The Association between Malnutrition and Physical Performance in Older Adults: A Systematic Review and Meta-Analysis of Observational Studies

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ABSTRACT

In recent years the focus of healthcare and nutritional science in older adults has shifted from mortality towards physical performance and quality of life. The aim of this review was to summarize observational studies on physical performance in malnourished (MN) or at risk of malnutrition (RMN) older adults compared with well-nourished (WN) older adults. Eligible studies had to report on nutritional status and objectively measured physical performance in older adults (≥60 y). MN or RMN groups had to be compared with a WN group, measured with a validated nutrition screener. Ovid Medline and Web of Science were searched until 13 November, 2020. Study quality was scored using a modified Newcastle–Ottawa Scale (NOS). Results were analyzed by meta-analysis when possible, or narratively reviewed otherwise. Forty-five studies (16,911 participants in total) were included from studies in outpatient clinics ($n = 6$), nursing homes ($n = 3$), community-dwelling older adults ($n = 20$), hospitalized patients ($n = 15$), or a combination ($n = 1$). Studies used 11 different screeners of malnutrition, and 8 types of physical performance measures. Meta-analysis showed that compared with MN, WN groups had better hand grip strength (mean difference [MD] = 4.92 kg; 95% CI: 3.43, 6.41; $P < 0.001$; $n = 23$), faster gait speed (MD = 0.16 m/s; 95% CI: 0.05, 0.27; $P = 0.0033$; $n = 7$), performed faster on timed-up-and-go (MD = –5.94 s; 95% CI: –8.98, –2.89; $P < 0.001$; $n = 8$), and scored 1.2 more short physical performance battery points (95% CI: 1.32, 2.73; $P < 0.001$; $n = 6$). Results were less pronounced when compared with RMN. Narratively, all studies showed an association for knee extension strength, 6-min walking test, and multicomponent tests, except for the chair stand test. Study limitations include no studies scoring "good" on NOS, lack of confounder adjustment, and high heterogeneity. Overall, evidence from cross-sectional studies indicate an association between malnutrition and worse physical performance in older adults. This study is registered in PROSPERO as CRD42020192893. *Curr Dev Nutr* 2022;6:nzac007.

Keywords: malnutrition, sarcopenia, undernutrition, aging, physical function, muscle strength, muscle function, elderly, community-dwelling

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Abbreviations used: CST, chair stand test; ESCEO, European Society for Clinical and Economic Aspects of Osteoporosis, Osteoarthritis and Musculoskeletal Diseases; ESPEN, European Society of Clinical Nutrition and Metabolism consensus statement on malnutrition; GLIM, Global Leadership Initiative on Malnutrition criteria; HGS, handgrip strength; KES, knee extension strength; MD, mean difference; MN, malnourished; MNA, Mini Nutritional Assessment; MNA-SF, Mini Nutritional Assessment-Short Form; MUST, Malnutrition Universal Screening Tool; NOS, Newcastle–Ottawa Scale; NRS2002, Nutrition Screening 2002; RMN, risk of malnutrition; SCREEN II, Seniors in the Community, Risk Evaluation for Eating and Nutrition, version II; SGA, Subjective Global Assessment; SNAQ, Short Nutritional Assessment Questionnaire; SPPB, short physical performance battery; TUG, timed-up-and-go; WN, well-nourished; 5CST, 5 times chair stand test; 6MWT, 6-min walking test.

Introduction

Malnutrition, sarcopenia, and low physical performance are prevalent among the older population (1, 2). Malnutrition (here used synonymously with *undernutrition*) can be defined as "a state resulting from lack of intake or uptake of nutrition that leads to altered body composition (decreased fat-free mass) and body cell mass leading to diminished physical and mental function and impaired clinical outcome from disease" (3). Low dietary intake is usually regarded as the main determinant of malnutrition, but many other factors can be at play (4); experts in geriatric nutrition consider low intake, high requirements, and impaired bioavailability as core determinants of malnutrition. These 3 are directly or indirectly affected by dozens of possible determinants at various levels and from various domains, including diarrhea, poverty, and multimorbidity for example (4–6).

The main diagnostic criteria for sarcopenia are low muscle strength and low muscle quantity or quality. Muscle quantity is measured by muscle mass, whereas quality considers muscle architecture or muscle function per unit of muscle mass (7). When additionally low physical performance is present, sarcopenia is categorized as severe (7). Low physical performance is an important indicator as it predicts adverse outcomes (7).

Physical performance is a broad and multidimensional concept. It has been described as including ambulatory status, postural control and stability, functional mobility, functional extremity strength, dynamic balance, and overall endurance (8). Recently, the European Society for Clinical and Economic Aspects of Osteoporosis, Osteoarthritis and Musculoskeletal Diseases (ESCEO) defined it as "an objectively measured whole-body function related with mobility," and that low physical performance may be evident before effects on activities of daily living can be measured (9). To study the treatment of sarcopenia they advise using the combination of muscle strength and physical performance (10).

Malnutrition, sarcopenia, and physical performance are thought to have complex origins and are interrelated. Malnutrition affects sarcopenia and physical performance via the loss of muscle mass and strength, and changes in the nervous and skeletal systems (11, 12). All 3 result in poor health outcomes such as higher morbidity, lower quality of life, and higher mortality (13–15).

Quality of life is among the most important outcomes among older adults, of which physical performance is a key element (16). Improving physical performance or preventing decline is a goal of many interventions aimed at older adults. Contrary to factors such as age, gender, and many comorbidities, nutritional status is a modifiable factor and nutritional interventions are a popular intervention aimed at improving physical performance. However, the effectiveness of improving physical performance via nutritional interventions remains unclear.

Systematic reviews on the association of nutritional interventions with physical performance are inconsistent (17–20); the included studies focused on a broad range of nutritional interventions and varying outcomes. Moreover, the nutritional status of the participants in these systematic reviews was not defined. Instead, participants were defined as frail, sarcopenic, or healthy older adults (17–20), potentially causing further discrepancies since the intervention effects may differ between well-nourished and malnourished older adults (21). The systematic review and meta-analysis that did include well-defined malnourished patients found inconsistent results (14).

Systematic reviews on the association of malnutrition with sarcopenia do exist. However, these reviews focused on hospitalized patients specifically (22) or reported that the lack of generally accepted definitions in the past prevented valid comparison (23). Additionally, the use of BMI in these reviews as a single measure of nutritional status is inadequate and likely contributes to inconclusive results due to the existence of sarcopenic obesity (23).

In order to improve understanding of the inconsistent results of nutritional intervention effects on physical functioning, it is important to clarify the underlying assumption that malnourished older adults have reduced physical performance compared with well-nourished (WN) peers. A systematic review on the association between malnutrition and physical performance is lacking despite many observational studies that report on these outcomes. Therefore, with this systematic review we aim to clarify current knowledge and summarize existing findings of observational studies on physical performance in malnourished compared with well-nourished older adults. We focus on studies that used validated, multidimensional screeners, or assessment tools of malnutrition as well as objectively measured outcomes of physical performance tests or muscle strength.

Methods

This systematic review is registered in PROSPERO as CRD42020192893 and adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines for systematic reviews and meta-analyses (24).

Search strategy

We conducted a systematic search in 2 online databases: "Ovid Medline" and "Web of Science core selection." Publications from any date until 13 November, 2020 were searched with terms selected based on literature, which consisted of synonyms of malnutrition, physical performance, older adults, and observational studies (full search strategy in **Tables 1** and **2**). Hand searching consisted of a nonsystematic presearch in Google Scholar and backward snowballing of the included studies from the systematic search. If full-text publications could not be obtained via the university library, the corresponding author was contacted via ResearchGate or email twice. If corresponding authors could not provide the full-text article, or if after 2 approaches no answer was received, the study was excluded. Abstracts and unpublished studies were not considered in the current review.

Study selection

The title and abstract of the systematic search results were screened to remove duplicates, animal studies, in vitro studies, intervention studies, and review articles. Subsequently, full-text articles of potentially relevant publications were independently screened based on study inclusion and exclusion criteria. Screening and data extraction were separately performed by 2 researchers. Conflicts were resolved through discussion between the 2 researchers. Remaining disagreements were discussed among the research team until consensus was reached.

Eligibility criteria

Studies published in Dutch or English were considered eligible. For full-text screening, inclusion criteria were used in the following order: the general older adult population was the target population of this review. As age cut-offs for "older adults" vary around the world, a low cut-off of 60 y or older was chosen to enable a broad worldwide inclusion. For validity and comparability, a common and validated nutrition screener or assessment tool that measured more than only BMI or unintentional weight loss had to be used. The studies had to compare participants who were malnourished (MN) or at risk of malnutrition (RMN) to a reference group of WN older adults. Physical performance had to be measured in an objective way for accuracy and comparability and had to measure ambulatory status, postural control, and stability, functional mobility, functional extremity strength, dynamic balance, or overall endurance. We included measures of muscle strength for their strong association with adverse outcomes and importance in activities of daily living (25) and recommendation by ESCEO (10). Due to the scarcity of cohort studies, the included studies had to report on the cross-sectional association between nutritional status and physical performance. Studies comprising mostly individuals with highly fatal disease were excluded.

TABLE 1 Ovid Medline search query

	Ovid Medline: 13/11/2020	Hits
1	exp malnutrition/	122,680
2	(malnutrition or malnourished or undernutrition or undernourished)	52,821
3	1 or 2	150,594
4	exp physical functional performance/	1744
5	(physical performance or functional performance or functional status or performance status or physical function or physical fitness or gait speed or walking speed or mobility or handgrip or leg strength or short physical performance battery or SPPB or EPESE or chair stand or sit to stand or timed up or TUG or balance)	466,631
6	4 or 5	467,049
7	3 and 6	4844
8	exp aged/	3,160,522
9	(aged or aging or ageing or older adult or elderly or geriatric)	5,610,038
10	8 or 9	5,610,038
11	7 and 10	2197
12	exp observational study/	87,463
13	(observational study or cohort or epidemiologic or case-control or cross-sectional or longitudinal)	1,576,745
14	12 or 13	1,576,745
15	11 and 14	770

EPESE, Established Populations for the Epidemiologic Study of the Elderly; SPPB, short physical performance battery; TUG, timed-up-and-go test.

Data extraction

The following data were extracted from each included study: bibliographic information [last name of first author, publication year, name of study (if applicable)]; country and setting; sample size; age and gender distribution; malnutrition screener or assessment tool; proportion of population that was MN or RMN; physical performance measure(s) used; association measures (including means for meta-analysis); covariates. For each study, a plus sign was added to indicate hypothesized results (MN/RMN was associated with significantly worse physical performance compared with WN people), a minus sign to indicate opposing results, and a zero indicates no significant association was found. When expected associations were only found in subgroups (in either the RMN or MN groups and/or when an association was only observed in men or women), this was indicated by 0/+. Studies were tabled in alphabetical order.

Quality assessment

The quality of the studies was assessed using the Newcastle–Ottawa Scale (NOS) for cohort studies adapted to cross-sectional studies (**Table 3**) (26, 27). The NOS assesses subject selection (representation of the sample, justification of sample size, nonrespondents' characteristics), ascertainment of the exposure (malnutrition screening or assessment tool), comparability of the studied groups and confounders, objectivity of the outcome assessment (physical performance or muscle strength measure), and appropriateness of the statistical analysis. A maximum score of 9 points could be obtained; selection (max. 5 points), comparability (max. 2 points), and outcome (max. 2 points). The overall study score was defined as unsatisfactory (0–4 points), satisfactory (5–7 points), or good (8–9 points). The quality assessment was independently performed by 2 reviewers and conflicting results were resolved

TABLE 2 Web of Science search query

	Web of Science core selection: 17/11/2020	Hits
1	ALL = (malnutrition OR malnourished OR undernutrition OR undernourished)	57,549
2	ALL = (physical performance OR functional performance OR functional status OR performance status OR physical function OR physical fitness OR gait speed OR walking speed OR mobility OR handgrip or leg strength OR short physical performance battery OR SPPB OR EPESE OR chair stand OR sit to stand OR Timed Up OR TUG OR balance)	3,119,235
3	#2 AND #1	6825
4	ALL = (aged OR aging OR ageing OR older adult OR elderly OR geriatric)	3,650,889
5	#4 AND #3	3766
6	ALL = (observational study OR cohort OR epidemiologic OR case-control OR cross-sectional OR longitudinal)	1,719,562
7	#6 AND #5	1413

EPESE, Established Populations for the Epidemiologic Study of the Elderly; SPPB, short physical performance battery; TUG, timed-up-and-go test.

TABLE 3 Modified Newcastle–Ottawa Scale

	Category	Points
	Selection (max. 5)	
1	Representative of the sample (max 1)	
	a. Truly representative of the average in the target population (random sample or whole population)	1
	b. Somewhat representative of the average in the target population (nonrandom sample)	1
	c. Selected group/convenience sample	
	d. No description of the sampling strategy	
2	Sample size (max 1)	
	a. Justified and satisfactory (including sample size calculation)	1
	b. Not justified	
3	Nonrespondents (max 1)	
	a. Comparability between respondents and nonrespondents characteristics is established, and the response rate is satisfactory (>60%)	1
	b. The response rate is unsatisfactory, or the comparability between respondents and nonrespondents is unsatisfactory	
	c. No description of the response rate or the characteristics of the responders and nonresponders	
4	Ascertainment of the exposure (malnutrition) (max 2)	
	a. A validated measurement tool is described and does not include a measure of physical functioning	2
	b. A validated measurement tool is described, but includes measure of physical functioning	1
	c. No description of the measurement tool or criteria	
	Comparability (max. 2)	
5	The subjects in different outcome groups are comparable, based on the study design or analysis. Confounding factors are controlled for	
	a. Study controls for age and gender	1
	b. Study controls for any additional factor	1
	Outcome (max. 2)	
6	Assessment of the outcome (physical performance measure)	
	a. Measurements are taken in a standardized manner/via a standardized protocol	1
	b. Record linkage	1
	c. Self-report	
	d. No description of standardization or reference to standardized way	
7	Statistical test	
	a. The statistical test used to analyze the data is clearly described and appropriate, and the measurement of the association is presented as either an OR/PR, CI, and *P* value, a β-coefficient, SE, and *P* value or means, SD, *P* value	1
	b. The statistical test is not appropriate, not described, or incomplete	

through discussion between the 2 researchers. Remaining disagreements were discussed among the research team until consensus was reached.

Synthesis of results

If information did not match up and authors did not reply, numbers in tables were chosen over numbers in text or over percentages. Narrative results reported effect measures from the articles, except for categorical data reported as numbers: these were converted to ORs where possible. The number of studies reporting an association were reported per category of physical functioning [categories data-driven and based on domain(s) of physical performance or muscle strength: hand grip strength (HGS), gait speed, timed-up-and-go (TUG), short physical performance battery (SPPB), chair stand test (CST), knee extension strength (KES), other multicomponent tests, 6-min walking test (6MWT), and remaining measures as "other"], and per setting (hospital inpatient, hospital outpatient, nursing home, community dwelling). For studies which assessed malnutrition with several screeners or assessment tools, the choice was made in the following order: Mini Nutritional Assessment (MNA), Nutritional Risk Screening 2002 (NRS2002), Subjective Global Assessment (SGA), Seniors in the Community: Risk Evaluation for Eating and Nutrition II (SCREEN II), Mini Nutritional Assessment-Short Form (MNA-SF), Short Nutritional Assessment Questionnaire (SNAQ) (based on times used in the other studies and ascertainment of exposure).

Meta-analysis

Meta-analysis was conducted if sufficient data were available (≥5 studies) and if outcomes between studies were reasonably homogeneous (e.g. same unit, scale, classification of malnutrition). Authors of relevant articles were contacted if required data were not reported. The Cochrane Handbook for conducting meta-analyses was followed (28). Results (mean differences) were pooled using a random-effects model. The extent of statistical heterogeneity was quantified using both the chi-squared test and the I-squared statistic. With respect to the latter, a value of >50% was used as a threshold for indicating substantial statistical heterogeneity (28). If >5 studies were included, sensitivity analyses were conducted to assess the influence of a single study on the overall estimate and to explore the impact of studies that were judged to be at high risk of bias as assessed by NOS.

The meta-analyses were conducted using R (version 3.6.3, R Foundation for Statistical Computing, Vienna). The "meta" package was used for calculations and data visualizations.

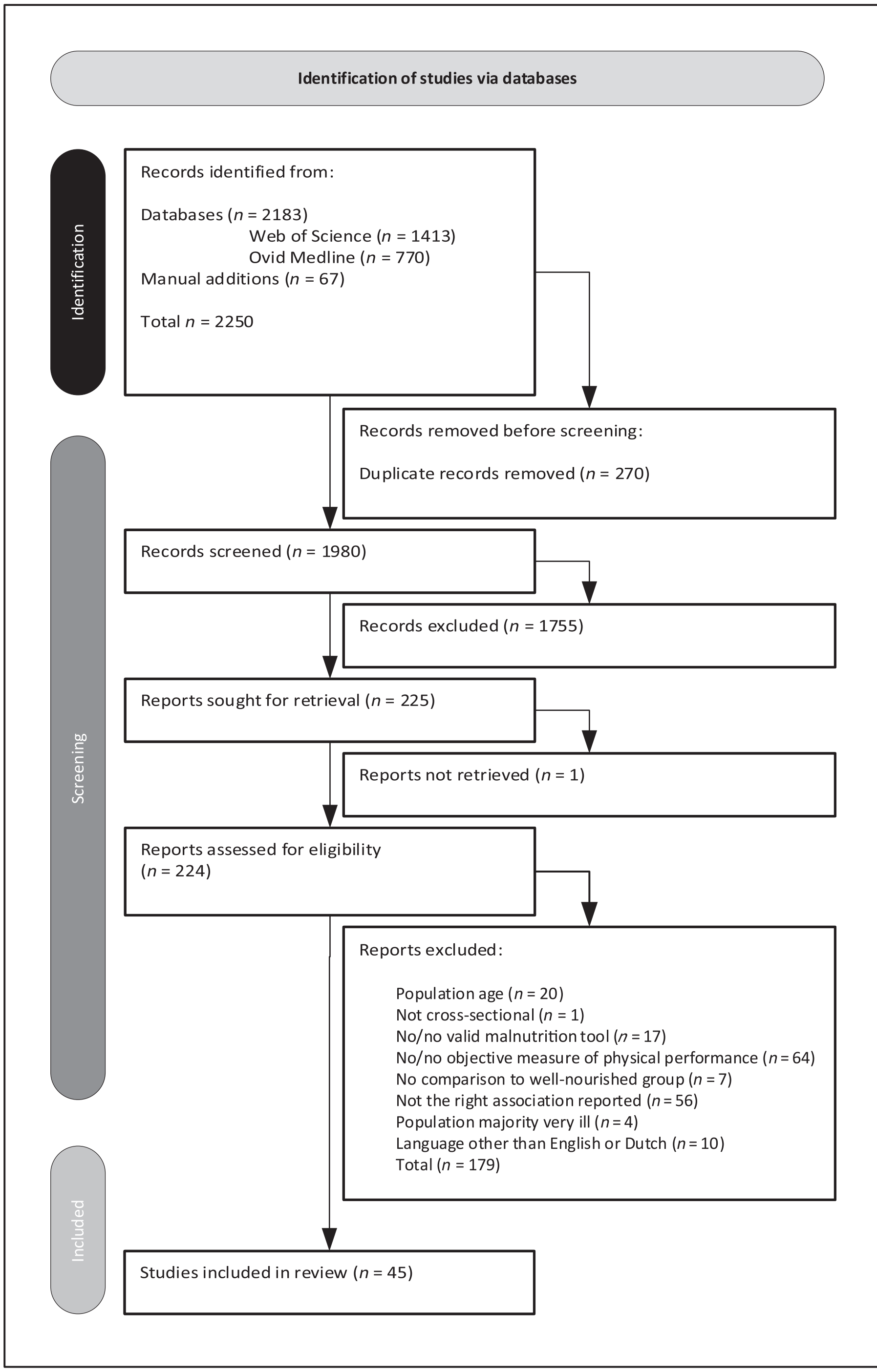

FIGURE 1 Preferred Reporting Items for Systematic Reviews and Meta-Analyses flow diagram of identification, screening, and inclusion of studies. Excluded reports mention the primary reason of exclusion.

Results

The searches resulted in a total of 2250 records, from which 270 duplicates were removed. The remaining 1980 records were screened based on title and abstract, leading to the further exclusion of 1755 studies. One other record could not be retrieved, leaving 224 records for full-text screening. At this stage, 179 records were excluded for not meeting the inclusion criteria, leaving 45 studies for the qualitative review (**Figure 1**). The included studies (**Table 4**) were published between 2002 and 2020 and included between 41 and 1425 participants, totaling 16,911 participants. Most studies were performed in Europe ($n = 20$) or Asia ($n = 14$). Others took place in Oceania ($n = 3$), South Amer-

TABLE 4 Alphabetic table—characteristics of included studies on nutritional status and physical performance

First author, year	Setting, country, study name	Sample size, (*n*);	Age (y), mean ± SD/ median [IQR]	Malnutrition criteria	(Risk of) malnutrition status (%)	Effect size[2]	Adjusted covariates	Strength (NOS)	Association (+/0)[1]	Outcome
Adly, 2020 (29)	Hospital, Egypt	Total: 190; W: 96, M: 94	68.67 ± 7.33	MNA-SF: 12–14: WN, 8–11: RMN, 0–7: MN	RMN: 37.4%, MN: 18.4%	Impaired sit-to-stand (>2 s) OR[3] (95% CI): MN vs. WN: 0.491 (0.12–1.94), *P* 0.31; RMN vs. WN: 0.35 (0.11–1.05), *P* 0.06	—	2	0	1 CST
Akin, 2014 (30)	Community dwelling, Turkey	Total: 845; W: 437, M: 408	71.6 ± 5.6	MNA: <23.5: RMN/MN, ≥23.5: WN	MN+RMN: 45.6%	Gait speed, s (4 m): OR (95% CI): 1.16 (1.07–1.25), (*P* < 0.001)	Depressive mood, diabetes mellitus, low income, living alone, waist circumference, MUAC	4	+	Gait speed
Bertschi, 2020 (31)	University department of geriatric medicine, Switzerland	Total: 305; W: 200, M: 105	84.0 [10.0]	NRS-2002: ≥3: RMN, <3: WN	RMN: 54.1%	low HGS (age ≥75: <34 kPa women, <50 kPa men; age ≤75: <42 kPa women, <64 kPa men): OR: 0.68 (0.35–1.29), *P* 0.236	Calf circumference, mid-arm circumference, BMI, cognitive impairment, physical performance, functional disability, age, sex	7	0	HGS
Borkent, 2020 (32)	Community dwelling, Netherlands	Total: 200; W: 129, M: 71	78.2 ± 6.9	SCREEN II: <54 RMN. SNAQ 65+: severe risk: ≥4 kg weight loss last month or UAC <25 cm, moderate risk: poor appetite and not able to walk stairs without rest	RMN (SCREEN II): 68.5%. RMN (SNAQ65+) (moderate/severe): 13.5%	SCREEN II: TUG, s: WN: 9.8 sec [8.6–12.4], RMN: 10.5 sec [8.5–14.1], *P* 0.203. HGS, kgF: WN: 28.8 kgF [23.8–35.0], RMN: 25.8 kgF [19.0–31.0], *P* 0.005. SNAQ65+: TUG, S: WN: 9.9 s [8.3–13.3], RMN: 12.1 s [9.0–19.7],	—	3 (SCREEN II-TUG and SNAQ-HGS),4 (SCREEN II-HGS), 2 (SNAQ-TUG)	0 (SCREEN II-TUG),+	TUG, HGS

(*Continued*)

TABLE 4 (*Continued*)

First author, year	Setting, country, study name	Sample size, (*n*);	Age (y), mean ± SD/ median [IQR]	Malnutrition criteria	(Risk of) malnutrition status (%)	Effect size[2]	Adjusted covariates	Strength (NOS)	Association (+/0)[1]	Outcome
						P 0.026. HGS, kgF: WN: 27.1 kgF [21.5–34.0], RMN: 20.9 kgF [16.0–26.6], $P <$ 0.001				
Chang, 2017 (33)	Community dwelling, Taiwan	Total: 432; W: 264, M: 168	RMN: 72.95 ± 9.28, WN: 71.55 ± 10.64	MNA-SF: 12–14: WN, 8–11: RMN, 0–7: MN	RMN: 30.6, MN: 0	30 s CST, no. times: WN: 16.74 ± 6.73, RMN: 13.79 ± 7.15, $P < 0.001$. TUG, s (8 foot): WN: 6.39 ± 3.07, RMN: 8.01 ± 5.76, $P = 0.008$	—	4	+	30 s CST, TUG
Chatindiara, 2019 (34)	Community dwelling, Auckland, New Zealand	Total: 257; W: 137, M: 120	79 [7]	MNA-SF: ≤11: RMN/MN, ≥12: WN	11.7	Low gate speed <0.8 m/s (2.4 m): OR[3] (95% CI): 3.46 (1.20–10.03), WN: 16 (7.1%), RMN: 6 (20.0%), P 0.028. Low 5CST, ≥17 s: OR[3] (95% CI): 0.76 (0.27, 2.11), (WN: 57 (37.7%), RMN: 6 (31.6), $P = 0.600$. Low HGS: women <20 kg, men <30 kg): OR[3] (95% CI): 0.75 (0.30–1.87), (WN: 123 (54.2%), RMN: 15 (50.0%) $P = 0.626$	—	4	+ (Gait speed), 0	Gait speed, 5 CST, HGS
Chevalier 2008 (35)	Hospital, Canada	Total: 182; W:121, M: 61	WN: 78.1 ± 0.6, RMN: 82.2 ± 1.6, MN: 85.9 ± 1.5	MNA: <17: MN, 17–23.5: RMN, >24: WN	RMN: 52.5, MN: 3.4	HGS, kg (max. value dominant hand): WN: 18.6 ± 1.0 kg, RMN: 17.1 ± 1.0 kg, MN means ± SD: 15.1 ± 4.2 kg, WN vs. RMN: NS, WN vs. MN: NS. Gait speed, m/s	—	5	0 (HGS), +/0	HGS, gait speed

(*Continued*)

TABLE 4 (*Continued*)

First author, year	Setting, country, study name	Sample size, (*n*);	Age (y), mean ± SD/ median [IQR]	Malnutrition criteria	(Risk of) malnutrition status (%)	Effect size[2]	Adjusted covariates	Strength (NOS)	Association (+/0)[1]	Outcome
						(15 m): WN: 0.64 ± 0.03 m/s, RMN: 0.53 ± 0.03 m/s, N means ± SD: 0.56 ± 0.13 m/s (WN vs. RMN: $P < 0.05$); (WN vs. MN: NS)				
Dent, 2018 (36)	Hospital, Australia	Total: 172; W: 123 M: 49	85.2 ± 6.4	MNA: <17: MN, 17–23.5: RMN ≥24: WN	MN: 30.81, RMN: 48.84	HGS, kg: WN: 19.7 ± 8.2 kg, RMN: 17.3 ± 7.7 kg, MN: 12.7 ± 6.2 kg, (WN vs. RMN: NS) (WN vs. MN: <0.001)	—	4	+/0	HGS
Ferdous, 2009 (37)	Community dwelling, Bangladesh (rural area)	Total: 457; W: 249, M: 208	69.5 ± 7.0	MNA. (excluding mobility): <15: MN, 15–21.5: RMN, ≥22: WN	MN: 26, RMN: 62	HGS, kg (max. value): WN women: 16.6 ± 4 kg, RMN women: 16.3 ± 6 kg, MN women: 13.8 ± 4 kg, women WN vs. RMN: N.S women WN vs. MN: $P =$ 0.003; WN men: 30.3 ±11 kg, RMN men: 27.1 ±7 kg, MN men: 23.9 ± 4 kg, men WN vs. RMN: $P = 0.034$, men WN vs. MN: $P = 0.001$. 6-item performance test, % limitation in any of the tasks, OR (95% CI): MN: OR 4.24 (2.17–8.27)[3,4] RMN: OR 1.92 (1.07–3.45)[3,4]; (WN: 36%, RMN: 53%, $P = 0.032$) (WN: 36%, MN: 71%, $P =$ 0.001)	Stratified by gender (HGS)	6	0/+ (HGS), +	HGS, 6-item performance

(*Continued*)

TABLE 4 (*Continued*)

First author, year	Setting, country, study name	Sample size, (*n*);	Age (y), mean ± SD/ median [IQR]	Malnutrition criteria	(Risk of) malnutrition status (%)	Effect size[2]	Adjusted covariates	Strength (NOS)	Association (+/0)[1]	Outcome
Gingrich, 2019 (38)	Hospital, Germany	Total: 100; W: 481, M: 52	76.5 ± 4.7	ESPEN	MN: 15%	Low HGS lowest 20% (by gender, BMI): 66.7% in MN group. MN vs. WN: NS. Low gait speed: 33% in MN group. MN vs. WN: NS. Reduced performance SPPB (<10 pts): 75.0% in MN group. MN vs. WN: $P < 0.05$	—	2	0, 0, + (SPPB)	HGS, gait speed, SPPB
Goldfarb, 2018 (39)	Hospital, Canada, USA, and France	Total: 1158; W: 481, M: 677	81.3 ± 6.1	MNA-SF: 12–14: WN, 8–11: RMN, 0–7: MN	RMN: 32.8, MN: 8.7	Gait speed, m/s (4 m): WN: 0.79 ± 0.35, RMN: 0.64 ± 0.35, MN: 0.49 ± 0.36, $P < 0.001$. HGS, kg: WN: 27.5 ± 10.4, RM: 24.0 ± 10.4, MN: 20.9 ± 9.9, $P < 0.001$. SPPB, score: WN: 7.4 ± 3.0, RM: 6.1 ± 3.3, MN: 4.9 ± 3.1, $P < 0.001$	—	4	+	Gait speed, HGS, SPPB
Gurina, 2011 (40)	Community dwelling, Russia	Total: 611; W: 438, M: 173	Women: 75.7 ± 6.1; men: 73.6 ± 5.3	MNA: ≤23.5: RMN/MN	MN: 1.8, RMN: 17.3	SPPB, score: RMN: $\beta = -0.219$, ($P < 0.05$)	Slow gait, less PA, exhaustion, muscle weakness	5	+	SPPB
Hegendörfer, 2020 (41)	BELFRAIL cohort, community dwelling, Belgium	Total: 567; (MNA: 556) W: 356, M: 211	84.7 ± 3.7 y	MNA: RMN: MNA <24 or screener >11, WN: ≥24	RMN: 12.2%	Physical test (score 0–14): RMN: 6.5 [4, 9.79], WN: 9 [6, 12], P 0.002. HGS, highest of 3: RMN: 16.5 [12.6–20.2], WN: 21.5 [16.7, 27.4], $P < 0.001$	—	5	+	Physical performance test, HGS

(*Continued*)

TABLE 4 (*Continued*)

First author, year	Setting, country, study name	Sample size, (*n*);	Age (y), mean ± SD/ median [IQR]	Malnutrition criteria	(Risk of) malnutrition status (%)	Effect size[2]	Adjusted covariates	Strength (NOS)	Association (+/0)[1]	Outcome
Holst, 2013 (42)	Hospitals, Denmark and Sweden	Total: 233; W: 152 M: 81	81.0 ± 7.64	MNA: ≤23.5: RMN/MN, >23.5: WN. MUST: 0 = WN 1–2 = RMN/MN. NRS-2002: ≥3: RMN	MNA: 68. MUST: 47. NRS-2002: 54	HGS, kg (max. value, predominant hand): MNA: WN: 15.8 ± 6 kg, RMN: 12.3 ± 7 kg, $P < 0.05$. MUST: WN: 14.4 ± 7 kg, RMN/MN means ± SD: 11.4 ± 7 kg, $P < 0.05$. NRS-2002: WN: 14.5 ± 7 kg, RMN: 12.4 ± 7 kg, $P < 0.05$	—	4	+	HGS
Inoue, 2017 (43)	Hip fracture patients at hospitals, Japan	Total: 204; W: 165, M: 39	82.7 ± 9.2	MNA-SF: 12–14: WN, 8–11 RMN, 0–7: MN,	RMN: 48.04, MN: 25.00	HGS, kg (max. value dominant hand): RMN: 11.9 ± 7.0 kg, WN: 14.6 ± 6.0 kg, MN: 8.7 ± 6.7 kg; WN vs. RMN: NS; WN vs. MN: <0.01	—	3	0/+	HGS
Johansson, 2009 (44)	Community dwelling, Sweden	Total:583; W: *n* = 278, M: *n* = 305	Aged 75 y and 80 y	MNA: 24–30: WN, <24: RMN/MN	All: 14.5; women: 18.8, men: 10.6	HGS, kg (max. measure of dominant hand): women: RMN: 19.7 ± 6.1, WN: 23.5 ± 5.7, $P < 0.001$; men: RMN: 34.2 ± 9.1, WN: 41.3 ± 8.5, $P < 0.001$	—	5	+	HGS
Kaburagi, 2011 (45)	Community dwelling, Japan	Total: 130; W: 104, M: 26	76.6 ± 6.3	MNA: >23.5: WN, ≤23.5: RMN	20.77	HGS, kg (mean of both hands): RMN: 18.9 ± 7.4 kg, WN: 22.9 ± 6.8 kg, $P = 0.009$. Usual gait speed, s (5 m): RMN: 5.1 ± 1.8 s, WN: 4.3 ±1.2 s, $P = 0.002$; max. gait speed, s (5 m): RMN: 3.6 ± 1.1 s, WN: 3.2 ± 0.7 s, $P = 0.001$	—	5	+	HGS, gait speed

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TABLE 4 (*Continued*)

First author, year	Setting, country, study name	Sample size, (*n*);	Age (y), mean ± SD/ median [IQR]	Malnutrition criteria	(Risk of) malnutrition status (%)	Effect size[2]	Adjusted covariates	Strength (NOS)	Association (+/0)[1]	Outcome
Kiesswetter, 2013 (46)	Community dwelling (home care), Germany	Total: 296; W: 185 M: 111	80.7 ± 7.7	MNA: >23.5: WN, 17–23.5: RMN, <17: MN	RMN: 56.8, MN: 12.2	TUG, s: WN: 19.9 ± 13.3 s, RMN: 23.2 ± 13.0 s, MN means ± SD: 23.8 ± 1 2.7, $P = 0.247$. HGS, bar (max. value) WN 0.57 ± 0.21 bar, RMN: 0.53 ± 0.20 bar, MN: 0.43 ± 0.20 bar, *P* trend: 0.014. SPPB, score: WN: 4.8 ± 2.6, RMN: 3.6 ± 2.5, MN: 3.8 ± 2.4, $P = 0.006$	Gender, age, MMSE, GDS, no. chronic diseases	7	0	sTUG, HGS, SPPB
Kocyigit, 2018 (47)	Outpatients, Turkey	Total: 862; W: 563, M: 299	74 ± 8.05	MNA-SF: 0–7: MN, 8–11: RMN, 12–14: WN	MN: 26.9, RMN: 7.7	Tinetti POMA: WN: 25.20 ± 3.82, RMN: 22.15 ± 6.28, MN: 20.09 ± 6.29; WN vs. RMN: $P < 0.0001$; WN vs. MN: $P < 0.0001$. Tinetti gait, score: WN: 10.82 ± 1.74, RMN: 9.51 ± 2.74, MN: 9.06 ± 2.68; WN vs. RMN: $P < 0.0001$; WN vs. MN: $P < 0.0001$. Tinetti balance, score: WN: 14.38 ± 2.30, RMN: 12.64 ± 3.76, MN: 11.03 ± 3.88; WN vs. RMN: $P < 0.0001$; WN vs. MN: $P < 0.0001$. TUG, s: WN: 12.68 ± 6.66, RMN: 17.10 ± 11.47, MN: 21.21 ± 12.90; WN vs. RMN: $P < 0.0001$; WN vs. MN: $P < 0.0001$	—	2	+	Mobility, Tinetti gait, balance, TUG

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TABLE 4 (*Continued*)

First author, year	Setting, country, study name	Sample size, (*n*);	Age (y), mean ± SD/ median [IQR]	Malnutrition criteria	(Risk of) malnutrition status (%)	Effect size[2]	Adjusted covariates	Strength (NOS)	Association (+/0)[1]	Outcome
Lecheta, 2017 (48)	Elderly Care Unit for Alzheimer's, Brazil	Total: 96; W: 68, M: 28	78.0 ± 6.52	MNA: >23.5: WN, 17–23.5: RMN, <17: MN	RMN: 55.2, MN: 5.2	TUG, s: WN: 12.7 ± 6.09, RMN: 12.8 ± 4.82, MN: 23.7 ± 14.24, P trend = 0.190. HGS, kg (mean, right hand): WN: 18.6 ± 5.74, RMN: 15.2 ± 5.70, MN: 20.5 ± 6.76; WN vs. RMN: $P <$ 0.05; WN vs. MN: NS	—	5	0 (sTUG), +/0	sTUG, HGS
Lelli, 2020 (49)	Chronic heart failure out-patients, Italy	Total: 88; W: 15, M: 73	77.8 ± 7.1	MNA: <17 MN, 17–23.5: RMN, ≥24: WN	MN $n = 1$ excluded, RMN: 33%	Gait speed m/s: (4 m usual pace): RMN: β −0.138, P 0.055	Age, sex, ejection fraction, GDS, ASMMI, caloric intake/ideal body weight	6	0	Gait speed (4 m)
Lim, 2018 (50)	Community dwelling, Korea	Total: 464 W	69.6 ± 2.96	Nutritional screening initiative (Korean): 0–2: WN, ≥6: MN	34.7	Mobility scale: WN: 86.14 ± 16.71, MN: 66.29 ± 23.23, $P <$ 0.001. 5CST, points (max. 3 points): WN: 2.88 ± 0.35, MN: 2.57 ± 0.57, $P < 0.001$	—	5	+	Mobility, 5CST
Mendes, 2018 (51)	Representative sample to the national level, Portugal	Total: 1425; W: 834, M: 591	WOMEN: low gait speed: 78.5 ± 7.1; normal gait speed: 72.4 ± 5.9; MEN: low gait speed: 77.4 ± 7.4; normal gait speed: 72.7 ± 5.8	MNA-SF (Portuguese version): MNA, <12: RMN, ≥12: WN	WOMEN: low gait speed: 23.3; normal gait speed: 12.6; MEN: low gait speed: 19.4; normal gait speed: 8.1	Low gait speed, ≤0.8 m/s (4.6 m): women OR (95% CI): 5.98 (2.46–14.53), men OR (95% CI): 2.96 (1.31–6.64)	Stratified by gender; adjusted for age, height, mid-arm muscle circumference, MMSE, self-reported sitting time, number of chronic diseases	5	+	Gait speed

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TABLE 4 (*Continued*)

First author, year	Setting, country, study name	Sample size, (*n*);	Age (y), mean ± SD/ median [IQR]	Malnutrition criteria	(Risk of) malnutrition status (%)	Effect size[2]	Adjusted covariates	Strength (NOS)	Association (+/0)[1]	Outcome
Mendes, 2019 (52)	Representative to the national level, Portugal	Total: 1425; W: 834, M: 591	Total: 74.9 ± 7.0; WOMEN: 75.0 [11.0]; MEN: 73.0 [10.0]	MNA-SF: <12: RMN/MN, ≥12: WN	WOMEN: 17.7, MEN: 11.7	Low HGS (<20 kgF women, <30 kgF men) (max. of nondominant hand): women OR (95% CI): 1.54 (1.01–2.36); men OR (95% CI): 1.57 (0.91–2.72)	Stratified by gender, adjusted for age	5	+/0	HGS
Misu, 2017 (53)	Community dwelling, Japan	Total: 204; W: 107, M: 97	73.4 ± 4.3	MNA-SF (Japanese): 12–14: WN; <11: RMN/MN	MN + RMN: 23.04	HGS, kg (max. value strongest hand): RMN: 28.6 ± 6.7 kg, WN: 29.6 ± 6.8 kg, $P = 0.374$. Gait speed, m/s (10 m, self-selected pace): Model 1: β (P value): –0.001 (0.991); Model 2: β (P value): –0.017 (0.832). 5CST, s: RMN: 8.86 ± 2.68 s, WN: 8.80 ± 2.71 s, $P = 0.883$. TUG, s: RMN: 6.54 ± 1.36 s, WN: 6.71 ± 1.13 s $P = 0.401$	Gait speed: Model 1: age, sex, BMI, musculoskeletal pain; Model 2: Model 1 plus: skeletal muscle mass index, HGS, 5CST, TUG. 5CST/sTUG/HGS: none	3 (HGS), 5 (gait speed), 4	0	HGS, gait speed, 5CST, sTUG
Norman, 2007 (54)	Institutionalized people, Germany	Total: 112; W: 78, M: 34	85.1 [79.1–91.4]	MNA: >23.5: WN, 17–23.5: RMN, <17: MN	RMN: 71.4, MN: 8.9	HGS, kg median [IQR] (max., nondominant hand): WN:16.3 [11.8–21.4], MN: 6.3 [3.6–10.8]; WN vs. RMN: N.S; WN vs. MN: $P < 0.01$. Knee extension strength, kg, median [IQR]: WN: 10.3 [7.3–16.4], RMN: 8.0 [5.0–12.0], MN: 5.0 [3.0–7.0], WN vs. RMN: $P < 0.05$; WN vs. MN: $P < 0.05$	—	4	0/+ (HGS), +	HGS, leg strength

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TABLE 4 (*Continued*)

First author, year	Setting, country, study name	Sample size, (*n*);	Age (y), mean ± SD/ median [IQR]	Malnutrition criteria	(Risk of) malnutrition status (%)	Effect size[2]	Adjusted covariates	Strength (NOS)	Association (+/0)[1]	Outcome
Ogawa, 2017 (55)	Hospital inpatients for cardiopulmonary bypass, Japan	Total: 131; W: 54, M: 77	73.7 ± 5.8	Geriatric nutritional risk index : ≥92: WN, <92: RMN	19.08	SPPB, score: RMN: 9.6 ± 2.9, WN: 11.6 ± 1.2, $P < 0.0001$. 6MWT, m: RMN: 320.9 ± 132.0, WN: 421.2 ± 141.4 $P = 0.0012$. HGS, kg (max. value): RMN: 21.0 ± 4.8, WN: 27.6 ± 6.9, $P = 0.034$. KES, Nm/kg: RMN: 35.8 ± 7.29, WN: 42.8 ± 10.9, $P = 0.009$	Sex, serum hemoglobin	5	+	SPPB, 6MWT, HGS, leg strength
Persson, 2002 (56)	Hospital, Sweden	Total: 83; (*n* = 68 for this analysis) W: 56, M: 27	83.0 ± 7.0	SGA: MN, moderate MN, WN. MNA: <17: MN, 17–23.5: RMN, >24: WN	SGA: MN: 20, possible MN: 43. MNA: MN: 26, RMN: 56. MNA-SF: MN/RMN: 69	HGS, kg (max. value, dominant hand), SGA: women: WN: 16.5 ± 3.7, moderate MN: 12.9 ± 6.1, MN: 15.5 ± 3.5; WN vs. moderate MN: $P < 0.05$); WN vs. MN: NS; men: WN: 29.0 ± 7.4, moderate MN: 26.6 ± 6.8, MN: 19.0 ± 7.6, WN vs. moderate MN: NS WN vs. MN: NS. HGS, kg: best of 2, MNA: women: WN: 16.4 ± 3.3, RMN: 16.4 ± 4.1, MN: 12.7 ± 5.7; WN vs. RMN: NS; WN vs. MN: NS; men: WN: 26.5 ± 16.3, RMN: 31.3 ± 9.1, MN: 24.3 ± 6.3; WN vs. RMN: NS; WN vs. MN: $P < 0.05$. MNA-SF:	Only stratified by gender	SGA, MNA: 3. 2 (MNA-SF)	+/0 (SGA, MNA), + (MNA-SF)	HGS

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TABLE 4 (*Continued*)

First author, year	Setting, country, study name	Sample size, (*n*);	Age (y), mean ± SD/ median [IQR]	Malnutrition criteria	(Risk of) malnutrition status (%)	Effect size[2]	Adjusted covariates	Strength (NOS)	Association (+/0)[1]	Outcome
						women: WN: 17.6 ± 3.7, MN/RMN: 13.1 ± 5.3, $P <$ 0.05; men: WN: 31.3 ± 9.1, MN/RMN: 24.3 ± 6.3, $P < 0.05$				
Pierik, 2017 (57)	EMPOWER study, hospital, The Netherlands	Total: 374; W: 183, M: 191	79.7 ± 6.39	SNAQ: RMN: ≥2, WN: ≤1	RMN: 34.8%	HGS: both hands max. 2 attempts, highest value kg OR [95% CI]: 0.98 [0.95–1.01]	Age, sex, comorbidities	7	0	HGS
Pourhassan, 2020 (58)	Acutely ill older adults in hospital, Germany	Total: 41; W: 30, M: 11	82.4 ± 6.6	GLIM: MN: ≥1 phenotypic and ≥1 etiologic component	MN: 17%	HGS, kg (max. of 3 attempts, dominant hand): WN: 20.3 kg ± 8.7, MN: 17.3 kg ± 5.7, *P* 0.268. Isometric knee extension strength: WN: 17.5 ± 6.8, MN: 12.4 kg ± 4.6, *P* 0.030	—	3 (HGS), 4	0 (HGS), +	HGS, KES
Ramsey, 2020 (59)	Outpatients, The Netherlands	Total: 286; W:170, M: 116	81.8 ± 7.4	SNAQ: ≥2: RMN/MN, <2: WN	19.9	Z gait speed, m/s (4 m): β (95% CI): –0.49 (–0.78, –0.20), $P < 0.001$. Side-by-side balance (unable to maintain 10 s): OR (95% CI): 0.69 (0.23, 2.02), $P = 0.497$; semi-tandem balance (unable to maintain 10 s): OR (95% CI): 0.67 (0.31, 1.43), $P = 0.294$; tandem balance (unable to maintain 10 s): OR (95% CI): 1.02 (0.51, 2.04), *P* = 0.957. Z LN 5CST, s: β (95% CI): 0.53	Age, sex, multimorbidity	6	+, 0 (balance, HGS)	Gait speed, balance, 5CST, TUG, SPPB

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TABLE 4 (*Continued*)

First author, year	Setting, country, study name	Sample size, (*n*);	Age (y), mean ± SD/ median [IQR]	Malnutrition criteria	(Risk of) malnutrition status (%)	Effect size[2]	Adjusted covariates	Strength (NOS)	Association (+/0)[1]	Outcome
						(0.19, 0.87), $P =$ 0.003. Z LN TUG, s β (95% CI): 0.37 (0.03, 0.70), $P =$ 0.032. Z HGS (max. value of both hands): β (95% CI): –0.24 (–0.54, 0.07), P 0.131. Z SPPB, score, β (95% CI): –0.40 (–0.70, –0.10), $P = 0.009$				
Reijnierse, 2015 (60)	Outpatients, The Netherlands	Total: 185; W: 111, M: 74	82.0 ± 7.3	SNAQ: <2: WN, ≥2: RMN/MN	16	Z gait speed, m/s (4 m): Model 1: β (P value): –0.35, SE = 0.24 (0.151); Model 2: β (P value): –0.35, SE = 0.25 (0.157). Z HGS, kg (best performance of both hands): Model 3: $\beta = -0.37$, SE = 0.20 ($P = 0.067$)	Gender specific Z-scores. Model 1: age; Model 2: age, height. HGS: Model 3: age, body mass, height	7	0	Gait speed, HGS
Riviati, 2017 (61)	Geriatric outpatient ward at hospital, Indonesia	Total: 352; W: 212, M: 140	69.7 ± 6.3	MNA: MN, WN	14.6	Low HGS, kg (unknown how measured): R (95% CI) 1.9 (1.4–2.6)	Age	1	+	HGS
Romero-Ortuno, 2011 (62)	Community dwelling, Ireland	Total: 556; W: 388, M: 168	WN: 72.08 ± 6.9, RMN/MN: 78.22 ± 7.3	MNA: ≥24: WN, <24: RMN/MN	7.2	TUG, s: OR (95% CI): 1.111 (1.048–1.177)	LSNS-18, age, gender, living alone, material deprivation	6	+	TUG
Schrader, 2016 (63)	Hospital, Germany	Total: 190; W: 137, M: 53 (186 with association SPPB)	80 [75–84]	MNA: ≥24: WN, 17–23.5: RMN, <17 points: MN	MNA: RMN: 44.7, MN: 5.8. MNA-SF: RMN: 36.3, MN: 8.9	SPPB, score median [IQR]: MNA: WN: 6 [5–8], RMN: 5 [3–8], MN: 5 [3–8], $P =$ 0.33. MNA-SF median [IQR]: WN: 6 [4–8], RMN: 6 [4–8], MN: 6 [3–9.5], $P = 0.717$	—	5	0	SPPB

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TABLE 4 (*Continued*)

First author, year	Setting, country, study name	Sample size, (*n*);	Age (y), mean ± SD/ median [IQR]	Malnutrition criteria	(Risk of) malnutrition status (%)	Effect size[2]	Adjusted covariates	Strength (NOS)	Association (+/0)[1]	Outcome
Schrader, 2014 (64)	Acute ward at hospital, Germany	Total: 205; W: 141, M: 64 (86 with TUG)	82 [80–86]	MNA: ≥24: WN. 17–23.5: RMN. <17: MN	RMN: 60.00, MN: 29.76	TUG ($n = 86$), s: WN: 15.5 ± 5.2 s, RMN: 18.9 ± 5.8 s, MN: 21.3 ± 8.0; WN vs. RMN: N.S; WN vs. MN: NS	—	6	0	sTUG
Soundararajan, 2017 (65)	Community dwelling, India	Total: 60; W: 41, M: 19	MN: 71.33 ± 7.41, WN: 68.67 ± 5.91	MNA: WN: ≥24, MN: 17– 23.5	50.0 (selection from original 20%)	TUG, score: WN: 1.36 ± 0.49, MN: 2.16 ± 0.83, $P < 0.001$	—	5	+	TUG
Suzana, 2013 (66)	Community dwelling, Malaysia	Total: 160; W:102, M: 58	65.0 ± 3.9	MNA-SF: >11: WN	42.5	HGS, kg (unknown how measured): RMN: 20.9 ± 7.5, WN: mean ± SD: 22.5 ± 7.6, NS. EMS score: RMN: 18.2 ± 2.2, WN: 18.9 ± 1.4, $P < 0.05$	—	1	0 (HGS), +	HGS, Mobility
Tian, 2016 (67)	Hospital and community dwelling, China	Total: 531, W: 299, M: 232	72.3 ± 7.7	MNA-SF: MN: ≤11	RMN: 18%	Gait speed: RMN: ≤0.8 m/s: $n = 64$, >0.8 m/s: $n = 34$, OR: 1.81 (CI: 1.14, 2.85)[3], $P = 0.011$	—	3	+	Gait speed
Tramontano, 2016 (68)	Community dwelling, Peru	Total: 222; W: 120, M: 102	73.8 ± 7.0	MNA: ≤17 MN, 18–23: RMN, ≥24: WN	RMN: 52.7, MN: 9.4	Poor gait speed, s (>4.4 s) (4 m): RMN vs. WN: OR (95% CI): 1.47 (0.68–3.18), $P = 0.33$; MN vs. WN: OR (95% CI): 3.30 (0.74–14.76) $P = 0.12$. Poor 6MWT, m (<331 m): RMN vs. WN: OR (95% CI): 1.91 (0.86–4.22), $P = 0.19$; MN vs. WN: OR (95% CI): 2.73	Age, sex, education, number of drugs, presence of chronic disease, BMI, work, calf and arm circumference	6	0/+, 0 (5CST)	Gait speed, 6MWT, 5CST, SPPB

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TABLE 4 (*Continued*)

First author, year	Setting, country, study name	Sample size, (*n*);	Age (y), mean ± SD/ median [IQR]	Malnutrition criteria	(Risk of) malnutrition status (%)	Effect size[2]	Adjusted covariates	Strength (NOS)	Association (+/0)[1]	Outcome
						(1.06–12.08), $P = 0.03$. Poor 5CST (>11.6 s): RMN vs. WN: OR (95% CI): 1.18 (0.56–2.46), $P = 0.65$; MN vs. WN OR (95% CI): 3.03 (0.68–13.45), $P = 0.14$. Poor SPPB, score (<10), OR (95% CI): RMN vs. WN: 1.75 (0.82–3.72), $P = 0.15$; MN vs. WN: 4.94 (1.01–24.07), $P = 0.04$				
Turusheva, 2017 (69)	Community dwelling, Russia	Total: 602; W: 436, M: 166	Age range: 65–91	MNA: 17–23.5: RMN, <17: MN	Women: RMN: 17.7, MN: 81.2; men: RMN: 15.7, MN: 82.5	Average/maximum P5 HGS or >P5 HGS: RMN OR (95% CI): 3.09 (1.81–5.27)[3]; MN OR (95% CI): 9.02 (2.19–37.21)[3];(RMN: P5, n: 26 (32.9%), >P5: 76 (14.6%), $P < 0.05$; MN: P5: 4 (5.1%), >P5: 4 (0.8%), $P < 0.05$ Average/maximum P10 HGS or >P10 HGS: RMN OR (95% CI): 2.68 (1.67–4.31)[3]; MN OR (95% CI): 5.14 (1.26–20.97)[3];(RMN: P10, n: 35 (29.4%), >P10: 67 (13.9%), $P < 0.05$; MN: P10: 4 (3.4%), >P10: 4 (0.8%), $P < 0.05$)	—	4	+	HGS

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TABLE 4 (*Continued*)

First author, year	Setting, country, study name	Sample size, (*n*);	Age (y), mean ± SD/ median [IQR]	Malnutrition criteria	(Risk of) malnutrition status (%)	Effect size[2]	Adjusted covariates	Strength (NOS)	Association (+/0)[1]	Outcome
Vahlberg, 2016 (70)	Community dwelling, Sweden	134	74 ± 7	MNA-SF (except mobility item): RMN: ≤ 10	MN: 0%, RMN: 14%	Low mobility (SPPB ≤8), OR (95% CI): 4.3 (1.9–9.8)	Age, gender	6	+	SPPB
Wang, 2019 (71)	Care home, Taiwan	Total (M): 333	85.4 ± 5.7	MNA-SF: <12: MN, ≥12: WN	50.15	Slow gait speed (<0.8 m/s, 6 m) reported: WN: 85 (54.1%), MN: 81 (68.6%), $P = 0.015$; OR (95% CI)[3]: 0.90 (0.58, 1.39), $P = 0.62$. HGS, kg (max. value, dominant hand): WN: 27.7 ± 7, MN: 21.3 ± 7.6, $P < 0.001$	—	2	+	Gait speed, HGS
Zhang, 2017 (72)	Hospital, China	Total: 1343, W: 652, M: 691	73.8 ± 5.9	NRS-2002: ≥3: RMN, <3: WN. SGA: SGA A: WN, SGA B or C: RMN/MN	NRS-2002: 63.81. SGA: 28.22	Optimal HGS, kg (mean of dominant hand), MN+RMN vs. WN: NRS-2002: WOMEN OR (95% CI): 0.93 (0.89–0.98); MEN OR (95% CI): 0.93 (0.90–0.97). Optimal HGS, kg (mean of dominant hand), MN+RMN vs. WN: SGA: WOMEN OR (95% CI): 0.93 (0.88–0.98); MEN OR (95% CI): 0.93 (0.89–0.96)	NRS-2002: Stratified by gender. SGA: age, disease state	5	+	HGS

(*Continued*)

TABLE 4 (*Continued*)

First author, year	Setting, country, study name	Sample size, (*n*);	Age (y), mean ± SD/ median [IQR]	Malnutrition criteria	(Risk of) malnutrition status (%)	Effect size[2]	Adjusted covariates	Strength (NOS)	Association (+/0)[1]	Outcome
Zhou, 2015 (73)	Surgery department of hospital, China	Total: 142; W: 66, M: 76	WOMEN: 71.8 ± 5.4, MEN: 72.0 ± 5.9	NRS-2002: 0–2: WN, ≥3: RMN/MN. MNA-SF: >11: WN, ≤11: RMN/MN	NRS-2002: 38. MNA-SF: 45	HGS, kg (max. value, but unknown hand): NRS-2002: WN: 24.40 ± 19.32 kg, MN: 18.01 ± 15.54 kg, $P = 0.04$. MNA-SF: WN: 24.91 ± 19.52 kg, MN: 18.38 ± 15.85 kg, $P = 0.03$	—	5 (NRS), 4	+	HGS

[1] Plus sign(+): MN or RMN is associated with worse physical functioning than WN; zero (0): MN or RMN is not associated with physical functioning compared to WN; minus sign (-): MN or RMN is associated with better physical functioning than WN.
[2]Values are means ± SD or median [IQR] or otherwise specified.
[3]ORs derived by calculation.
[4]OR approximated as exact number of missing participants per category in this analysis is unknown; ASMMI, appendicular skeletal muscle mass index; BELFRAIL, Belgian Cohort of the Very Elderly; EMS, Elderly Mobility Scale; ESPEN, European Society of Clinical Nutrition and Metabolism consensus statement on malnutrition; GDS, Geriatric Depression Scale; GLIM, Global Leadership Initiative on Malnutrition criteria; HGS, handgrip strength; KES, knee extension strength; kgF, kilogram force; kPa, kilo pascal; LSNS-18, Lubben social network scale-18; M, men; MMSE, Mini Mental State Examination; MN, malnourished; MNA, Mini Nutritional Assessment; MNA-SF, Mini Nutritional Assessment - Short Form; MUAC, midupper arm circumference; MUST, Malnutrition Universal Screening Tool; NOS, Newcastle-Ottawa Scale; NRS-2002, Nutrition Screening 2002; NSI, Nutritional screening initiative; NS, not significant; PA, physical activity; POMA, Performance Oriented Mobility Assessment; RMN, risk of malnutrition; SCREEN II, Seniors in the Community, Risk Evaluation for Eating and Nutrition, version II; SGA, Subjective Global Assessment; SNAQ, Short Nutritional Assessment Questionnaire; SPPB, short physical performance battery; TUG, timed-up-and-go; W, women; WN, well-nourished; Z LN, Z-scores of the natural logarithm; 1CST, 1-time chair stand test; 5CST, 5 times chair stand test; 6MWT, 6-min walking test; 30sCST, 30-second chair stand test.

TABLE 5 Study quality scoring according to the modified Newcastle–Ottawa Scale

Study	Substudy difference	Representation	Sample size	Nonresponders	Ascertainment of exposure	Comparability	Assessment of the outcome	Statistical test	Total NOS (max.9)
Adly, 2020 (29)		0	0	0	1	0	0	1	2
Akin, 2014 (30)		1	0	0	2	0	0	1	4
Bertschi, 2020 (31)		0	1	0	2	2	1	1	7
Borkent, 2020 (32)*	TUG/SCREEN II	0	0	0	2	0	0	1	3
	HGS/SCREEN II	0	0	0	2	0	1	1	4
	TUG/SNAQ	0	0	0	1	0	0	1	2
	HGS/SNAQ	0	0	0	1	0	1	1	3
Chang, 2017 (33)		0	1	0	1	0	1	1	4
Chatindiara, 2019 (34)		1	0	0	1	0	1	1	4
Chevalier, 2008 (35)		1	0	0	2	0	1	1	5
Dent, 2018 (36)		0	0	1	2	0	0	1	4
Ferdous, 2009 (37)		1	0	1	2	1	0	1	6
Gingrich, 2019 (38)		0	0	0	1	0	1	0	2
Goldfarb, 2018 (39)		1	0	0	1	0	1	1	4
Gurina, 2011 (40)		1	0	0	2	1	1	0	5
Hegendorfer, 2020 (41)		1	0	0	2	0	1	1	5
Holst, 2013 (42)	MNA/ MUST/NRS2002	0	0	0	2	0	1	1	4
Inoue, 2017 (43)		1	0	0	1	0	0	1	3
Johansson, 2008 (44)		1	0	0	2	0	1	1	5
Kaburagi, 2011 (45)		1	0	0	2	1	0	1	5
Kiesswetter, 2013 (46)		1	0	1	2	1	1	1	7
Kocyigit, 2018 (47)		0	0	0	1	0	0	1	2
Lecheta, 2017 (48)		0	1	0	2	0	1	1	5
Lelli, 2020 (49)		1	0	0	2	2	0	1	6
Lim, 2018 (50)		1	1	0	1	0	1	1	5
Mendes, 2018 (51)		1	0	0	1	1	1	1	5
Mendes, 2019 (52)		1	0	0	1	1	1	1	5

(*Continued*)

TABLE 5 (*Continued*)

Study	Substudy difference	Representation	Sample size	Nonresponders	Ascertainment of exposure	Comparability	Assessment of the outcome	Statistical test	Total NOS (max.9)
Misu, 2017 (53)*	Gait speed	1	0	0	1	1	1	1	5
	HGS	1	0	0	1	0	0	1	3
	5CST, TUG	1	0	0	1	0	1	1	4
Norman, 2007 (54)		0	0	0	2	0	1	1	4
Ogawa, 2017 (55)		0	0	0	2	1	1	1	5
Persson, 2002 (56)*	SGA, MNA	0	0	0	2	0	0	1	3
	MNA-SF	0	0	0	1	0	0	1	2
Pierik, 2017 (57)		1	1	0	2	1	1	1	7
Pourhassan (58)*	HGS	0	1	0	1	0	0	1	3
	KES	0	1	0	1	0	1	1	4
Ramsey, 2019 (59)		1	0	0	2	1	1	1	6
Reijnierse, 2015 (60)		1	0	0	2	2	1	1	7
Riviati, 2017 (61)		1	0	0	0	0	0	0	1
Romero-Ortuno, 2011 (62)		1	0	0	2	1	1	1	6
Schrader, 2014 (64)		1	0	0	2	1	1	1	6
Schrader, 2016 (63)*	MNA	1	0	0	2	0	1	1	5
	MNA-SF	1	0	0	1	0	1	1	4
Soundararajan, 2017 (65)		1	0	0	2	0	1	1	5
Suzana, 2013 (66)		0	0	0	1	0	0	0	1
Tian, 2016 (67)		0	0	0	1	0	1	1	3
Tramontano, 2016 (68)		0	0	0	2	2	1	1	6
Turusheva, 2017 (69)		1	0	0	2	0	1	0	4
Vahlberg, 2016 (70)		1	0	1	1	1	1	1	6
Wang, 2019 (71)		0	0	0	1	0	0	1	2
Zhang, 2017 (72)	NRS-2002/SGA	0	0	0	2	1	1	1	5
Zhou, 2015 (73)*	NRS-2002	1	0	0	2	0	1	1	5
	MNA-SF	1	0	0	1	0	1	1	4

*Quality differs within the study, based on the use of malnutrition tools and/or outcomes; HGS, hand grip strength; KES, knee extension strength; MNA, Mini Nutritional Assessment; MNA-SF, Mini Nutritional Assessment Short Version; MUST, Malnutrition Universal Screening Tool; NRS-2002, Nutrition Screening 2002; SCREEN II, Seniors in the Community: Risk Evaluation for Eating and Nutrition, version II; SGA, Subjective Global Assessment; SNAQ, Short Nutritional Assessment Questionnaire; TUG, timed-up-and-go; 5CST, 5 times chair stand test.

TABLE 6 Number of studies showing an association between malnutrition or risk of malnutrition and worse physical performance, split per type of physical performance test, both when all studies are included and when only studies of satisfactory quality (NOS ≥5) are included[1]

Type of physical performance test	No association, *n* (%)		Association in subgroups only,* *n* (%)		Expected association, *n* (%)		Total, *n*	
	All	NOS ≥5	All	NOS ≥5	All	NOS ≥5	All	NOS ≥5
HGS	9 (30%)	4 (26.7%)	8 (26.7%)	4 (26.7%)	13 (43.3%)	7 (46.7%)	30	15
Gait speed	6 (42.9%)	5 (62.5%)	0 (0%)	0 (0%)	8 (57.1%)	3 (37.5%)	14	8
TUG	5 (50%)	3 (50%)	0 (0%)	0 (0%)	5 (50%)	3 (50%)	10	6
CST	4 (57.1%)	1 (33.3%)	0 (0%)	0 (0%)	3 (42.9%)	2 (66.7%)	7	3
KES	0 (0%)	0 (0%)	0 (0%)	0 (0%)	3 (100%)	1 (100%)	3	1
6MWT	0 (0%)	0 (0%)	1 (50%)	1 (50%)	1 (50%)	1 (50%)	2	2
SPPB	1 (11.1%)	1 (14.3%)	1 (11.1%)	1 (14.3%)	7 (77.8%)	5 (71.4%)	9	7
Multi-component	0 (0%)	0 (0%)	0 (0%)	0 (0%)	5 (100%)	3 (100%)	5	3
Other	1 (33.3%)	1 (100%)	0 (0%)	0 (0%)	2 (66.7%)	0 (0%)	3	1
Total	26 (31.3%)	15 (32.6%)	10 (12.1%)	6 (13.0%)	47 (56.6%)	25 (54.5%)	83	46

[1]CST, chair stand tests; HGS, hand grip strength; gait speed, gait speed test; TUG, timed up-and go; KES, knee extension strength; NOS, Newcastle–Ottawa Scale; MN, malnourished; multi-component tests, mobility and physical performance tests spanning multiple domains; RMN, risk of malnutrition; SPPB, short physical performance battery; 6MWT, 6-min walking test.

*Association in subgroups only: an association is *a*) only found in the MN group, not in the RMN group or *b*) vice versa, or *c*) an association is only observed in RMN or MN groups, but only in men or in women, or *d*) associations differ in RMN/MN groups per gender.

ica ($n = 2$), Russia ($n = 2$), Turkey ($n = 2$), Egypt ($n = 1$), or Europe and North America combined ($n = 1$). The NOS quality score was "unsatisfactory" for 19 studies, "satisfactory" for 23 studies, and 3 studies scored in both those categories, depending on the analysis. No studies scored "good" on the NOS (**Table 5**), which could mainly be attributed to lack of confounder adjustment (comparability), no sample size justification, and lack of information on nonresponders.

Most studies used the MNA (74) ($n = 18$) to assess malnutrition, followed by its shorter screener version, MNA-SF (75) ($n = 13$). The remaining articles used the SNAQ (76) ($n = 3$), Geriatric Nutritional Risk Index (77) ($n = 1$), NRS2002 (78) ($n = 1$), European Society for Clinical Nutrition and Metabolism (ESPEN) definition (79) ($n = 1$), Nutrition Screening Initiative (NSI) (80) ($n = 1$), or Global Leadership Initiative on Malnutrition (GLIM) criteria (81) ($n = 1$). Six studies used 2 or 3 screeners or assessments of malnutrition; Borkent et al. (32) used SCREEN II (82) and SNAQ65+ (83), Holst et al. (42) used MNA, Malnutrition Universal Screening Tool (MUST) (84), and NRS2002, Persson et al. (56) used SGA (85), MNA, and MNA-SF, Schrader et al. (63) used MNA and MNA-SF, Zhang et al. (72) used NRS2002 and SGA, and Zhou et al. (73) used NRS2002 and MNA-SF.

As a measure of physical performance, HGS was used most often ($n = 30$), followed by gait speed measures ($n = 14$), TUG (86) ($n = 10$), SPPB (87) ($n = 9$), and CST (88) ($n = 7$). Three studies used KES, 5 used a multicomponent performance measure, and 2 used 6MWT (89). The remaining 3 outcomes were grouped as "other" (Tinetti gait test, and balance tests from Tinetti (90) or from SPPB).

Meta-analyses were performed for the outcomes gait speed ($n = 7$), SPPB ($n = 6$), TUG ($n = 8$), and HGS ($n = 23$). For each outcome, the WN group was compared with the RMN and MN groups. Substantial heterogeneity ($I^2 > 50\%$) was present for gait speed (both comparisons), SPPB (WN compared with MN), TUG (WN compared with RMN), and HGS (both comparisons). Studies not included in the meta-analysis were used in the narrative review.

When taking into account all data regardless of study quality, of the 83 analyses included from the 45 articles, 56.6% showed an association between malnutrition and low physical performance. Another 12% re-

TABLE 7 Number of studies showing an association between malnutrition or risk of malnutrition and worse physical performance, split per setting, both when all studies are included and when only including studies of satisfactory quality (NOS ≥5) are included[1]

Setting	No association, *n* (%)		Association in subgroups only,* *n* (%)		Expected association, *n* (%)		Total, *n*	
	All	NOS ≥5	All	NOS ≥5	All	NOS ≥5	All	NOS ≥5
Hospital inpatient	8 (33.3%)	5 (41.7%)	4 (16.7%)	1 (8.3%)	12 (50%)	6 (50%)	24	12 (50%)
Outpatient	6 (40%)	5 (55.6%)	0 (0%)	0 (0%)	9 (60%)	4 (44.4%)	15	9 (60)
Nursing home	1 (16.7%)	1 (50%)	2 (33.3%)	1 (50%)	3 (50%)	0 (0%)	6	2 (33.3%)
Community dwelling	11 (29.7%)	4 (17.4%)	4 (10.8%)	4 (17.4%)	22 (59.5%)	15 (65.2%)	37	23 (62.2%)
Community dwelling & hospital	0 (0%)	NA	NA	NA	1 (100%)	NA	1	0 (0%)
Total	26 (31.3%)	15 (32.6%)	10 (12.1%)	6 (13.0%)	47 (56.6%)	25 (54.5%)	83	46

[1]MN, malnourished; NOS: Newcastle-Ottawa Scale; RMN, risk of malnutrition.

*Association in subgroups only: an association is *a*) only found in the MN group, not in the RMN group or *b*) vice versa, or *c*) an association is only observed in RMN or MN groups, but only in men or in women, or *d*) associations differ in RMN/MN groups per gender.

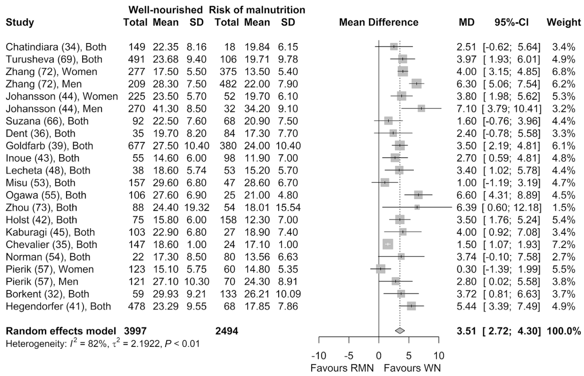

FIGURE 2 Forest plot illustrating the mean difference of HGS (kg) between well-nourished versus at risk of malnutrition groups. HGS, handgrip strength; MD, mean difference; RMN, risk of malnutrition; WN, well-nourished.

ported associations in subgroups only, meaning an association was only found in the RMN or MN group, in men or women, or a combination of these. Lastly, 31.3% did not report any association. No studies described a statistically significant association between a worse nutritional status and better physical performance. Leaving out the studies of unsatisfactory quality, 25 studies remained, comprising results on 46 relevant analyses. Of these, 54.4% reported an association between nutritional status and physical performance (**Table 6**). Another 13.0% of analyses showed results in subgroups only, with 32.6% not reporting an association.

The included populations consisted mainly of community-dwelling older adults ($n = 20$) and hospitalized patients ($n = 15$), with some outpatient populations ($n = 6$) and older adults living in nursing homes ($n = 3$) or a combination of community-dwelling and hospital populations ($n = 1$). In all of these settings, at least half of the analyses showed an association between nutritional status and physical performance (**Table 7**); 12 of the 24 (50%) analyses in hospitalized patients reported the expected association, as well as 9 of the 15 (60%) analyses in outpatient clinic settings, 3 of the 6 (50%) analyses in nursing homes, and 22 of the 37 (59.5%) analyses in community-dwelling populations. When only studies of satisfactory quality were included, the expected association remained similar for hospitalized patients (50%), and community-dwelling (65.2%) populations, but was somewhat lower in studies with outpatient data (44.4%). In nursing home residents, no studies showed a clear association when only data of satisfactory quality were included.

HGS

For HGS, 13/30 (43.4%) studies showed an association with nutritional status and 8/30 (26.7%) showed an association in subgroups only. When only including studies of satisfactory quality, 7/15 (46.7%) studies report an association.

Twenty-three out of the 30 studies using HGS were included in the meta-analysis (**Figures 2** and **3**). WN groups had a significantly higher HGS compared with groups at RMN [mean difference (MD) = 3.51 kg; 95% CI: 2.72, 4.30; $P < 0.001$] and compared with MN groups (MD = 4.92 kg; 95% CI: 3.43, 6.41; $P < 0.001$). Sensitivity analyses

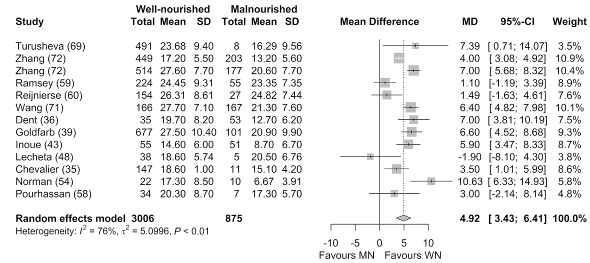

FIGURE 3 Forest plot illustrating the mean difference of HGS (kg) between well-nourished versus malnourished groups. HGS, handgrip strength; MD, mean difference; MN, malnourished; WN, well-nourished.

showed that there was no single study affecting the overall estimate considerably.

Gait speed

Most studies measuring gait speed (8/14, 57.1%) reported an association with nutritional status, but this reduced to 3/8 (37.5%) when only including studies of satisfactory quality.

Seven of the 14 studies were included in the meta-analysis (**Figures 4** and **5**). WN groups walked significantly faster compared with RMN groups (MD = 0.09 m/s; 95% CI: 0.03, 0.16; $P = 0.0038$) and MN groups (MD = 0.16 m/s; 95% CI: 0.05, 0.27; $P = 0.0033$).

TUG

Half of all studies reporting the TUG test showed an association with MN (5/10) and was the same (3/6) when selecting only studies of satisfactory quality.

Eight of the 10 studies assessing TUG were included in the meta-analysis (**Figures 6** and **7**). WN groups were faster on the TUG compared with RMN groups (MD = –2.53 s; 95% CI: –4.42, –0.65; $P = 0.0085$). However, sensitivity analyses showed that the study of Romero-Ortuno (62) affected the overall estimate considerably (results without this study: MD = –1.84 s; 95% CI: –3.53; –0.16; $P = 0.032$). The difference was more pronounced for WN groups compared with MN groups (MD = –5.94 s; 95% CI: –8.98, –2.89; $P < 0.001$).

CST

CST was the only measure of physical performance for which most studies (4/7, 57.1%) did not find an association with nutritional status. However, in studies of satisfactory quality 2/3 (66.7%) did find an association.

Seven studies reported on a type of CST, all using different effect estimates. Adly et al. (29) reported on 1-time impaired sit-to-stand time (>2 s) for which the MN group had an OR of 0.491 (95% CI: 0.12–1.94) and the RMN group an OR of 0.35 (95% CI: 0.11–1.05) compared with WN. Chang et al. reported the number of times participants could rise from a chair in 30 s; for the WN group this was 16.74 ± 6.73 and for the RMN group 13.79 ± 7.15 times (33). Lim et al. reported on 5-times CST in points (max. 3), with the WN group scoring 2.88 ± 0.35 and the MN group 2.57 ± 0.57 (50). Misu et al. reported on the 5 times chair stand test (5CST) in seconds; the WN group had a mean of 8.80 ± 2.71s and the MN group of 8.86 ± 2.68 s (53). Ramsey et al. re-

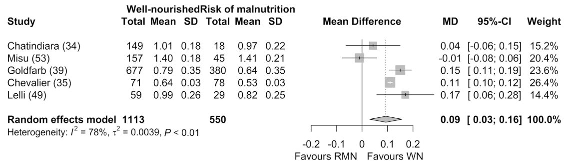

FIGURE 4 Forest plot illustrating the mean difference of gait speed (m/s) between well-nourished versus at risk of malnutrition groups. MD, mean difference; RMN, risk of malnutrition; WN, well-nourished.

ported on the Z-scores of the natural logarithm (Z LN) 5CST in seconds, with β 0.53 (95% CI: 0.19, 0.87) (59) and Tramontano reported on poor 5CST (>11.6 s), showing an OR of 3.03 (95% CI: 0.68–13.45) for MN compared with WN and an OR of 1.18 (95% CI: 0.56–2.46) for RMN compared with WN (68). Chatindiara et al. defined low 5-times CST as ≥17 s, resulting in an OR of 0.76 (95% CI: 0.27, 2.11) in RMN compared with WN (34).

KES

All 3 studies reporting KES showed an association with MN, of which one was of satisfactory quality. Norman et al. reported a median KES of 10.3 kg (7.3–16.4) in WN people, 8.0 kg (5.0–12.0) in RMN, and 5.0 kg (3.0–7.0) in MN (54). Ogawa et al. reported KESs of 42.8 ± 10.9 Nm/kg in WN and 35.8 ± 7.29 in RMN (55). Pourhassan et al. reported a mean isometric KES of 17.5 ± 6.8 in WN and 12.4 kg ± 4.6 in MN participants (58).

6MWT

Two studies used the 6MWT, both of which were of satisfactory quality. One study showed an association with a mean of 421.2 ± 141.4 m in WN and 320.9 ± 132.0 m in RMN (55). Tramontano et al. defined poor 6MWT as <331 m, for which MN showed an OR of 2.73 (95% CI: 1.06–12.08), whereas RMN had an OR of 1.91 (95% CI: 0.86–4.22) compared with WN.

SPPB

The majority of all (7/9, 77.8%) and of satisfactory quality studies (5/7, 71.4%) showed an association between nutritional status and SPPB. Six of the 9 studies were included in the meta-analysis (**Figures 8** and **9**). WN groups scored 1.2 more points compared with RMN groups (95% CI: 0.88, 1.51; $P < 0.001$) and 2.0 more points compared with MN groups (95% CI: 1.32, 2.73; $P < 0.001$).

Multicomponent test

Five studies used a multicomponent test spanning multiple domains, all of which showed an association with nutritional status. Three of these studies were of satisfactory quality. WN people scored a mean 25.20 ± 3.82 pts on the Tinetti performance-oriented mobility assessment compared with 22.15 ± 6.28 in RMN and 20.09 ± 6.29 in MN (47). Mobility scale scores were 86.14 ± 16.71 in WN and 66.29 ± 23.23 in MN (50). WN people scored a mean 18.9 ± 1.4 on Tinetti's Elderly mobility scale, whereas the RMN group scored 18.2 ± 2.2 (66). Hegendörfer et al. used a physical test for which the median value of WN people was 9 (6, 12) and for RMN/MN this was 6.5 (4, 9.79) (41). Lastly, Ferdous et al. used a 6-item performance test, scoring the percentage of limitation in any of the tasks. The RMN had an OR of 1.92 (95% CI: 1.07–3.45) and MN an OR of 4.24 (95% CI: 2.17–8.27) compared with WN (ORs are approximated due to missing values) (37).

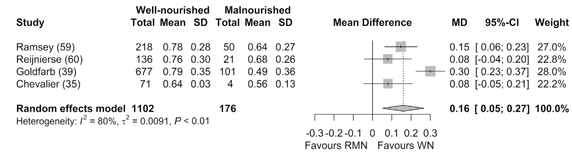

FIGURE 5 Forest plot illustrating the mean difference of gait speed (m/s) between well-nourished versus malnourished groups. MD, mean difference; RMN, risk of malnutrition; WN, well-nourished.

Other measures of physical performance

The remaining physical performance measures are the Tinetti gait analysis, Tinetti balance component, and balance component from SPPB (59, 47). Two of the 3 showed an association with nutritional status. The one showing no association was of satisfactory quality.

The mean Tinetti gait score in WN people was 10.82 ± 1.74, in RMN this was 9.51 ± 2.74, and in MN it was 9.06 ± 2.68 (47). The Tinetti balance component had a mean score of 14.38 ± 2.30 in WN, 12.64 ± 3.76 in RMN, and 11.03 ± 3.88 in MN (47). Ramsey et al. looked at the 3 balance components of SPPB separately, calculating ORs for being unable to maintain 10 seconds for each of the 3 tests, comparing RMN/MN with WN (side-by-side: OR 0.69 (95% CI: 0.23, 2.02), semi-tandem: OR 0.67 (95% CI: 0.31, 1.43), tandem: OR 1.02 (95% CI: 0.51, 2.04) (59).

Discussion

This systematic review and meta-analysis aimed to summarize observational, cross-sectional studies on physical performance in MN or at-risk groups compared with WN older adults. The majority of the included 45 studies on physical performance in MN or at-risk groups and WN older adults reported that being MN or being RMN is associated with lower physical performance compared with WN older adults. Meta-analyses with gait speed, SPPB, TUG, and HGS data showed that WN groups walked faster, scored higher on the SPPB, were faster in the TUG, and had better handgrip strength compared with MN groups. These associations were also already present, but to a lesser extent, when comparing to RMN groups. The narrative review of the satisfactory quality

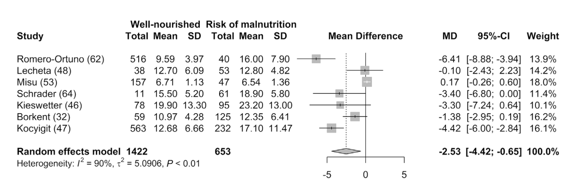

FIGURE 6 Forest plot illustrating the mean difference of the TUG (s) between well-nourished versus at risk of malnutrition groups. MD, mean difference; RMN, risk of malnutrition; TUG, timed-up-and-go test; WN, well-nourished.

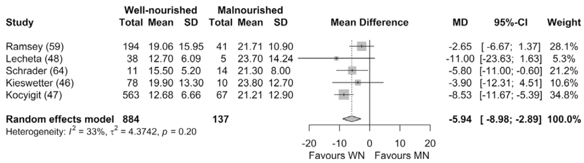

FIGURE 7 Forest plot illustrating the mean difference of the TUG (s) between well-nourished versus malnourished groups. MD, mean difference; MN, malnourished; TUG, timed-up-and-go test; WN, well-nourished.

studies using KES, 6MWT, CST, and multicomponent tests showed that the majority of these studies reported lower physical performance in MN (or RMN) groups compared with WN groups as well. No studies reported an inverse association.

The remaining "other" tests are the only category for which most studies did not report a statistically significant association, although most effect estimates reported that MN people (or RMN people) had lower physical performance and the number of studies was low.

Population

Comparing studies performed in different healthcare settings, studies in hospitalized patients, outpatients, and community-dwelling people overall showed similar results in the narrative review, with approximately half of the studies confirming an association between malnutrition and physical performance. These results were similar when using all quality studies and when only studies of satisfactory quality were included. In contrast, studies in nursing home populations were mostly of poor quality and none of the studies of satisfactory quality reported an association.

The high prevalence of (risk of) malnutrition of $\geq$50% in the nursing home studies could have contributed to this difference (71, 54, 48), in line with previous results (91).

Secondly, none of the care home studies adjusted their analyses for confounders. Other factors that play an important role in malnutrition and physical performance are thus not accounted for, despite being highly prevalent in nursing home residents, such as comorbidities, polypharmacy (71), and sarcopenia (92).

Malnutrition screeners and assessment tools

In the included studies, 11 different screeners or assessment tools of malnutrition were used. These needed to be validated and address more than weight loss or a low BMI only. Although both weight loss and low

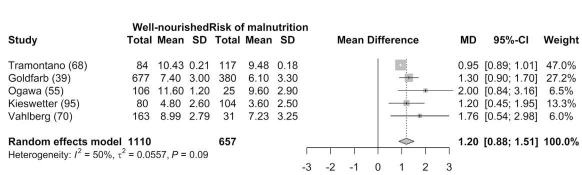

FIGURE 8 Forest plot illustrating the mean difference of the SPPB (points) between well-nourished versus at risk of malnutrition groups. MD, mean difference; RMN, risk of malnutrition; SPPB, short physical performance battery; WN, well-nourished.

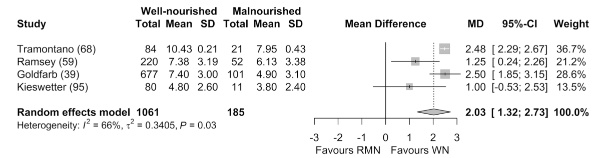

FIGURE 9 Forest plot illustrating the mean difference of the SPPB (points) between well-nourished versus malnourished groups. MD, mean difference; RMN, risk of malnutrition; SPPB, short physical performance battery; WN, well-nourished.

BMI can be indicators of malnutrition and are part of the phenotypic side of malnutrition, the latest GLIM consensus paper of the global clinical nutrition community diagnoses malnutrition when etiologic as well as phenotypic factors are present (81). Etiologic factors consist of inflammation/disease burden or reduced food intake/absorption and are essential in selecting the right treatment. Many of the validated nutrition screeners and assessment tools (MNA-SF, NRS2002, MUST, ESPEN, SGA) measure weight reduction as well as disease burden and reduced food intake (81) and therefore, reflect the recent GLIM consensus better than assessing 1 aspect only. Only 1 included study in our review (58) used the actual GLIM criteria for diagnosis, with 10 other screening and assessment methods used by others. However, no single screening or assessment method can adequately screen and predict relating outcomes (93) and reported prevalence of malnutrition or RMN is dependent on the screener or assessment of choice (94, 95), likely contributing to differences between studies and withing studies that used multiple methods to identify malnutrition or malnutrition risk.

Physical performance

The outcome of interest for this systematic review, physical performance, had to be measured objectively, rather than self-reported measures or estimates to reduce reporting bias. We grouped these into 8 main categories of HGS, gait speed, TUG, CST, KES, 6MWT, multicomponent tests, and a category of "others." There is no consensus on the best measure of physical performance; the European Society for Clinical and Economic Aspects of Osteoporosis and Osteoarthritis working group on frailty and sarcopenia advises the use of 4 m walking test and SPPB to measure physical performance and HGS for muscle strength (9). The European Working Group on Sarcopenia suggests the use of gait speed, SPPB, TUG, and the 400 m walking test and provides cut-off points (7). These tests were among the most used test in this systematic review, although individual studies used a myriad of different methods (e.g. average walking speed compared with maximum walking speed, or means compared with dichotomizing), units and cut-offs, reducing comparability even within a category. Additionally, this systematic review included studies using CST, KES, 6MWT, various multicomponent tests, and some others. Due to low study numbers and study quality, we could not compare the different measures of physical performance. In this systematic review, there seems to be no large differences between these methods in their association with malnutrition, but this should be studied in more detail in future.

Meta-analysis

Meta-analyses showed that MN groups had worse scores on HGS, gait speed, TUG, and SPPB compared with WN groups and that these results were also present in RMN people, but with a smaller effect. Since for multiple comparisons substantial statistical heterogeneity was present, results of the meta-analyses should be interpreted with care. Heterogeneity among studies originated from the way of classifying nutritional status (i.e. different tools/screeners and cut-off points) and small differences in measuring the outcome. An example of the latter is how HGS was determined in studies: taking the mean or maximum value and measuring the dominant hand or both hands. However, mean differences of the 4 outcomes were often at the same side of the spectrum, favoring the WN groups.

Additional heterogeneity in reporting and/or low numbers of studies, meant that not all studies were included in meta-analysis. Heterogeneity in reporting included different units of outcome that could not be translated, such as using m/s versus total distance, or different distances/number of repetitions. CSTs, KES, 6-min walking test, multicomponent tests, and the remaining "other" tests were therefore only reviewed narratively.

Physical performance is a clinically meaningful outcome measure for sarcopenia and frailty (96). Clinically relevant changes need to be of such a size that a participant can perceive this or that it affects participation (96). Although this study included cross-sectional data, we suggest that the aforementioned, clinically relevant changes could give an indication of what differences between WN and MN or at-risk populations are relevant. The meta-analysis results showed a gait speed difference of 0.16 m/s for MN and 0.09 m/s for RMN groups compared with WN people and a 1.2 point and 1.3 point difference, respectively, on SPPB. Perera et al. reported that a decline of 0.1 m/s on 4 m gait speed or 1 point on SPPB per year increased the risk of 5-y mortality in observational and clinical populations, indicating these differences could be clinically relevant (97). This is in line with other studies showing that lower gait speed, SPPB, and CST can lead to disability in activities of daily living (25, 98, 99).

Notably, clinical relevance is dependent on context, perspective, and purpose (96). Considering the variation in the older population, relevant differences likely vary between subgroups such as community-dwelling, nursing home, and hospital populations. Regardless of subgroup, interventions should aim at clinically relevant improvements in physical performance through improvement of nutritional status.

Bias and quality

In this review and meta-analysis of observational, cross-sectional data, study quality was scored using a modified NOS and included studies of unsatisfactory and satisfactory quality. None of the included studies had a "good" NOS score. Using only satisfactory quality studies showed similar result for most categories of physical performance compared with using all studies, except for the category "other," which included a very low number of studies.

One of the contributors to the low NOS scores was that often the data on nutritional status and physical functioning used in this review were not the main analysis of the study, and were results of simple analysis, meaning confounders were not accounted for. Cognition, social support (100), intestinal permeability (101), physical activity, education, pain, depression (102), and multimorbidity (103) play an important role in physical performance and malnutrition (104). Not taking these into account might have changed the estimates and obscured differences between types of physical performance measures. A potential upside of nutritional status and physical performance not being the main focus of many articles is that the risk of publication bias might be limited.

Physiology

This systematic review and meta-analysis showed low-quality evidence that malnutrition and physical performance are associated. The 2 likely form a vicious cycle (105), with some suggesting the existence of a malnutrition-sarcopenia syndrome (20). On the one hand, moderate evidence exists that low physical performance is a determinant of malnutrition (5). On the other hand, malnutrition increases the risk of sarcopenia incidence (106). Sarcopenia severity is determined by physical performance (81) in the presence of low muscle mass and strength but cannot be explained by muscle mass loss alone (107). The pathophysiology is not fully understood, but protein and energy balance play a key role. Muscles are a key metabolic site for glucose and protein storage, which are released to maintain the protein content of other organs when energy uptake does not meet demands, leading to muscle breakdown (108). Low energy and protein intake, low absorption, and/or disease-related inflammation all favor this catabolic state (109). Low intake of other nutrients such as vitamin D or antioxidants might also play a role, although their role in this remains unclear (105).

Intervention studies specifying MN populations (or at risk of) and measuring physical performance are scarce and showed mixed results. One systematic review in RMN adults showed no improvements in gait speed, balance, and HGS due to volunteer-delivered interventions (110). Other systematic reviews showed no effect on HGS (111) and TUG (14) after dietary counseling or oral nutritional supplementation, respectively. Interventions with combinations of supplementation with counseling or exercise were inconsistent (14). Some other intervention studies in MN or at-risk populations (14) show improvements in walking distance, but not HGS and SPPB (112), or performance improvements only in subgroups at 1 of 3 time points (113) in community-dwelling older adults.

Systematic reviews on related outcomes or in different populations of older adults are more numerous, but also show mixed results: in clinical muscle wasting populations (114), and frail and prefrail older adults (20, 115), certain dietary or physical performance interventions increased physical performance. In another systematic review in older adults using the European Working Group on Sarcopenia in Older People definition of sarcopenia (116), and an umbrella review of healthy aging outcomes (117), results on nutritional interventions and physical performance were ambiguous due to low numbers and heterogeneity.

We carried out this systematic review to study the underlying association and to provide some clarity that could help decipher the inconsistencies in the intervention studies. We aimed to reduce heterogeneity due to interventions and by clearly defining the nutritional (risk) status of the population and the outcome measure. Overall, as expected, it appears that malnutrition in older adults is associated with low physical performance, despite overall poor to moderate quality (no "good" NOS scores) of the studies. Perhaps the complexity and diversity in the origin of malnutrition and its relation to physical performance underlie the inconsistencies of intervention studies on this topic, and interventions should take into account the underlying etiology (81, 112). However, low study quality and remaining heterogeneity in measurements imply that strong conclusions cannot be drawn and corrections for confounders are mostly lacking. Future studies should focus on clearly defined MN populations, instead of grouping them together with frailty, sarcopenia, or other diseases, and standardization and clear reporting of physical performance would be welcomed. With this, high-quality interventions tailored specifically to the MN populations can be studied, since proof of high-quality evidence on effective interventions in treating malnutrition in older adults is still lacking (14).

Conclusion

This meta-analysis and narrative review provide low-quality evidence for the association between malnutrition or risk of malnutrition and low physical performance in older adults in studies in outpatient, hospital, nursing home, and community-dwelling settings. Although 11 different screeners or assessment tools of malnutrition and 8 main types of physical performance tests were used, an association between malnutrition and lower physical performance seems present among older adults. Without studies of "good" quality according to the NOS scale and with many methodological differences between the included studies regarding population, determination of malnutrition, the reported outcomes, and method of analysis, the overall results should be interpreted with care.

For future research, both observational and interventional, we recommend performing studies of high quality with clearly defined MN populations or at-risk populations and standardized outcomes and methods of testing. Malnutrition should be assessed according to standardized GLIM criteria (81) and physical performance should be measured in standardized ways, as recommended in the latest European Working Group on Sarcopenia in Older People number 2 consensus paper. Future studies could additionally focus on differences between the various physical performance tests and differences between subpopulations.

Good quality studies in clearly defined MN older adult populations are required to gain better insight into the relation between nutritional status and physical performance. This way interventions can be developed to improve physical performance specifically in the MN populations, while being careful to consider the underlying reasons of malnutrition.

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