Figure 6

Forest plot showing the association between other physical performance measures with activity of daily living (ADL) at follow-up. (A) One leg balance time (low vs. high), heterogeneity ($I^2$) = 88.5. (B) Timed up and go (slow vs. fast), heterogeneity ($I^2$) = 41.6. (C) Chair stand test time (slow vs. fast), heterogeneity ($I^2$): ADL = 0.0. Instrumental activity of daily living (IADL) = 74.8. Articles that reported both ADL and IADL were denoted a and b.

#### A

| Group by Outcome | First author | FU (yrs) | N | Statistics for each study | Odds ratio | Lower limit | Upper limit | p-Value | Relative weight |
|-----------------|--------------|---------|---|---------------------------|-----------|-------------|------------|---------|----------------|
| ADL             | Sourdé (2012)| 2       | 500|                           | 1.420     | 0.982       | 2.003     | 0.066   | 34.08          |
| ADL             | Shinki (2000)| 6       | 500|                           | 4.400     | 2.855       | 6.706     | 0.000   | 33.42          |
| ADL             | Helalani (2019)| 6 | 187|                           | 3.400     | 2.032       | 5.889     | 0.000   | 31.90          |
| ADL             | 2.735       | 1.311   | 5.717  | 0.007    |            |             |           |         |                |

#### B

| Group by Outcome | First author | FU (yrs) | N | Statistics for each study | Odds ratio | Lower limit | Upper limit | p-Value | Relative weight |
|-----------------|--------------|---------|---|---------------------------|-----------|-------------|------------|---------|----------------|
| ADL             | Schoenenberg (2013)| 1 | 119|                           | 2.300     | 0.961       | 5.589     | 0.063   | 36.00          |
| ADL             | Soleromo (2010)| 2       | 188|                           | 4.190     | 1.910       | 9.191     | 0.000   | 90.20          |
| ADL             | 3.412       | 1.855   | 2.276  | 0.000    |            |             |           |         |                |

#### C

| Group by Outcome | First author | FU (yrs) | N | Statistics for each study | Odds ratio | Lower limit | Upper limit | p-Value | Relative weight |
|-----------------|--------------|---------|---|---------------------------|-----------|-------------|------------|---------|----------------|
| ADL             | Ozir (1996)  | 2       | 1342|                           | 2.070     | 0.972       | 4.400     | 0.069   | 4.01           |
| ADL             | Zhang (2013) a| 3 | 504|                           | 1.140     | 0.286       | 4.516     | 0.882   | 1.21           |
| ADL             | Gill (2009)  | 11      | 722|                           | 1.900     | 1.620       | 2.220     | 0.000   | 94.78          |
| ADL             | 1.885       | 1.520   | 2.300  | 0.000    |            |             |           |         |                |
| IADL            | Zhang (2013) b| 3 | 504|                           | 1.280     | 0.661       | 2.557     | 0.464   | 49.63          |
| IADL            | Carriere (2009)| 7 | 545|                           | 3.410     | 1.742       | 6.076     | 0.000   | 50.37          |
| IADL            | 2.067       | 0.927   | 3.477  | 0.131    |            |             |           |         |                |
reserve against the development of ADL and IADL dependence.\textsuperscript{13} Thus, individuals with lower muscle strength, and therefore a lower protective reserve, are at higher risk of developing new ADL and IADL dependence at follow-up.\textsuperscript{14}

The prevalence of ADL and IADL dependence increases with age, muscle strength amongst older adults has been shown to decrease.\textsuperscript{126–129} Gender has also been suggested to influence muscle strength as hospitalized older adults demonstrated an association between handgrip strength with ADL and IADL in male patients, but not female patients.\textsuperscript{112} Individuals with high muscle strength at baseline are also likely to preserve their higher handgrip strength at follow-up.\textsuperscript{129} It would be expected that the association is stronger with longer follow-up duration. However, this was not observed in our meta-analysis. A reason this could be due to the different baseline ages and follow-up duration between studies. Given that muscle mass decreases at a slower rate compared with muscle strength, it may be easier to preserve and maintain muscle mass, which can also prevent the decline in muscle strength.\textsuperscript{130}

Muscle quality, which refers to the muscle strength or power per unit of muscle mass,\textsuperscript{131} has been associated with worse ADL in a previous cross-sectional study.\textsuperscript{10} As previous studies support the assumption that muscle strength decline occurs faster than muscle mass, it also suggests that muscle quality has likewise declined.\textsuperscript{130} Physical performance measured by gait speed has previously shown that a higher gait speed to be associated with higher muscle quality in older adults.\textsuperscript{132,133} Currently, no studies have explored the association between muscle quality and worsening ADLs; however, as muscle quality has been shown to decline with age\textsuperscript{134–136}, it can be expected to observe similar results as muscle mass, strength, and physical performance.

### Physical performance

Lower SPPB scores were associated with worsening ADL at follow-up. The SPPB encompasses three assessments that require strength, balance, dexterity, and cognitive control, which captures functional elements that are required for the completion of ADL and IADL.\textsuperscript{137–139} Lower extremity physical performance measured by the SPPB was associated with worse ADL. Furthermore, a difference in score of 1 point on the SPPB was also significantly associated with worse ADLs as shown in this review and prior research.\textsuperscript{138} Lower SPPB scores are a reflection of impaired skeletal muscle function and structural changes associated with chronic inflammatory processes\textsuperscript{140}, as well as neurological pathologies that impair gait and balance\textsuperscript{141} that are thought to mediate the development of ADL and IADL dependence.\textsuperscript{142} High heterogeneity was observed between studies that evaluated the SPPB as a continuous variable compared with a dichotomous variable (low vs. high). The findings from this review were consistent with a previous systematic review, where the SPPB was predictive of long-term disability.\textsuperscript{143}

Gait speed measured by a 4 m walk test is a component of the SPPB and is often used in clinical settings to identify individuals at high risk of adverse health outcomes\textsuperscript{144} and assist in the diagnosis of sarcopenia.\textsuperscript{145} Gait speed is both a simple and highly reproducible measure of physical performance and is comparable with the SPPB as a predictor of ADL dependence.\textsuperscript{146,146} In community-dwelling outpatients, the association between gait speed with ADL and IADL was stronger than its association with the other sarcopenia diagnosis criteria.\textsuperscript{147} While having a higher 0.1 m/s gait speed was not statistically significant in this study, all other analyses showed a lower gait speed favoured a worsening ADL and/or IADL. One study, which evaluated 27 200 community-dwelling older adults for gait speed, demonstrated its predictive value on the development of disability.\textsuperscript{148} Other studies reported different cut-offs for slow and fast gait speed, but no single threshold was evident with the incidence of disability.\textsuperscript{148} Therapies or preventative interventions targeted at improving or maintaining gait speed should be considered amongst older adults, as these changes are reflective of the progression and development of ADL and IADL dependence.\textsuperscript{149,150} The findings of this meta-analysis also resonate with a previous systematic review, which demonstrated that slow gait speed was associated with worsening ADL in older populations.\textsuperscript{15,151}

One leg balance was significantly associated with worsening ADL in the follow-up. The importance of balance is well described controlling both static and dynamic posture while performing a variety of daily activities,\textsuperscript{152,153} such that it has been used as a predictor of high-risk individuals prone to falls.\textsuperscript{154} Although one previous study reported no statistically significant association between one leg balance and ADL dependence, the three studies included in this meta-analysis demonstrated a strong association between low one leg balance and worsening ADLs.\textsuperscript{155} Timed up and go is a measure of walking, balance, strength, and cognition.\textsuperscript{156} A descriptive meta-analysis exploring the cut-off times of the timed up and go test reported cut-off values of 8.1, 9.2, and 11.3 s for those aged 60–69, 70–79, and 80–99 years old, respectively.\textsuperscript{157} All studies included in the meta-analysis\textsuperscript{84,89,91} had greater cut-offs for a slow timed up and go time, potentially underestimating the pooled effect size. Timed up and go had a smaller effect size but less heterogeneity in predicting worsening ADLs compared with one leg balance in this meta-analysis. Prior research comparing different measures of balance reported timed up and go as being a better predictor of ADL in older the community-dwelling population.\textsuperscript{158}

The chair stand test was significantly associated with worsening ADL but not IADL. Chair stand test has been used as a measure of lower body strength in older adults in community-dwelling older adults and as part of the SPPB.\textsuperscript{11,159} A previous study reported that 22% of community-dwelling older individuals are unable to complete
the chair stand test (5 to 10 rises) without the use of hands and/or arms. The 30 s chair stand test may be a better protocol as it is more reliable given that some individuals are unable to complete standard protocols and the floor effect. Surprisingly, no studies included in the meta-analysis reported the 30 s protocol; only the 5× chair stand test was used. High heterogeneity was observed in IADL perhaps because of the different cut-off points used (11.2 s and 13 s) although this was not the case for ADLs.

**Strength and limitations**

This systematic review and meta-analysis explored muscle mass, muscle strength, and physical performance as predictors for ADL and IADL rather than limiting to just a single measure. By evaluating the effects of all three measures, this review presented the most detailed assessment of this topic. To reduce the risk of reverse causation when interpreting the associations reported, only prospective studies were included. There are also limitations to this review. Not all studies were pooled into a meta-analysis because of differences in measures and cut-offs of muscle mass, muscle strength, and physical performance, the use of different statistical analyses, or the lack of data required to calculate an OR. Studies that were pooled were also reporting univariate and multivariate analyses, adjusting for different confounders that were inconsistent between studies that may have further led to an over or under estimation of the effect sizes. Studies that did not have a primary aim of exploring the association between baseline muscle measures with ADL and/or IADL may have used less standardized procedures. The follow-up duration between studies varied significantly, which may have impacted the results.

**Future recommendations**

There were few pre-existing studies that explored the association between baseline muscle mass and ADL and/or IADL. Studies should continue to investigate the association of muscle mass alone with ADL and/or IADL. Interventions tailored for specifically increasing muscle measures should be developed to prevent individuals from having worsening ADL and/or IADL in their future. Interventions should be developed with the focus of preserving or increasing muscle measures as we age.

**Conclusions**

This study quantified the current research available between muscle measures and (I)ADL. Muscle mass is predictive of ADL and IADL decline whereas muscle strength and physical performance are predictive of both ADL and/or IADL decline. Future studies should continue to develop and improve interventions to preserve and improve muscle measures to prevent ADL and IADL dependence.

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**Online supplementary material**

Additional supporting information may be found online in the Supporting Information section at the end of the article.

**Table S1. Search Strategy**

**Data S2. Newcastle–Ottawa Scale**

**Table S3. Breakdown of the ADL components in articles that created their own questionnaire**

**Conflict of Interest**

Daniel X. M. Wang, Jessica Yao, Yasar Zirek, Esme M. Reijnierse, and Andrea B. Maier declare that they have no conflict of interest.

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