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SYSTEMATIC REVIEW

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Association of lower-limb strength with different fall histories or prospective falls in community-dwelling older people: a systematic review and meta-analysis

Ringo Tang-Long Zhu[1,2], Jenny Jing-Jing Zuo[1], Ke-Jing Li[1], Freddy Man Hin Lam[3], Arnold Yu Lok Wong[2,3], Lin Yang[4], Xue Bai[2,5], Man Sau Wong[2,6], Timothy Kwok[7], Yong-Ping Zheng[1,2] and Christina Zong-Hao Ma[1,2*]

Abstract

Background Fall is a major health threat to older people. The lower-limb power and rate of torque or force development (RTD or RFD) are prominently affected by aging and are crucial for maintaining postural balance. However, there have been inconsistent findings regarding the association of such aspects of lower-limb strength with falls among community-dwelling older adults. Comprehensive synthesis and appraisal are needed to examine what deficits in lower-limb rapid force generation could identify the fallers (i.e., those with a fall history or prospective falls).

Methods This systematic review searched six databases, including PubMed, Web of Science, EMBASE, Scopus, CINAHL, and Cochrane CENTRAL. Meta-analysis was conducted to aggregate standardized mean differences (SMD) or odds ratios (OR). The quality of evidence regarding each strength parameter's ability to identify fallers was assessed using the GRADE approach.

Results Twenty observational studies with 8,231 community-dwelling older adults were included (mean age: 73.5 years; male to female ratio: approximately 6:1). Moderate quality of evidence showed that the lower average leg-press power (SMD & 95% CI: -0.17 [-0.23, -0.12]; OR & 95% CI: 0.84 [0.79, 0.89]) and lower peak sit-to-stand power (Cohen's $d=0.41$) could predict prospective falls in older adults, especially the injurious/recurrent falls. Low quality of evidence showed that the lower peak sit-to-stand power could also discern fall history (SMD & 95% CI: -0.58 [-0.96, -0.20]). Conversely, low to very low quality of evidence showed that the RTD of a single muscle group could not predict prospective falls and was generally unable to identify fall history in older adults.

Discussions and Conclusion The decline of entire lower-limb power appears a good indicator of prospective falls in community-dwelling older adults. Tests of entire lower-limb power required the cumulative and coordinated contractions of more leg muscles, possibly explaining why they could identify the fallers whereas the RTD or power of a single muscle group could not. Future studies are warranted to determine cut-point values of the entire lower-limb power measurements in fall-risk assessment and explore rapid force generation of a single muscle group in predicting the injurious falls among older adults.

Trial registration Registration No.: CRD42021237091.

*Correspondence:
Christina Zong-Hao Ma
czh.ma@polyu.edu.hk
Full list of author information is available at the end of the article

Keywords Community-dwelling older adults, Falls, Fallers, Risk factors, Fall incidence, Fall history, Muscle strength/power, Rate of torque development (RTD), Rate of force development (RFD), Balance

Introduction

Fall, defined by the World Health Organization (2021) as an event that an individual comes to rest on the ground or floor or other lower level inadvertently, commonly occurs in older people. As reported by a most recently systematic review, the global prevalence of falls in the older people was 26.5% [46]. Although most falls are non-lethal, many serious physical (e.g., hip fractures, traumatic brain injuries) and psychological consequences (e.g., fear of falling) secondary to falls render it as a major health concern in older people [1]. The resulted declined physical/daily activity, limited social participation, and even deconditioning may further weaken the older adults gradually [26]. Falls also burden society heavily due to the direct health care costs and the indirect societal productivity losses [15]. The early identification of modifiable risk factors for falls is crucial for implementing targeted preventive interventions in older adults, which could further help prevent falls and fall injuries.

Physical function assessments, including lower-limb strength, balance control, and gait, are key components of a multifactorial fall-risk assessment for the older adults [32]. Nevertheless, relying on a single test or scale for physical function assessment alone often has limited success in identifying the fall histories or predicting prospective falls in older people. Based on the previous systematic reviews, the Berg Balance Scale (BBS), Functional Reach Test, Single-Leg Stance Test, or Tinetti Performance-Oriented Mobility Assessment has shown low diagnostic accuracy for predicting prospective falls among older individuals [25, 34]. Given this, emerging studies have explored additional measures that can enhance fall-risk assessment.

Concurrently assessing the physical function and the speed may be necessary to enhance the fall-risk assessment. The World Falls Guidelines recommend using a gait speed of 0.8 m/s or a Timed Up and Go (TUG) test completion time of 15 s to categorize older adults into low and intermediate risk of falls [29]. This indicates the speed of volitional balance control or gait as a critical measure for fall-risk assessment. Considering that lower-limb muscles are the fundamental components for accomplishing these physical function tasks, measuring the rapid force generation of various lower-limb muscles is expected to help reveal the specific reasons for the declined speed of balance control or gait [2, 22]. This may facilitate a more in-depth understanding of the physiological factors that contribute to fall risk in older adults, and also provide insights on what specific muscles could be targeted for training to prevent falls [53, 57, 58].

Two types of speed measures of strength, i.e., power and the rate of torque or force development, have been used to quantify lower-limb rapid force generation. They reflect the ability of how large and how fast the force is produced, by recording both the amplitude and temporal characteristics of force signals during instrumented physical function assessments [24, 35]. The power of the entire unilateral/bilateral lower limb(s) is commonly measured during the leg-press task, the sit-to-stand task, and the jumping task in participants [7, 44]. The rate of torque development (RTD) or the rate of force development (RFD) describes the slope of the torque or force rise over a short time duration (i.e., Δtorque/Δt or Δforce/Δt). It has been commonly measured in the maximal voluntary isometric contraction (MVIC) task of a single muscle group [23, 41]. Emerging studies have focused on these speed measures of strength because of their important roles in older adults. On the one hand, the power, RTD, or RFD declines more prominently than the maximal strength with ageing, as fast-twitch fibers in skeletal muscles are more affected than slow-twitch fibers [18, 43]. On the other hand, the lower-limb rapid force generation is crucial for maintaining postural balance [33, 56, 58] and avoiding experimentally-induced tripping [38, 39]. The quantitative measurement of power, RTD, or RFD is thought to be more sensitive indicators of physical function degradation for early identification of the fall-prone older adults.

There have been numerous studies comparing the lower-limb power, RTD, or RFD in fallers (i.e., older people with a fall history or with prospective falls) versus non-fallers. However, no consensus was achieved regarding the abilities of these strength parameters in identifying fallers. Firstly, taking the RTD of knee flexors during the MVIC task for example, one study reported that fallers had smaller values in this parameter than non-fallers [4], while the other two studies found no difference [11, 24]. This makes it difficult to determine the effectiveness/appropriateness of using this RTD parameter to identify the fall history in older people. Secondly, some studies have measured the power or RFD of the entire unilateral/bilateral lower limb(s), whereas other studies have measured the RTD or power values of different muscle groups in various physical function tests. It is worthwhile to conduct a comprehensive synthesis to summarize evidence for each strength measure. Thirdly, several studies investigated the lower-limb power, RTD, and RFD in older adults with recurrent falls [2, 4, 21, 24] or injurious falls [2, 55]. These populations are more prone to falls and place greater demands on medical resources [17, 40]. Critical appraisal is essential to confirm the impact of lower-limb rapid force generation on them.

So far, few published review articles have synthesized the various measures of lower-limb rapid force generation to identify the fallers. Most previous literature reviews have focused on the use of sit-to-stand power to identify the older people with a fall history [50, 54]. While Watt et al. [54] only conducted a narrative review, Shukla et al. [50] only synthesized the sit-to-stand power parameters that were measured by the motion sensors. It remained unclear whether the sit-to-stand power measured by other devices, such as the force plate, could identify the fall history. To the best of our knowledge, no prior systematic reviews have summarized the causal relationships between lower-limb power, RTD, or RFD and prospective falls in older people. There has also been a lack of quantitative analyses (or meta-analyses) on this topic in the field. As such, it remains difficult to draw a conclusion with confidence regarding the effectiveness or appropriateness of using sit-to-stand power, or other varieties of lower-limb RTD and RFD parameters, to identify the fall-prone older people.

Given the above, this systematic review and meta-analysis focused on the clinical question of "which lower-limb strength parameter (power, RTD, or RFD) could effectively identify the community-dwelling older adults with a fall history or prospective falls?". The objective was to systematically examine and appraise the association of each lower-limb power, RTD, or RFD parameter with falls, including injurious falls and recurrent falls. It is expected to provide evidence, recommendations, and implications for clinical practice regarding the use of lower-limb rapid force generation measurements in fall-risk assessment among community-dwelling older adults.

Methods

The review protocol was pre-registered in the International Prospective Register of Systematic Reviews (PROSPERO, registration No.: CRD42021237091). Review methods were established during registration and before the conduct of the review. For the currently used methodology, there are two main points that are different from the protocol, i.e., the quality assessment tool and the models used in meta-analyses. Justifications are presented in the texts below.

Search and screening strategy

Following the Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) guidelines, two reviewers undertook the literature search and screening by using a three-step strategy (Fig. 1) [27].

Databases were firstly searched to identify relevant records. In step 1, an initial search of PubMed was conducted by reading titles and abstracts to identify the appropriate keywords, e.g., "old" AND "fall risk" AND "power" AND "lower limb". Step 2 was conducted by using all the identified keywords to search across six electronic databases: PubMed, Web of Science, EMBASE, Scopus, CINAHL, and Cochrane CENTRAL. Following the PTSD standard, i.e., population, test, standard, and disease, the keywords of primary searching are presented in Appendices A1 [28]. There were no restrictions on the publishing date. Searching alerts were created to monitor the publication of articles until 31 May 2023. The gray literature was not searched for this systematic review.

Then the titles, abstracts, and full texts of the identified records were reviewed to screen eligible studies based on the below criteria. The inclusion criteria were studies involving: (1) adults chronologically aged 60 years or older living in the community with family or independently; (2) quantitative measurements of power (in the unit of Watt or Watt·kg^{-1}), rate of torque development (RTD, in the unit of Nm/s or Nm/s·kg^{-1}), or rate of force development (RFD, in the unit of N/s, kgf/s, N/s·kg^{-1}, or kgf/s·kg^{-1}) of lower limbs; (3) evaluations of the fall history or the prospective falls; and (4) effect measures indicating comparisons (e.g., mean difference), associations (e.g., odds ratio, risk ratio, hazards ratio), or diagnostic accuracies (e.g., sensitivity, specificity, area under the curve). There was no restriction on the study design. Both observational studies and interventional studies were considered. Studies were excluded if they: (1) focused on older people living in the institutional settings (e.g., nursing homes, hospitals) or older people with a specific neuromuscular, orthopedic, cardiopulmonary or cognitive disease (e.g., Parkinson's disease, stroke, multiple sclerosis, fractures, diabetic foot); (2) assessed the strength parameters of the upper-limb/trunk muscle or assessed the strength parameters indirectly, such as estimating power from the sit-to-stand time [51]; (3) assessed the fall risks indirectly, i.e., not based on the fall history or prospective falls, such as via the comparison between older and young participants or via balance tests; or (4) were review articles, conference papers, proceedings, or not written in English.

Step 3 was reviewing the reference lists of the publications for full-text screening to identify additional eligible studies. Forward citation tracking was conducted to identify any relevant studies that were published subsequent

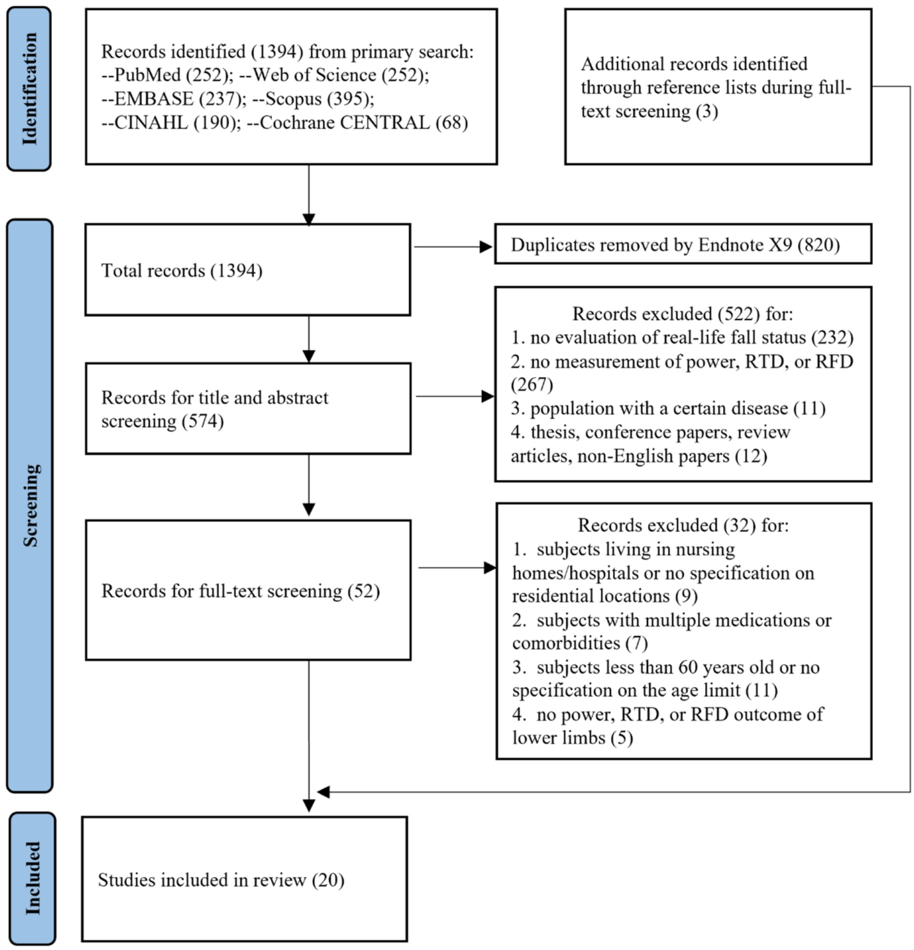


Fig. 1 Flow chart of study identification and screening. (RTD: rate of torque development; RFD: rate of force development.)

to the included studies. In addition to the primary three-step search and screening above (Fig. 1), a final search was conducted in December 2024 using additional keywords in databases to identify any missing eligible studies on injurious falls (Appendix A2). Detailed records of title, abstract, and full-text screening are presented in Additional File 1.

Data extraction

For each included study, one reviewer first extracted the below information: study design, definition of "faller", participant characteristics, device and task for a strength test, definition of measured strength parameter, together with the measured lower-limb muscles. If data for conducting a meta-analysis was unavailable in the main text, the supplemental materials were reviewed. If unavailable, the reviewer further contacted the corresponding authors via e-mail. If contact via emails was unsuccessful due to no response, that study was included in the systematic review but not in the meta-analysis. Another reviewer checked the extracted data against the original text to ensure the input data was correct.

Quality assessment

Two tools were chosen for quality assessments. The 14-item Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies was used to assess the methodological quality of each included study [31]. When one item was rated as "Yes", it scored 1 point [12]. The item was given 0 point if it was rated as "No", "not reported" or "not applicable" [12]. The Grading of Recommendations, Assessment, Development and Evaluation (GRADE) approach was used to evaluate the quality of evidence of each lower-limb power, RTD, or RFD parameter as a risk factor for falls or as an indicator of fall history [48]. The overall quality of evidence was rated based on the study design, factors downgrading quality (including risk of bias, imprecision, inconsistency, indirectness, and publication bias), and factors upgrading quality (including large magnitude of effect, dose–response gradient, and confounders that work to reduce the demonstrated effect or increase the effect if no effect was demonstrated) [48]. Considering that all the included studies were observational studies, the Downs and Black scale, which was initially proposed in the PROSPERO protocol and more suitable for assessing the quality of interventional studies, was not used in this systematic review.

Two reviewers independently conducted the quality assessment above. Disagreements over the rating results were first discussed between the two reviewers; if agreements persisted, a third reviewer made the final decision.

Data synthesis and analysis

Meta-analyses were conducted separately for each strength parameter, if two or more included studies had the same study design and similar testing conditions [19]. Random-effects inverse-variance models were used to pool effect measures in Review Manager software (Version 5.4.1), as recommended by the recent Cochrane guideline [19]. Therefore, we did not use the method as initially proposed in the PROSPERO protocol, which was choosing the fixed- or random-effects model based on the I^2 value.

The primary effect measure for meta-analyses was the standardized mean difference (SMD). Some studies detailed the data of strength parameters in non-fallers (i.e., with no fall event), single fallers (i.e., with one fall event), and recurrent fallers (i.e., with two or more fall events). As the older adults with different fall status could indicate different fall risks [17], meta-analysis was conducted separately to compare "fallers (single fallers + recurrent fallers) vs non-fallers", "single fallers vs non-fallers", "recurrent fallers vs non-fallers", "recurrent fallers vs single fallers", and "recurrent fallers vs non-recurrent fallers (single fallers + non-fallers)". The Cochrane's formula was used to merge data from two participant groups into a single participant group, such as aggregating the data of single fallers and recurrent fallers into that of fallers [19]. The value of SMD indicates the effect size of "very small" (0–0.2), "small" (0.2–0.5), "medium" (0.5–0.8), and "large" (> 0.8) [8].

The secondary effect measure was odds ratio (OR). The odds ratio (OR) represents the very small (1.00–1.68 or 0.60–1.00), small (1.68–3.47 or 0.29–0.60), medium (3.47–6.71 or 0.15–0.29), or large effect size (> 6.71 or < 0.15) (Chen et al., 2010). For other effect measures such as risk ratios (RR), they were reported in only one study and were unavailable for meta-analysis.

The funnel plot and tests for funnel plot asymmetry were used to examine the potential publication bias when there are at least 10 studies included in a meta-analysis [19].

Results

Types and methodological quality of included studies

The primary three-step search and screening identified 20 eligible articles (Fig. 1), and no additional eligible studies were found in the final search. All of them were observational studies. Eight of them were prospective cohort studies, and examined the relationships between lower-limb power, RTD, or RFD parameters and prospective falls [2, 6, 20, 22, 23, 36, 41, 55]. The remaining 12 cross-sectional studies measured the lower-limb power, RTD, or RFD in older adults with and without a fall history.

The methodological quality evaluation revealed an overall moderate risk of bias for the included studies (see Appendix B). The scores ranged from 3 to 12 points (mean: 7.55 points; median: 7 points; full score: 14 points). Over half of the included studies clearly specified the research questions, exposure measures, outcome measures, and participant characteristics. They also applied the uniform eligibility criteria during participant recruitment, examined the relationships between different levels of exposures and outcomes, and adjusted for the impact of key confounders (e.g., sex, height, weight) on the exposure-outcome relationship. High risk of bias commonly existed in the items of "exposure measured before outcome", "sufficient timeframe", "participation rate", "follow-up rate", "sample size justification", "assessors blinded", and "exposure assessed more than once".

Participants' demographics and fall status

A total of 8,231 older adults aged 60 years or above were involved (Table 1). The sample sizes of the included studies ranged from 15 [35] to 5,995 [6]. The mean age of all the participants included in this review was 73.5 years, and the mean age of the participants for each included study ranged from 66 to 80 years. The male to female ratio of the included participants was approximately 6:1, and such skewed ratio was primarily contributed by Chan et al. [6]'s study which included a large sample of only male participants. Of the older participants included, the majority (99.15%) were specified as living in the community and/or living independently, while the remaining (0.85%) were not specified regarding their residence but were specified as healthy (Appendix C).

Fallers ($n = 2{,}058$) accounted for approximately 1/4 of all the included older participants (Table 1). Regarding the definition of "fall", 13 studies clearly defined it as the event that resulted in a person coming to rest unintentionally on the ground or other lower level [4, 7, 10, 11, 14, 16, 22, 35, 41, 44, 52], while the remaining studies did not specify it. As the study designs of the included studies varied, "fallers" in this review referred to participants with fall event(s) that happened either before or after the strength measurement. The eight prospective cohort studies monitored fall incidence through the below methods: monthly telephone calls [41], monthly calendar records [2, 20], tri-annual questionnaires [6], yearly recalls [23, 36, 55],

Table 1 Characteristics of included articles ($N = 20$)

Author (year) & Study design	Definition of fallers	Group	Sample size	Male/ Female	Age (year, mean ± SD)	Device	Task	Definition of the measured power, RTD, or RFD parameter	Measured anatomical locations of the power/ RTD/RFD parameters
Atrsaei et al. [2] Prospective cohort	≥ 2 falls or 1 injurious fall in future 12 months	NF	350	163/187	74.9 ± 1.4	Accelerometer	Five-time Sit-to-stand test	Peak, minimum, and average **power** value by multiplying acceleration, body mass and velocity	Entire bilateral lower limbs
		F	108	35/73	74.7 ± 1.4				
Bento et al. [4] Cross-sectional	≥ 1 fall(s) in past 12 months	NF	13	0/13	67.6 ± 7.5	Load cell	MVIC	**RTD** from the 20% to 80% of peak torque	Single muscle group (Hip Flex. & Ext., Hip Abd. & Add., Knee Flex. & Ext., Ankle Plantar. & Dorsi.)
		SF	8	0/8	66.0 ± 4.9				
		RF	10	0/10	67.8 ± 8.8				
Chan et al. [6] Prospective cohort	≥ 1 fall(s) in future 4.5 years	NF	5995	5995/0	73.7 ± 5.9	Nottingham power rig	Leg press	Average **power** value calculated based on the final angular velocity of the power rig flywheel. The largest power of nine repetitive trials was used	Entire unilateral lower limb
		F							
Cheng et al. [7] Cross-sectional	≥ 1 fall(s) in past 12 months	NF	35	23/12	75.2 ± 6.4	Force plate	Sit-to-stand test	Peak **power** value by multiplying the vGRF and the vertical upward velocity of center of body mass	Entire bilateral lower limbs
		F	35	22/13	77.5 ± 7.8				
Crozara et al. [11] Cross-sectional	≥ 1 fall(s) in past 12 months	NF	22	0/22	66.1 ± 6.1	Isokinetic dynamometer	MVIC	**RTD** over 0–50, 50–100, 100–150, and 150–200 ms (onset: 5% of peak torque)	Single muscle group (Knee Flex. & Ext., Ankle Plantar. & Dorsi.)
		F	21	0/21	69.6 ± 7.2				
Crozara et al. [10] Cross-sectional	≥ 1 fall(s) in past 12 months	NF	23	0/23	66.0 ± 6.0	Isokinetic dynamometer	Isokinetic contraction	Average **power** value by multiplying the mean torque and the angular velocity	Single muscle group (Knee Flex. & Ext., Ankle Plantar. & Dorsi.)
		F	22	0/22	70.0 ± 7.0				

Table 1 (continued)

Author (year) & Study design	Definition of fallers	Group	Sample size	Male/Female	Age (year, mean ± SD)	Device	Task	Definition of the measured power, RTD, or RFD parameter	Measured anatomical locations of the power/RTD/RFD parameters
Dietzel et al. [14] Cross-sectional	≥ 1 fall(s) in past 12 months	NF	246	131/115	71.4 ± 7.3	Force plate	1) Jumping; 2) Sit-to-stand test	Peak **power** value by multiplying the vGRF and the vertical upward velocity of center of body mass	Entire bilateral lower limbs
		F	47	16/31	74.2 ± 7.5				
Ejupi et al. [16] Cross-sectional	≥ 1 fall(s) in past 12 months	NF	60	64/30	79.9 ± 6.5	Accelerometer	Sit-to-stand test	Peak **power** value by multiplying acceleration, body mass and velocity	Entire bilateral lower limbs
		F	34						
Hsieh et al. [20] Prospective cohort	≥ 1 fall(s) in future 12 months	NF	63	64/60	72.4 ± 6.3	Nottingham power rig	Leg press	Average **power** value calculated based on the final angular velocity of the power rig flywheel. The largest power of ten repetitive trials was used	Entire unilateral lower limb
		F	61		73.6 ± 5.9				
Kamo et al. [21] Cross-sectional	≥ 1 fall(s) in past 12 months	NF	88	45/43	71.3 ± 4.7	Hand-held dynamometer	MVIC	**RTD** over 0–200 ms (onset: 4 Nm)	Single muscle group (Knee Ext.)
		SF	24	13/11	71.2 ± 3.7				
		RF	10	4/6	71.4 ± 2.9				
Kemoun et al. [22] Prospective cohort	≥ 1 fall(s) in the future 12 months	NF	38	26/12	66.7 ± 4.9	Motion capture system	Favored-paced walking	Peak or minimum **power** value of a joint in a gait cycle	Single joint (Hip joint, Knee joint, & Ankle joint)
		F	16	12/4					
Kera et al. [23] Prospective cohort	≥ 2 falls in future 12 months	NF	433	170/263	72.3 ± 6.0	Force plate	Sit-to-stand test	**Rate of vGRF development** between the onset of sit-to-stand motion and the peak force	Entire bilateral lower limbs
		F	23	11/12	72.7 ± 6.7				
LaRoche et al. [24] Cross-sectional	≥ 3 falls in past 12 months	NF	12	0/12	71.2 ± 6.2	Isokinetic dynamometer	MVIC	The largest value of **RTD**s calculated for every 50 ms from onset (0.5 Nm) to 200 ms	Single muscle group (Knee Flex. & Ext., Ankle Plantar. & Dorsi.)

Table 1 (continued)

Author (year) & Study design	Definition of fallers	Group	Sample size	Male/Female	Age (year, mean ± SD)	Device	Task	Definition of the measured power, RTD, or RFD parameter	Measured anatomical locations of the power/RTD/RFD parameters
		F	11	0/11	71.3 ± 5.4				
Palmer et al. [35] Cross-sectional	≥ 1 fall(s) in past 12 months	NF	9	0/9	71.4 ± 7.0	Load cell	MVIC	**RTD** over 0–50 ms (onset: 4 Nm) and 100–200 ms	Single muscle group (Hip Ext.)
		F	6	0/6	72.7 ± 6.9				
Parsons et al. [36] Prospective cohort	≥ 1 fall(s) in future 2 years	NF	129	/	75.1 ± 2.5	Force plate	Jumping	Peak **power** value	Entire bilateral lower limbs
		F	40						
Perry et al. [37] Cross-sectional	≥ 1 fall(s) in past 12 months	NF	44	15/29	75.9 ± 0.6	Nottingham power rig	Leg press	Average **power** value calculated based on the final angular velocity of the power rig flywheel. The largest power of at least six repetitive trials was used	Entire unilateral lower limb
		F	34	4/30	76.4 ± 0.8				
Porto et al. [41] Prospective cohort	≥ 1 fall(s) in future 12 months	NF	72	19/53	66.7 ± 4.5	Isokinetic dynamometer	MVIC	**RTD** over 30–80 ms, 200–250 ms (onset: 5% of peak torque)	Single muscle group (Hip Flex. & Ext., Hip Abd. & Add., Knee Flex. & Ext., Ankle Plantar. & Dorsi.)
		F	28	4/24	69.8 ± 5.7				
Ribeiro et al. [44] Cross-sectional	≥ 1 fall(s) in past 6 months	NF	15	0/15	70.6 ± 6.8	Extension machine + potentiometer	Concentric contraction	**Power** of knee extensors calculated from the force obtained in 1-RM test, lever arm, and angular displacement (not specifying peak or average power)	Single muscle group (Knee Ext.)
		F	11	0/11	68.5 ± 4.3				
Skelton et al. [52] Cross-sectional	≥ 3 falls in past 12 months	NF	15	0/15	74.0 ± 6.3	Nottingham power rig	Leg press	Average **power** value calculated based on the final angular velocity of the power rig flywheel. The largest power of at least six repetitive trials was used	Entire unilateral lower limb
		F	20	0/20	74.5 ± 5.7				

Table 1 (continued)

Author (year) & Study design	Definition of fallers	Group	Sample size	Male/Female	Age (year, mean ± SD)	Device	Task	Definition of the measured power, RTD, or RFD parameter	Measured anatomical locations of the power/RTD/RFD parameters
Winger et al. [55] Prospective cohort	≥ 1 injurious fall(s) in future 9 years	NF	3088	5178/0	72.9 ± 5.6	Nottingham power rig	Leg press	Average **power** value calculated based on the final angular velocity of the power rig flywheel. The largest power of ten repetitive trials was used	Entire unilateral lower limb
		F	2090		74.0 ± 5.8				

F fallers, *NF* non-fallers, *SF* single fallers, i.e., older people experiencing one fall, *RF* recurrent fallers, i.e., older people experiencing two or more falls, *SD* standard deviation, *RTD* rate of torque development, *RFD* rate of force development, *vGRF* vertical ground reaction force, *RM* repetition maximum, *Flex.* Flexors, *Ext.* extensors, *Abd.* Abductors, *Add.* Adductors, *Plantar.* Plantarflexors, *Dorsi.* dorsiflexors triennial questionnaires [55], or a combination of participants' diary records and bimonthly telephone calls from researchers [22]. The follow-up period was within 1 year [2, 20, 22, 23, 41], 2 years [36], 4.5 years [6], or 9 years [55]. The remaining cross-sectional studies retrospectively evaluated the history of falls in older participants, and defined "fallers" as participants experiencing at least one fall in the past one year [4, 7, 10, 11, 14, 16, 21, 37], at least three falls in the past one year [24, 52], or at least one fall in the past six months [44]. Regarding fall consequences, four studies detailed the injuries in fallers [2, 41, 44, 55], and only two of them examined the association of lower-limb power parameters with prospective injurious falls [2, 55]. One focused on older people with at least 1 injurious fall [55], and the other one focused on the injurious/recurrent fallers who had at least 1 injurious fall or at least 2 non-injurious falls [2].

Testing tasks and equipment for measurement of power, RTD, and RFD

The power, RTD, and RFD parameters have been evaluated in the diverse tests regarding a single muscle group, regarding a single joint, or regarding the entire unilateral/bilateral lower limb(s). (Table 1 and Appendix C). More details on the testing tasks and devices are described as follows:

Strength tests for a single muscle group

Eight included studies evaluated the RTD or power of a single muscle group in fallers and non-fallers. The MVIC tasks were the most frequently used [4, 11, 21, 24, 35, 41], followed by the isokinetic [10] and the submaximal concentric contraction tasks [44]. The measuring devices involved dynamometers, load cells or force sensors. Participants were instructed to exert force or accomplish a certain joint motion as hard and as fast as possible. Almost all the major lower-limb muscle groups have been evaluated, including hip flexors/extensors [4, 35, 41], hip abductors/adductors [4, 41], knee flexors/extensors [4, 11, 21, 24, 41], and ankle dorsiflexors/plantarflexors [4, 11, 24, 41]. The RTD parameters were analyzed during the MVIC tasks, while the average power was measured during the isokinetic and the submaximal concentric contraction tasks.

Analysis of single joint power

One study also evaluated the lower-limb joint power during the favored-paced walking tasks in fallers vs. non-fallers [22]. Participants were asked to walk at their comfortable speed, and the three-dimensional motion capture system with cameras and force plate(s) was used to capture the kinematic and kinetic data. Based on the inverse dynamics, the hip, knee, and ankle joint power in a gait cycle was estimated. Noted that the term, "joint power", was frequently used in gait analysis. It was the product of the net torques about a joint and the angular velocity of the joint [45]. Therefore, joint power involves contributions of the muscle power of multiple muscle groups that cross the joint [9].

Strength tests for the entire unilateral/bilateral lower limb(s)

The power or RFD of the entire unilateral/bilateral lower limb(s) in older adults was evaluated during the leg-press tasks, sit-to-stand tasks, stand-to-sit tasks, and jumping tasks. During the leg-press task, the Nottingham Power Rig was used to measure the average power of leg extensors as the participant was instructed to push the pedal down as hard and fast as possible using one leg [6, 20, 37, 52, 55]. During the sit-to-stand task, a force plate [7, 14, 23] or wearable accelerometer [2, 16] was used to measure the peak/minimum/average power or the rate of ground reaction force development. The participant was instructed to stand up until reaching the full knee extension, without any help from their hands or arm support during the movement. In addition, one study analyzed the lower-limb power parameters during the stand-to-sit process when the participant was performing the five-time sit-to-stand test [2]. During the jumping test, the peak power was evaluated in older adults as they were instructed to stand on the force plate, bend knees, swing arms, and jump as high as possible [14, 36].

Parameters to predict the prospective falls

There was moderate quality of evidence regarding the associations between the average leg-press power, sit-to-stand or stand-to-sit power parameters at baseline and the prospective falls among older adults, particularly injurious/recurrent falls (see Table 2). As risk ratios (RR) or odds ratios (OR) were reported for these parameters, their overall qualities of evidence were rated up one level for such dose–response gradients [48]. Regarding the average leg-press power, meta-analyses of two relevant studies showed that this parameter was significantly smaller at baseline in fallers than non-fallers (SMD = −0.17, $I^2 = 0\%$; OR = 0.84, $I^2 = 0\%$; see Fig. 2 and Appendix D1) [20, 55]. Another relevant study also found that older men with larger average leg-press power exhibited significantly lower fall incidences during a follow-up period of 4.5 years (Quartile 2: RR = 0.88, 95% CI: 0.81–0.97; Quartile 3: RR = 0.86, 95% CI: 0.77–0.95; Quartile 4: RR = 0.82, 95% CI: 0.73–0.92) [6]. Regarding the sit-to-stand or stand-to-sit power parameters, Atrsaei et al. [2] demonstrated that the peak power value and the minimum power value during a sit-to-stand task could significantly predict the odds of injurious/recurrent falls within the ensuing 12 months, but these power parameters

Table 2 Summary of effect size and quality of evidence for each power, RTD, or RFD parameter in identifying prospective falls/history

Study design	Lower-limb power, RTD, or RFD parameter	Effect measure and size [95% CI]	No. of studies	Study design	Factors downgrading quality					Factors upgrading quality	Overall quality of evidence
					Risk of bias	Inconsistency	Indirectness	Imprecision	Publication bias		
Prospective cohort studies	Average leg-press power[a]	**Pooled SMD:** −0.17 [−0.23, −0.12] **Pooled OR:** 0.84 [0.79, 0.89] **RR:** Quartile 1: 1.00 Reference Quartile 2: 0.88 [0.81, 0.97] Quartile 3: 0.86 [0.77, 0.95] Quartile 4: 0.82 [0.73, 0.92]	3	−2 (No RCT)	No	No	No	No	NA	+1 (Dose–response gradient)	⊕⊕⊕○ **Moderate**
	Peak sit-to-stand power[a] Minimum sit-to-stand power[a] Average sit-to-stand power Normalized peak sit-to-stand power[a] Peak stand-to-sit power Minimum stand-to-sit power Average stand-to-sit power Normalized peak stand-to-sit power	***Cohen's d*:** 0.41 0.40 0.08 0.38 0.28 0.19 0.07 0.25	1	−2 (No RCT)	No	No	No	No	NA	+1 (Dose–response gradient)	⊕⊕⊕○ **Moderate**
	Peak jumping power[a]	**OR:** 0.91 [0.85, 0.98]	1	−2 (No RCT)	No	No	No	−1 (Sample size < 400)	NA	+1 (Dose–response gradient)	⊕⊕○○ **Low**
	RFD of entire lower limbs during the sit-to-stand task	**SMD:** −0.33 [−0.75, 0.09]	1	−2 (No RCT)	No	No	No	No	NA	None	⊕⊕○○ **Low**
	RTD of hip flexors during the MVIC task RTD of hip extensors during the MVIC task RTD of hip abductors during the MVIC task RTD of hip adductors during the MVIC task RTD of knee flexors during the MVIC task RTD of knee extensors during the MVIC task RTD of ankle dorsiflexors during the MVIC task RTD of ankle plantarflexors during the MVIC task	**OR:** 0.80 [0.40, 1.58] 0.77 [0.33, 1.82] 1.00 [0.26, 3.80] 1.15 [0.34, 3.94] 0.41 [0.07, 2.22] 0.99 [0.59, 1.68] 1.35 [0.34, 5.25] 0.82 [0.13, 4.90]	1	−2 (No RCT)	No	No	No	−1 (Sample size < 400)	NA	+1 (Dose–response gradient)	⊕⊕○○ **Low**

Table 2 (continued)

Study design	Lower-limb power, RTD, or RFD parameter	Effect measure and size [95% CI]	No. of studies	Study design	Factors downgrading quality					Factors upgrading quality	Overall quality of evidence
					Risk of bias	Inconsistency	Indirectness	Imprecision	Publication bias		
	Minimum hip joint power during the favored-paced walking test Minimum knee joint power during the favored-paced walking test Peak ankle joint power during the favored-paced walking test	**Median Difference**	1	−2 (No RCT)	No	No	No	−1 (Sample size < 400)	NA	None	⊕○○○ **Very low**
Cross-sectional studies	Peak sit-to-stand power[a]	**Pooled SMD:** −0.58 [−0.96, −0.20]	3	−2 (No RCT)	No	No	No	No	NA	None	⊕⊕○○ **Low**
	Average leg-press power[a]	**Pooled SMD:** −0.49 [−0.87, −0.11]	2	−2 (No RCT)	No	No	No	−1 (Sample size < 400)	NA	None	⊕○○○ **Very low**
	RTD of knee flexors during the MVIC task[a] RTD of ankle dorsiflexors during the MVIC task RTD of ankle plantarflexors during the MVIC task	**Pooled SMD:** −0.57 [−0.98, −0.16] −0.23 [−0.63, 0.18] −0.25 [−0.65, 0.15]	3	−2 (No RCT)	No	No	No	−1 (Sample size < 400)	NA	None	⊕○○○ **Very low**
	RTD of knee extensors during the MVIC task	**Pooled SMD:** −0.18 [−0.46, 0.11]	4	−2 (No RCT)	No	No	No	−1 (Sample size < 400)	NA	None	⊕○○○ **Very low**
	RTD of hip extensors during the MVIC task	**Pooled SMD:** −0.75 [−1.98, 0.49]	2	−2 (No RCT)	No	No	No	−1 (Sample size < 400)	NA	None	⊕○○○ **Very low**
	RTD of hip flexors during the MVIC task RTD of hip abductors during the MVIC task RTD of hip adductors during the MVIC task	**SMD:** −0.04 [−0.75, 0.67] −0.34 [−1.06, 0.38] −0.24 [−0.95, 0.48]	1	−2 (No RCT)	No	No	No	−1 (Sample size < 400)	NA	None	⊕○○○ **Very low**
	Peak jumping power ([a] in female participants)	**SMD:** −0.47 [−0.78, −0.15]	1	−2 (No RCT)	No	No	No	−1 (Sample size < 400)	NA	None	⊕○○○ **Very low**

Table 2 (continued)

Study design	Lower-limb power, RTD, or RFD parameter	Effect measure and size [95% CI]	No. of studies	Study design	Factors downgrading quality					Factors upgrading quality	Overall quality of evidence
					Risk of bias	Inconsistency	Indirectness	Imprecision	Publication bias		
	Average power of knee flexors during the isokinetic contraction task at 90°/s[a] Average power of knee flexors during the isokinetic contraction task at 120°/s Average power of knee extensors during the isokinetic contraction task at 90°/s[a] Average power of knee extensors during the isokinetic contraction task at 120°/s[a] Average power of ankle dorsiflexors during the isokinetic contraction task at 90°/s[a] Average power of ankle dorsiflexors during the isokinetic contraction task at 120°/s Average power of ankle plantarflexors during the isokinetic contraction task at 90°/s Average power of ankle plantarflexors during the isokinetic contraction task at 120°/s	**SMD:** −0.82 [−1.44, −0.21] −0.56 [−1.15, 0.04] −0.80 [−1.41, −0.19] −0.73 [−1.33, −0.12] −0.65 [−1.26, −0.05] −0.08 [−0.67, 0.50] −0.22 [−0.81, 0.36] −0.31 [−0.90, 0.28]	1	−2 (No RCT)	No	No	No	−1 (Sample size < 400)	NA	None	⊕○○○ **Very low**
	Power of knee extensors during the concentric contraction task at 70% 1-RM	**SMD:** 0.13 [−0.65, 0.91]	1	−2 (No RCT)	No	No	No	−1 (Sample size < 400)	NA	None	⊕○○○ **Very low**

The quality of evidence was rated based on the Grading of Recommendations, Assessment, Development and Evaluation (GRADE) criteria

RTD rate of torque development, *RFD* rate of ground reaction force development; *SMD* standardized mean difference, *OR* odds ratio, *RR* risk ratio, *MVIC* maximal voluntary isometric contraction, *RM* repetition maximum, *RCT* randomized controlled trial, *NA* not applicable

[a] Indicates the parameter could significantly predict the prospective falls or identify the different fall histories

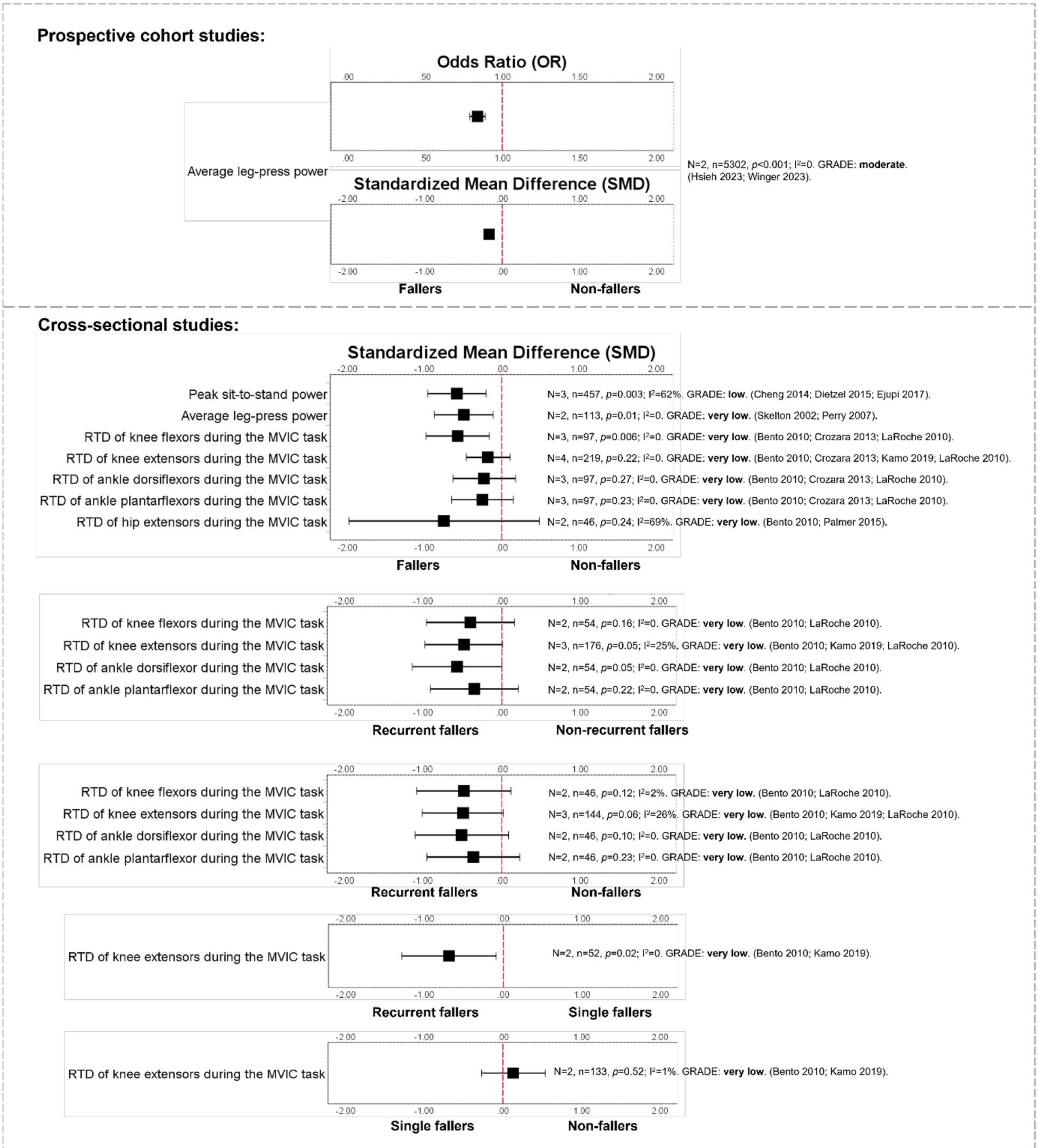


Fig. 2 Meta-analysis for the comparison of each lower-limb power, RTD, or RFD parameter in older adults with different fall status. (: the effect measure with 95% confidence intervals; RTD: rate of torque development; MVIC: maximal voluntary isometric contraction; N: number of studies; n: pooled sample size. GRADE: Grading of Recommendations, Assessment, Development and Evaluation)

during a stand-to-sit task could not (see Table 2). In addition, one study specifically examined average leg-press power in the injurious fallers [55], and another study specifically examined sit-to-stand or stand-to-sit power parameters in injurious/recurrent fallers [2]. The quality of evidence was moderate due to relatively large sample sizes (> 400) of the two studies.

Low quality of evidence indicated the associations between peak jumping power, rate of ground reaction force (RFD) for a sit-to-stand task, or RTD of a single muscle group and prospective falls (see Table 2). By using a logistic regression model, Parsons et al. [36] found that the greater peak jumping power was associated with decreased odds of falls (OR = 0.91, 95% CI: 0.85–0.98), while Porto et al. [41] reported that none of the RTD values of the hip, knee, or ankle muscles during the MVIC task could significantly predict the prospective falls within a 2-year follow-up period. By using the Cox proportional hazards regression analysis, Kera et al. [23] revealed that the RFD value during a sit-to-stand task was unable to significantly predict the prospective falls within the ensuing 1 year. Regarding the favored-paced walking task, very low quality of evidence indicated that there was no significant difference in the estimated peak power at the hip, knee, or ankle joint at baseline between people with and without prospective fall incidence within the 1-year follow up [22] (see Table 2).

Parameters to identify the fall history

Meta-analysis results (Fig. 2 and Appendices D2-D18) showed that fallers had significantly smaller peak sit-to-stand power (SMD = −0.58, I^2 = 62%) and average leg-press power (SMD = −0.49, I^2 = 0%) as compared to non-fallers. By contrast, the RTD of a single muscle group during the MVIC task could not significantly identify the fall history in community-dwelling older adults, except that the RTD of knee flexors could significantly differentiate fallers from non-fallers (SMD = −0.57, I^2 = 0%) and the RTD of knee extensors could significantly differentiate recurrent fallers from single fallers (SMD = −0.69, I^2 = 0%). Noted that some studies were included in more than one meta-analysis (Fig. 2 and Appendices D2-D18). This was because these studies had examined multiple parameters related to rapid force generation [4, 11, 24]. Therefore, the same studies contributed data to separate meta-analyses.

Effect size and quality of evidence for each lower-limb power, RTD, or RFD parameter (including those unavailable for meta-analysis) were listed in Table 2. Regarding the abilities of power, RTD, and RFD parameters in identifying older adults' fall histories, the quality of evidence ranged from very low to low. As the study designs were not randomized controlled trials, the overall qualities of evidence for these parameters were rated down two levels [48]. The sample sizes were commonly small and less than 400, which caused the "imprecision" and further downgraded the overall quality of evidence [48] (see Table 2).

Publication bias

According to the Cochrane guideline, quantitative tests for publication bias should be used only when there are at least 10 studies included in the meta-analysis as a rule of thumb [19]. Due to the limited number of studies reporting a same strength parameter, it is not applicable to use a funnel plot to accurately determine the presence of publication bias (Table 2).

Discussion

This is the first systematic review and meta-analysis to synthesize evidence regarding the associations of lower-limb power, RTD, and RFD measured during various functional tests with different fall status in community-dwelling older people. Moderate quality of evidence showed that the average leg-press power and the peak sit-to-stand power could predict the prospective falls, particularly the injurious/recurrent falls. Low quality of evidence showed that the peak sit-to-stand power could identify the fall history. These findings support the use of lower-limb power measurements for early detection of older adults at risk of falls, and may potentially inform interventions to prevent injurious/recurrent falls in future practices.

Methodological quality of the included studies

The studies included showed generally moderate methodological quality (Appendix B). Most studies have sought to enhance validity when investigating the relationship between lower-limb power, RTD, or RFD and falls in older people. They usually used uniform eligibility criteria when recruiting fallers and non-fallers, and controlled for potential confounding factors (e.g., age-matched fallers and non-fallers, regression analysis adjusted for age and sex). However, most included studies used cross-sectional designs and lacked sufficient long timeframes to establish causality between lower-limb power, RTD, or RFD and falls. The unjustified sample size, convenience sampling method, and retrospective evaluation of fall history (which was prone to recall bias) in most included studies were also the factors compromising the overall methodological quality.

Evidence on parameters to predict prospective falls in older adults

The current evidence supported that the power parameters of entire unilateral/bilateral lower limb(s) instead of the RTD parameters of a single muscle group could predict the prospective falls in community-dwelling older adults (Table 2). Possible explanations for this difference are as follows.

Effects of the sample size and the follow-up duration for tracking prospective falls need to be primarily considered. An example was that more than 5,000 older male participants were followed up for 4.5 years [6] and 9 years [55] after the baseline measurement of average leg-press power, while only 100 older participants (male to female: 23/77) were followed up for 1 year after the measurements of RTD values of multiple muscle groups [41]. As fewer fall events and participants were tracked, the latter was more prone to the imprecision in effect estimates (i.e., larger confidence interval) than the former, which may be a reason of why the

RTD of a single muscle group could not significantly predict the fall incidence (Table 2). In addition, the different sex ratios seemed to have confounded the causal relationships between lower-limb rapid force generation and falls in older adults [6, 41, 55].

The effect size of a lower-limb strength measure in fall prediction may also be influenced by the measured muscles (entire unilateral/bilateral lower limbs vs. single muscle group), the nature of testing task (concentric vs. eccentric), and the type of parameter (power vs. RTD or RFD). Firstly, the leg-press task (pooled SMD and 95% CI: −0.17 [−0.23, −0.12]; RR ranging from 0.82 to 0.88), sit-to-stand task (*Cohen's d*: 0.41), and jumping task (OR and 95% CI: 0.91 [0.85, 0.98]) all demand the contractions of multiple lower-limb muscle groups (Table 2). Apart from the cumulative force exertions of multiple leg extensors, i.e., hip extensors, knee extensors, and ankle plantarflexors, these tasks may also require the coordinated contractions of other more leg muscles for postural balance, such as the co-contraction of ankle dorsiflexors and plantarflexors to stabilize the body position after rising from a chair [2, 7]. This may explain why they showed better abilities in detecting the older adult's risk of prospective falls than the RTD measurement of a single muscle group (Table 2). Secondly, the lower-limb power assessed in the concentric contraction tasks appeared more sensitive to the fall risks in older adults. The capability of quickly generating adequate force is essential for the task that demands concentric strength to accelerate body segments and overcome gravity [2, 36]. For those requiring the eccentric control (e.g., stand-to-sit task) or those not demanding the rapid force generation (e.g., favored-paced walking), older adults could therefore demonstrate the similar lower-limb power values even if they had different fall risks [2, 3, 22]. Thirdly, even in the same task, prospective falls could be predicted by the measured peak power but not by the measured rate of ground reaction force development [2, 23]. Although the two parameters both reflect the capability of explosive force generation, their definitions are different. The former was the largest rate of energy generated by lower-limb muscles, while the latter was the rate of force generated by lower-limb muscles. Nevertheless, it remains unclear why the peak power rather than the RFD during the sit-to-stand task could predict the prospective falls in older adults (Table 2). Further evidence is warranted.

In summary, via a single functional task that involves the coordination of multiple lower-limb muscles and/or the postural balance control, the power measurement was able to detect the risk of prospective falls in community-dwelling older adults. This is promising, as a single conventional test for physical function assessment, such as the BBS or the TUG test, usually shows insufficient ability in identifying fall risks [25, 34, 47]. Nevertheless, it is worth noting that the average leg-press power, peak sit-to-stand power, and peak jumping power all showed small effect sizes in predicting prospective falls in older adults (see Fig. 2 and Table 2). Future studies may be warranted to examine whether the combination of some tests for lower-limb power was better in fall risk prediction.

Evidence on parameters to identify older adults with fall history

Community-dwelling older people with a fall history, especially history of recurrent falls, had a greater decline in several lower-limb power and RTD parameters than non-fallers. A previous meta-analysis reported that the decline of lower-limb maximal strength could be the risk factor of falls in community-dwelling adults and the effect size was small (OR = 1.66, 95% CI: 1.20–2.29) [30]. Our meta-analysis result indicated that older adults with a fall history could also have the impaired ability of quickly generating adequate force in lower-limb muscles, which showed similarly small effect sizes in differentiating fallers from non-fallers (see Table 2). Further, single fallers appeared to have better ability to rapidly generate force in lower limbs compared with recurrent fallers (see Fig. 2). One possible reason was that the older adults with only one previous fall may not indicate their poorer physical function or poorer balance capability, as those with two or more previous falls were more prone to future falls [17].

Among the various power and RTD parameters, the peak sit-to-stand power showed the higher quality of evidence in differentiating fallers from non-fallers although the heterogeneity was large (pooled SMD and 95% CI: −0.58 [−0.96, −0.20], see Fig. 2 and Table 2). Factors like the chair height, the use of arms or not, and the instruction to participants may all affect the performance of the sit-to-stand test [54]. There were also diversities in the types of devices in measuring the power (force plates vs. accelerometer). The power measured by a force plate was the product of vertical ground reaction force and vertical velocity [7, 14], while that measured by an accelerometer was the product of vertical net force (ground reaction force subtracted by gravity) and vertical velocity [16]. These factors may explain the large between-study heterogeneity of this meta-analysis. A previous systematic review found that the five times sit-to-stand test time (cut-off point: 12 s) could predict the prospective falls of community-dwelling older adults [26]. The current meta-analysis provided additional kinetic evidence to support the ability of sit-to-stand performance in identifying fall history.

Power, RTD, or RFD parameters of the entire unilateral/bilateral lower limb(s) and of a single muscle group exhibited different abilities in identifying an older adult's fall history (see Fig. 2 and Table 2). There was a clear trend for the RTD of a single muscle group to be lower in the fallers than non-fallers, but this usually did not reach a statistical significance. By contrast, the peak sit-to-stand power and average leg-press power were able to differentiate fallers from non-fallers. This may indicate that the fallers had relatively small force decrements across the individual muscles, which could accumulate and lead to a decline of entire lower-limb power [37]. Measuring the ability of rapid force generation in entire unilateral/bilateral lower limb(s) rather than in a single muscle group could be a more suitable way to distinguish the fallers from non-fallers.

Impact and recommendations for future clinical practice

Suggestions for fall-risk assessment

Measurement of lower-limb power seems necessary to be incorporated into the routine physical function assessment for fall-risk detection in community-dwelling older people. This systematic review and meta-analysis have supported that the decline of entire lower-limb power could identify the fallers, particularly injurious/recurrent fallers. Quantitative measurement of it during the leg-press test or instrumented sit-to-stand test is therefore worthy of being promoted. This is expected to complement the current physical function assessments in clinical practice, such as the TUG test and the timed sit-to-stand test [5], and facilitate early detection of fall risks in older adults, especially in those community-dwelling ones with relatively good health.

Implications for future fall-prevention or intervention programs

Given that older people with a fall history or prospective falls had generally poorer lower-limb power, relevant exercises should be prescribed to reduce the decline in muscle power and fall incidences in older adults. High-velocity resistance training, or power training, has been proposed as a more promising stimulus for improving the physical performance (e.g., sit-to-stand time, walking speed) in older adults compared to traditional resistance training [13]. A previous meta-analysis also showed moderate-certainty evidence supporting the balance and functional exercises (gait, balance, coordination, and functional task training) plus resistance exercises (resistance/power training) to reduce fall rates in community-dwelling older adults [49]. The results of the current study could highlight the importance of engaging older adults in exercises that enhance lower-limb power to help prevent falls.

Perspectives for future research

It is hard to recommend a cut-point value of lower-limb power to stratify the fall risks in community-dwelling older adults, based on the current evidence. Although the average leg-press power and the peak sit-to-stand power have shown small effect sizes in identifying fallers, only one included study conducted the diagnostic accuracy analysis [2]. Knowing the cut-point values can facilitate the judgement and more accurate stratification of fall risks in clinical practice. Future research is warranted to investigate the diagnostic accuracy (e.g., sensitivity, specificity, area under the curve) of lower-limb power parameters in fall-risk prediction.

The current evidence level was low to very low regarding whether the declined rapid force generation of a single muscle group in older adults was a fall-risk factor. Exercise training targeting on a certain or a few lower-limb muscles would be more time-efficient and increase the older adult's adherence to the fall-prevention exercise [42]. The existing evidence showed generally no significant associations between the RTD parameters of single muscle groups and the falls (see Fig. 2). However, such results were from a limited number of studies with small sample sizes, making us uncertain of the effect estimates (see Fig. 2). Additionally, it is worth noting that few studies have reported the impact of rapid force generation of a specific lower-limb muscle group on injurious falls. These merit more longitudinal studies in the future to provide higher quality of evidence, which may inform a targeted high-velocity resistance training in older adults to prevent falls and fall injuries.

More portable devices with the real-time power, RTD, or RFD values displayed can be developed to facilitate the clinician's judgement on an older client's risk of falls. Portable force plates [23] or wearable motion sensors [2, 16] have been popular in the measurement of rapid force generation (Table 1). They provide convenient and continuous monitoring of lower-limb strength measures, making the tests not confined to location and time. Such tools may thus be quite useful for the long-term monitoring of fall risks in a wider older population. However, most of these portable devices have no real-time display of power, RTD or RFD values to inform the clinicians or the clients. A more uniform standard on raw data processing and calculation is expected to be reached so that a relatively standardized algorithm can be included in the testing devices (Table 1).

Limitations

There are several limitations for this systematic review and meta-analysis. Firstly, the keywords used in the primary systematic literature search did not specifically include the "injurious falls" or "fall injuries". Additional searches in databases and screening have been conducted to identify any missing eligible studies relevant to injurious falls. However, this approach was not planned and systematic, which may still have resulted in some eligible studies being overlooked. Secondly, only the articles written in English were included in this systematic review due to the review authors' language capabilities. Some studies written in other languages were not considered [59–62], which may introduce potential language bias. Thirdly, this review only focused on the population of community-dwelling older adults without a specific disease. The current results may not be generalized to the other older populations, such as older people who live in nursing homes or have multiple comorbidities. Finally, the associations between lower-limb power, RTD, or RFD parameters and falls are unavoidably affected by some confounding factors. The causes of falls are multifactorial. Some factors such as the environmental factors have hardly been adjusted in the regression models. This may also partly explain why the power parameters have shown small effect sizes in detecting risk of prospective falls. Therefore, the quantitative measurement of lower-limb power alone cannot provide a full picture to identify the fall risks in older adults.

Conclusion

This systematic review and meta-analysis found that the decline of entire lower-limb power appears a good indicator of prospective falls in community-dwelling older adults. Specifically, moderate quality of evidence indicated that the average leg-press power and peak sit-to-stand power had small effect sizes to predict older adults' prospective falls, especially injurious/recurrent falls (moderate quality of evidence). The peak sit-to-stand power could also identify the older adults' fall history (low quality of evidence). By contrast, the RTD of a single muscle group could occasionally identify the older adults' fall history (very low quality of evidence) and could not predict the prospective falls (low quality of evidence). These suggest the need of incorporating the lower-limb power measurement into the routine physical function assessment to identify the older adults with high fall risks early. Further investigations into the diagnostic accuracy of the lower-limb power parameters in predicting prospective falls are needed to facilitate clinical practice. Future longitudinal studies may also consider examining how the rapid force generation of a specific muscle group relates to injurious falls, which could potentially inform the more targeted training for fall prevention and injury reduction in older people.

Appendix A1

Keywords used in the primary search.

Web of Science	252	((((ALL = (elder* OR "old*" OR "senior*")) AND ALL = (explosive force* OR "explosive strength" OR "explosive torque" OR "power" OR "rapid force*" OR "rapid moment*" OR "rapid strength" OR "rapid torque" OR "rate of development" OR "rate of change" OR "rate of force*" OR "rate of generation" OR "rate of production" OR "rate of strength" OR "rate of moment" OR "rate of torque*" OR "slope of force*" OR "slope of torque*")) AND ALL = (faller* OR "risk of fall*" OR "fall* risk*" OR "nonfaller*" OR "history of fall*" OR "fall* status" OR "fall* group*" OR "number of fall*" OR "fall* number" OR "frequency of fall*" OR "fall* frequency" OR "fall* history" OR "fall* injur*" OR "injur* fall*")) AND ALL = (differen* OR "identif*" OR "predict*" OR "diagno*" OR "classif*" OR "distin*" OR "discriminat*" OR "compar*" OR "discern*")) AND ALL = (ankle OR "knee" OR "hip" OR "lower limb*" OR "lower body" OR "lower extremit*" OR "foot" OR "leg*")
PubMed	252	(((("elder*" OR "old" OR "senior*" OR "older*") AND ("explosive force*" OR "explosive strength" OR "explosive torque" OR "power" OR "rapid force*" OR "rapid moment*" OR "rapid strength" OR "rapid torque" OR "rate of development" OR "rate of change" OR "rate of force*" OR "rate of generation" OR "rate of production" OR "rate of strength" OR "rate of moment" OR "rate of torque*" OR "slope of force*" OR "slope of torque*")) AND ("faller*" OR "risk of fall*" OR "fall* risk*" OR "nonfaller*" OR "history of fall*" OR "fall* status" OR "fall* group*" OR "number of fall*" OR "fall* number" OR "frequency of fall*" OR "fall* frequency" OR "fall* history")) AND ("differen*" OR "identif*" OR "predict*" OR "diagno*" OR "classif*" OR "distin*" OR "discriminat*" OR "compar*" OR "discern*")) AND ("ankle" OR "knee" OR "hip" OR "lower limb*" OR "lower body" OR "lower extremit*" OR "foot" OR leg*)

Embase	237	(((("elder*" OR "old" OR "senior*" OR "older*") AND ("explosive force*" OR "explosive strength" OR "explosive torque" OR "power" OR "rapid force*" OR "rapid moment*" OR "rapid strength" OR "rapid torque" OR "rate of development" OR "rate of change" OR "rate of force*" OR "rate of generation" OR "rate of production" OR "rate of strength" OR "rate of moment" OR "rate of torque*" OR "slope of force*" OR "slope of torque*")) AND ("faller*" OR "risk of fall*" OR "fall* risk*" OR "nonfaller*" OR "history of fall*" OR "fall* status" OR "fall* group*" OR "number of fall*" OR "fall* number" OR "frequency of fall*" OR "fall* frequency" OR "fall* history")) AND ("differen*" OR "identif*" OR "predict*" OR "diagno*" OR "classif*" OR "distin*" OR "discriminat*" OR "compar*" OR "discern*")) AND ("ankle" OR "knee" OR "hip" OR "lower limb*" OR "lower body" OR "lower extremit*" OR "foot" OR "leg*")
CINAHL	190	TX ("elder*" OR "old*" OR "senior*") AND AB ("explosive force*" OR "explosive strength" OR "explosive torque" OR "power" OR "rapid force*" OR "rapid moment*" OR "rapid strength" OR "rapid torque" OR "rate of development" OR "rate of change" OR "rate of force*" OR "rate of generation" OR "rate of production" OR "rate of strength" OR "rate of moment" OR "rate of torque*" OR "slope of force*" OR "slope of torque*") AND TX ("faller*" OR "risk of fall*" OR "fall* risk*" OR "nonfaller*" OR "history of fall*" OR "fall* status" OR "fall* group*" OR "number of fall*" OR "fall* number" OR "frequency of fall*" OR "fall* frequency" OR "fall* history") AND TX (differen* OR "identif*" OR "predict*" OR "diagno*" OR "classif*" OR "distin*" OR "discriminat*" OR "compar*" OR "discern*") AND TX ("ankle" OR "knee" OR "hip" OR "lower limb*" OR "lower body" OR "lower extremit*" OR "foot" OR "leg*")
Scopus	395	(TITLE-ABS-KEY("elder*" OR "old*" OR "senior*") AND TITLE-ABS-KEY("explosive force*" OR "explosive strength" OR "explosive torque" OR "power" OR "rapid force*" OR "rapid moment*" OR "rapid strength" OR "rapid torque" OR "rate of development" OR "rate of change" OR "rate of force*" OR "rate of generation" OR "rate of production" OR "rate of strength" OR "rate of moment" OR "rate of torque*" OR "slope of force*" OR "slope of torque*") AND TITLE-ABS-KEY("faller*" OR "risk of fall*" OR "fall* risk*" OR "nonfaller*" OR "history of fall*" OR "fall* status" OR "fall* group*" OR "number of fall*" OR "fall* number" OR "frequency of fall*" OR "fall* frequency" OR "fall* history") AND ALL("differen*" OR "identif*" OR "predict*" OR "diagno*" OR "classif*" OR "distin*" OR "discriminat*" OR "compar*" OR "discern*") AND ALL("ankle" OR "knee" OR "hip" OR "lower limb*" OR "lower body" OR "lower extremit*" OR "foot" OR "leg*"))
Cochrane central	68	("elder*" OR "old*" OR "senior*") AND ("explosive force*" OR "explosive strength" OR "explosive torque" OR "power" OR "rapid force*" OR "rapid moment*" OR "rapid strength" OR "rapid torque" OR "rate of development" OR "rate of change" OR "rate of force*" OR "rate of generation" OR "rate of production" OR "rate of strength" OR "rate of moment" OR "rate of torque*" OR "slope of force*" OR "slope of torque*") AND ("faller*" OR "risk of fall*" OR "fall* risk*" OR "nonfaller*" OR "history of fall*" OR "fall* status" OR "fall* group*" OR "number of fall*" OR "fall* number" OR "frequency of fall*" OR "fall* frequency" OR "fall* history") AND (differen* OR "identif*" OR "predict*" OR "diagno*" OR "classif*" OR "distin*" OR "discriminat*" OR "compar*" OR "discern*") AND ("ankle" OR "knee" OR "hip" OR "lower limb*" OR "lower body" OR "lower extremit*" OR "foot" OR "leg*")

Appendix A2

Keywords used in the final search to additionally identify the injurious falls or fall injuries.

Web of Science	18	((((ALL = (elder* OR "old*" OR "senior*")) AND ALL = (explosive force* OR "explosive strength" OR "explosive torque" OR "power" OR "rapid force*" OR "rapid moment*" OR "rapid strength" OR "rapid torque" OR "rate of development" OR "rate of change" OR "rate of force*" OR "rate of generation" OR "rate of production" OR "rate of strength" OR "rate of moment" OR "rate of torque*" OR "slope of force*" OR "slope of torque*")) AND ALL = ("fall* injur*" OR "injur* fall*")) AND ALL = (differen* OR "identif*" OR "predict*" OR "diagno*" OR "classif*" OR "distin*" OR "discriminat*" OR "compar*" OR "discern*")) AND ALL = (ankle OR "knee" OR "hip" OR "lower limb*" OR "lower body" OR "lower extremit*" OR "foot" OR "leg*")
PubMed	19	(((("elder*" OR "old" OR "senior*" OR "older*") AND ("explosive force*" OR "explosive strength" OR "explosive torque" OR "power" OR "rapid force*" OR "rapid moment*" OR "rapid strength" OR "rapid torque" OR "rate of development" OR "rate of change" OR "rate of force*" OR "rate of generation" OR "rate of production" OR "rate of strength" OR "rate of moment" OR "rate of torque*" OR "slope of force*" OR "slope of torque*")) AND ("fall* injur*" OR "injur* fall*")) AND ("differen*" OR "identif*" OR "predict*" OR "diagno*" OR "classif*" OR "distin*" OR "discriminat*" OR "compar*" OR "discern*")) AND ("ankle" OR "knee" OR "hip" OR "lower limb*" OR "lower body" OR "lower extremit*" OR "foot" OR leg*)
Embase	11	(((("elder*" OR "old" OR "senior*" OR "older*") AND ("explosive force*" OR "explosive strength" OR "explosive torque" OR "power" OR "rapid force*" OR "rapid moment*" OR "rapid strength" OR "rapid torque" OR "rate of development" OR "rate of change" OR "rate of force*" OR "rate of generation" OR "rate of production" OR "rate of strength" OR "rate of moment" OR "rate of torque*" OR "slope of force*" OR "slope of torque*")) AND ("fall* injur*" OR "injur* fall*")) AND ("differen*" OR "identif*" OR "predict*" OR "diagno*" OR "classif*" OR "distin*" OR "discriminat*" OR "compar*" OR "discern*")) AND ("ankle" OR "knee" OR "hip" OR "lower limb*" OR "lower body" OR "lower extremit*" OR "foot" OR "leg*")
CINAHL	20	TX ("elder*" OR "old*" OR "senior*") AND AB ("explosive force*" OR "explosive strength" OR "explosive torque" OR "power" OR "rapid force*" OR "rapid moment*" OR "rapid strength" OR "rapid torque" OR "rate of development" OR "rate of change" OR "rate of force*" OR "rate of generation" OR "rate of production" OR "rate of strength" OR "rate of moment" OR "rate of torque*" OR "slope of force*" OR "slope of torque*") AND TX ("fall* injur*" OR "injur* fall*") AND TX (differen* OR "identif*" OR "predict*" OR "diagno*" OR "classif*" OR "distin*" OR "discriminat*" OR "compar*" OR "discern*") AND TX ("ankle" OR "knee" OR "hip" OR "lower limb*" OR "lower body" OR "lower extremit*" OR "foot" OR "leg*")
Scopus	15	(TITLE-ABS-KEY("elder*" OR "old*" OR "senior*") AND TITLE-ABS-KEY("explosive force*" OR "explosive strength" OR "explosive torque" OR "power" OR "rapid force*" OR "rapid moment*" OR "rapid strength" OR "rapid torque" OR "rate of development" OR "rate of change" OR "rate of force*" OR "rate of generation" OR "rate of production" OR "rate of strength" OR "rate of moment" OR "rate of torque*" OR "slope of force*" OR "slope of torque*") AND TITLE-ABS-KEY("fall* injur*" OR "injur* fall*") AND ALL("differen*" OR "identif*" OR "predict*" OR "diagno*" OR "classif*" OR "distin*" OR "discriminat*" OR "compar*" OR "discern*") AND ALL("ankle" OR "knee" OR "hip" OR "lower limb*" OR "lower body" OR "lower extremit*" OR "foot" OR "leg*"))
Cochrane central	0	("elder*" OR "old*" OR "senior*") AND ("explosive force*" OR "explosive strength" OR "explosive torque" OR "power" OR "rapid force*" OR "rapid moment*" OR "rapid strength" OR "rapid torque" OR "rate of development" OR "rate of change" OR "rate of force*" OR "rate of generation" OR "rate of production" OR "rate of strength" OR "rate of moment" OR "rate of torque*" OR "slope of force*" OR "slope of torque*") AND ("fall* injur*" OR "injur* fall*") AND (differen* OR "identif*" OR "predict*" OR "diagno*" OR "classif*" OR "distin*" OR "discriminat*" OR "compar*" OR "discern*") AND ("ankle" OR "knee" OR "hip" OR "lower limb*" OR "lower body" OR "lower extremit*" OR "foot" OR "leg*")

Appendix B

Results of NIH quality assessment tool for observational cohort and cross-sectional studies ($N = 20$).

First author	Published year	1 Research question or objective clearly stated?	2 Study population clearly specified and defined?	3 Participation rate of eligible persons ≥ 50%?	4 Subjects selected or recruited from the same or similar population?	5 Sample size justification, power description or variance and effect estimates provided?	6 Exposure(s) of interest measured prior to outcome(s)?	7 Time frame sufficient for outcome to be shown if present?
Atrsaei	**2021**	Yes	Yes	Yes	Yes	NR	Yes	Yes
Bento	**2010**	Yes	Yes	NR	Yes	No	No	No
Chan	**2007**	Yes	Yes	Yes	Yes	NR	Yes	Yes
Cheng	**2014**	Yes	No	NR	Yes	No	No	No
Crozara	**2013**	Yes	Yes	NR	Yes	No	No	No
Crozara	**2016**	Yes	Yes	NR	Yes	Yes	No	No
Dietzel	**2015**	Yes	Yes	NR	Yes	No	No	No
Ejupi	**2017**	Yes	Yes	NR	Yes	No	No	No
Hsieh	**2023**	Yes	Yes	NR	Yes	NR	Yes	Yes
Kamo	**2019**	Yes	Yes	Yes	Yes	NR	No	No
Kemoun	**2002**	Yes	Yes	NR	Yes	No	Yes	Yes
Kera	**2020**	Yes	Yes	No	Yes	No	Yes	Yes
LaRoche	**2010**	Yes	No	NR	No	No	No	No
Palmer	**2015**	Yes	Yes	NR	Yes	Yes	No	No
Parsons	**2020**	Yes	Yes	Yes	Yes	No	Yes	Yes
Perry	**2007**	Yes	Yes	NR	No	No	No	No
Porto	**2022**	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ribeiro	**2012**	Yes	Yes	NR	Yes	No	No	No
Skelton	**2002**	Yes	Yes	NR	No	No	No	No
Winger	**2023**	Yes	Yes	Yes	Yes	NR	Yes	Yes

First author	8	9	10	11	12	13	14	
	Different levels of exposure examined in relation to outcome?	Exposure measures clearly defined, valid, reliable and implemented consistently?	Exposure(s) measured more than once over time?	Outcome measures clearly defined, valid, reliable and implemented consistently?	Outcome assessors blinded to exposure status of participants?	Loss of follow up after baseline ≤ 20%?	Key potential confounding variable measured and adjusted for?	Overall score
Atrsaei	Yes	Yes	No	Yes	NR	NR	Yes	**10**
Bento	Yes	Yes	NA	Yes	NR	NA	Yes	**7**
Chan	Yes	Yes	No	Yes	NR	Yes	Yes	**11**
Cheng	Yes	Yes	NA	Yes	NR	NA	Yes	**6**
Crozara	No	Yes	NA	Yes	NR	NA	Yes	**6**
Crozara	Yes	Yes	NA	Yes	NR	NA	No	**7**
Dietzel	Yes	Yes	NA	Yes	NR	NA	Yes	**7**
Ejupi	No	Yes	NA	Yes	NR	NA	NA	**5**
Hsieh	Yes	Yes	No	Yes	NR	Yes	Yes	**10**
Kamo	Yes	Yes	NA	Yes	NR	NA	Yes	**8**
Kemoun	No	Yes	No	Yes	Yes	Yes	No	**9**
Kera	Yes	Yes	No	Yes	NR	NR	Yes	**9**
LaRoche	No	Yes	NA	Yes	NR	NA	NA	**3**
Palmer	No	Yes	NA	Yes	NR	NA	NA	**6**
Parsons	Yes	Yes	No	Yes	NR	No	Yes	**10**
Perry	No	Yes	NA	Yes	NR	NA	No	**4**
Porto	Yes	Yes	No	Yes	NR	Yes	Yes	**12**
Ribeiro	Yes	Yes	NA	Yes	NR	NA	NA	**6**
Skelton	No	Yes	NA	Yes	NR	NA	No	**4**
Winger	Yes	Yes	No	Yes	NR	Yes	Yes	**11**

NR Not reported *NA* Not applicable

Appendix C1

Additional demographic information of the included studies ($N = 20$).

First author (Year)	Group	Age requirement (year)	Exclusion criteria	Definition of falling	Residence information	Mass (kg, mean ± SD)	Height (cm, mean ± SD)	BMI (kg/m^2, mean ± SD)
Atrsaei (2022)	NF	≥ 65	1) cognitive impairment (MMSE < 24 or unable to recall 3/3 words from delayed recall domain of MMSE) 2) unable to perform the 5xSTS test without using their hands or unable to complete the 5xSTS test	not specified	community	74.2 ± 14.5	165.5 ± 8.8	27.0 ± 4.3
	F					72.4 ± 14.3	163.8 ± 8.2	27.0 ± 4.8
Bento (2010)	NF	≥ 60	1) joining any physical activity program in past half year 2) orthopedic or balance problems affecting gait	1) unintentionally coming to rest on the ground, floor, or other lower level 2) with or without an injury	community	73.5 ± 16.1	157.9 ± 12.0	29.1 ± 3.9
	NF					73.3 ± 4.4	157.5 ± 4.1	29.5 ± 3.0
	RF					75.8 ± 12.0	157.1 ± 7.4	30.6 ± 2.1
Chan (2007)	NF	≥ 65	1) unable to walk without assistance of another person 2) with bilateral hip replacement 3) unable to participate or survive the duration of study	not specified	community	83.2 ± 13.3	174.1 ± 6.8	27.4 ± 3.9
	F							
Cheng (2014)	NF	≥ 65	1) dizziness or vertigo 2) degenerative neurological diseases, stroke 3) lower limb fractures 4) cardiopulmonary distress 5) any sensory, visual, auditory, or cognitive impairment hindering testing procedures	1) unintentional coming to a lower level 2) not caused by any external force or influence	healthy	60.8 ± 13.0	not reported	not reported
	F					60.6 ± 12.9		
Crozara (2013)	NF	≥ 60	1) uncontrolled cardiovascular disease 2) dementia or cognitive impairment (MMSE < 20) 3) balance disturbance (BERG balance score < 36), hemiparesis, pain in the lower limbs or trunk, or a progressive motor disorder	any balance perturbation that caused the person's body to have significant contact with the floor	community	65.0 ± 12.9	155.0 ± 6.0	27.1 ± 4.8
	F					65.9 ± 10.0	152.0 ± 5.0	28.5 ± 4.0

First author (Year)	Group	Age requirement (year)	Exclusion criteria	Definition of falling	Residence information	Mass (kg, mean ± SD)	Height (cm, mean ± SD)	BMI (kg/m^2, mean ± SD)
Crozara (2016)	NF	≥ 60	1) MMSE score lower than that expected for their education level 2) orthopedic, vestibular, cardiovascular or respiratory problems 3) pain, fracture, or significant soft tissue injuries in the previous six months	1) coming to rest inadvertently on the ground, floor, or other lower level 2) with or without injury	community; living independently	65.0 ± 13.0	155.0 ± 6.0	not reported
	F					66.0 ± 10.0	152.0 ± 5.0	not reported
Dietzel (2015)	NF	≥ 60	1) metal implants or artificial prostheses 2) edema or medications affecting water mineral homeostasis 3) unable to walk without a walking aid 4) unable to understand the study or follow instructions	1) coming to rest on the ground, floor, or lower level 2) not syncopal falls and high-trauma falls (e.g., due to an external force like a car accident)	community	Male 82.8 ± 12.5; Female 66.8 ± 9.4	Male 172.4 ± 6.4; Female 160.5 ± 6.3	Male 27.8 ± 3.7; Female 25.9 ± 3.5
	F					Male 78.9 ± 15.0; Female 70.8 ± 11.3	Male 172.3 ± 6.4; Female 160.9 ± 5.2	Male 26.4 ± 3.9; Female 27.4 ± 4.4
Ejupi (2017)	NF	≥ 65	unable to walk with or without the use of a walking aid	unintentionally coming to rest on the ground, floor, or lower level	community	70.2 ± 12.7	162.3 ± 8.9	26.6 ± 4.1
	F							
Hsieh (2023)	NF	65—90	1) SPPB score > 10 2) dependent on a walker 3) serious or uncontrolled chronic disease 4) Montreal Cognitive Assessment score < 18 5) Taking prescription vitamin D 6) knee or hip surgery in the last 6 months 7)body mass index over 40 kg/m^2	unintentionally coming to rest on the ground, floor, or lower level	community	not reported	not reported	30.4 ± 4.7
	F							30.1 ± 4.3
Kamo (2019)	NF	≥ 65	1) unable to walk independently 2) certificated as frailty status 3) severe cognitive impairment 4) severe cardiac, pulmonary, or musculoskeletal disorders 5) Parkinson's disease or stroke	not specified	community	57.0 ± 9.3	158.6 ± 9.0	22.6 ± 2.7
	SF					57.3 ± 10.0	159.1 ± 8.7	22.5 ± 2.7
	RF					63.6 ± 13.9	159.9 ± 7.8	24.7 ± 4.2

First author (Year)	Group	Age requirement (year)	Exclusion criteria	Definition of falling	Residence information	Mass (kg, mean ± SD)	Height (cm, mean ± SD)	BMI (kg/m^2, mean ± SD)
Kemoun (2002)	NF	≥ 60	1) falling in the past year 2) neurological, locomotor or cardiovascular pathologies 3) taking medication known to increase falls	1) unintentionally coming to rest on the ground from an upper level or on the same level 2) including falls on stairs and onto furniture	community; living independently	not reported	not reported	not reported
	F							
Kera (2020)	NF	≥ 65	nursing-home occupants or participants	not specified	community	not reported	not reported	22.8 ± 3.4
	F							23.4 ± 2.1
LaRoche (2010)	NF	≥ 65	1) severe arthritis, osteoporosis 2) uncontrolled blood pressure over 160/90 mmHg 3) neurological disorders, knee, or hip replacement in the dominant leg 4) severe heart disease or dysrhythmia	not specified	living independently	65.1 ± 12.4	160.5 ± 6.7	25.2 ± 4.1
	F					73.7 ± 17.6	163.1 ± 6.2	27.6 ± 5.7
Palmer (2015)	NF	≥ 60	neuromuscular diseases or musculoskeletal injuries specific to the ankle, knee, or hip joints	any balance perturbation that caused the person's body to have significant contact with the floor	community	66.3 ± 16.3	157.4 ± 6.1	not reported
	F					68.0 ± 16.0	159.7 ± 5.3	
Parsons (2020)	NF	≥ 70	Not specified	not specified	community	76.5 ± 11.7	167.1 ± 8.9	not reported
	F							
Porto (2022)	NF	≥ 60	1) history of falls in the previous year 2) musculoskeletal or neurological conditions 3) dizziness complaints, visual complaints impairing daily activities, or deficit in the protective sensitivity of the feet 4) cardiovascular or metabolic conditions contraindicating physical activity 5) low score on the 10-point Cognitive Screener according to educational level (< 8 points)	unintentionally coming to rest on a lower level	community; living independently	70.5 ± 16.1	158.0 ± 8.0	27.8 ± 4.5
	F					70.1 ± 11.5	155.0 ± 7.0	28.9 ± 4.1

First author (Year)	Group	Age requirement (year)	Exclusion criteria	Definition of falling	Residence information	Mass (kg, mean ± SD)	Height (cm, mean ± SD)	BMI (kg/m^2, mean ± SD)
Perry (2007)	NF	≥ 70	1) any cardiovascular disorders likely to be exacerbated by maximal muscle contractions 2) neurological disorders, musculoskeletal pathology in the lower limbs or spine affecting test procedures 3) dementia	not specified	community; living independently	70.4 ± 1.6	168.0 ± 1.0	not reported
	F					70.7 ± 2.0	164.0 ± 1.0	
Ribeiro (2012)	NF	≥ 60	1) unable to perform the sit-to-stand test 2) cardiovascular, neurologic, or vestibular disease, peripheral neuropathies 3) use of medication for central nervous system 4) MMSE < 23	1) unintentionally coming to rest on the ground, the floor, or other lower level 2) not coming to rest against furniture or a wall	community; living independently	62.7 ± 11.3	153.1 ± 8.1	26.9 ± 5.6
	F					69.7 ± 7.7	154.5 ± 5.6	29.3 ± 4.2
Skelton (2002)	NF	≥ 65	1) acute rheumatoid arthritis; diagnosed osteoporosis 2) uncontrolled heart failure or hypertension; 3) marked cognitive impairment; 4) multiple sclerosis, Parkinson s disease	inadvertently coming to rest on a lower object	community	64.5 ± 9.7	158.0 ± 3.0	25.9 ± 3.6
	F					66.5 ± 10.1	155.0 ± 6.0	27.5 ± 3.1
Winger (2023)	NF	≥ 65	1) unable to walk without assistance of another person 2) with bilateral hip replacement 3) unable to participate or survive the duration of study	landing on the floor or ground, or falling and hitting an object	community	83.5 ± 13.2	174.3 ± 6.7	27.3 ± 3.7
	F					83.0 ± 12.9	174.3 ± 6.9	27.4 ± 3.8

F Fallers, *NF* Non-fallers, *SF* Single fallers, *RF* Recurrent fallers, *MMSE* Mini-mental state examination score, 5xSTS five-time sit-to-stand test

Appendix C2

Additional information on the testing tasks and equipment ($N=20$).

First author (Year)	Warm-up or familiarization trials	Testing task and position	Testing leg	Instruction	Sampling rate of equipment
Atrsaei (2021)	Not specified	Five-time sit-to-stand test: an IMU was attached to the sternum	Two-leg	Perform the five-time sit-to-stand test as fast as possible	200 Hz
Bento (2010)	Yes, three to five familiarization trials	1) Isometric hip, knee, and ankle flexion/extension: in a recumbent posture with the joints positioned at approximately 90°. The proximal segments were firmly secured and stabilized by a Velcro strap 2) Isometric hip abduction/adduction: in a standing posture and the experimenters ensured no use of additional movements to improve performance	Dominant leg	As fast and hard as possible and maintain for 2–3 s	1000 Hz
Chan (2007)	Not specified	Leg press: push the pedal	Each of two legs	As hard and as fast as possible through a full range of motion	Not specified
Cheng (2014)	Not specified	Sit-to-stand test: seat heights were adjusted so that hip and knee joints were at 90° and the ankle was at 0° of dorsiflexion	Two-leg	Not specified	100 Hz
Crozara (2013)	Yes, a 5-min walk on a treadmill to warm up & familiarization trials	1) Isokinetic knee flexion/extension at the velocity of 90°/s and 120°/s: seated with hip flexed at 90° and knee flexed at 30°. The dynamometer was aligned to the line traversing the femoral epicondyles, and the resistance pad was placed on the tibia (slightly proximal to the superior border of the medial malleolus). The subject's thigh, trunk, and pelvis were stabilized with straps, and subjects crossed their arms in front of their chests throughout the test 2) Isokinetic ankle dorsiflexion/plantarflexion at the velocity of 90°/s and 120°/s: seated with their hip flexed at 70°, knee flexed at 45°, and ankle in neutral inversion/eversion. The dynamometer was aligned to approximate the axis of rotation of the ankle joint passing obliquely through the distal tip of the tibia and fibula, and the foot was strapped securely to a foot plate. Proximal thigh and trunk stabilization (using belts) was provided to prevent extraneous movement	Dominant leg	As fast and hard as possible and maintain for 5 s	2000 Hz

First author (Year)	Warm-up or familiarization trials	Testing task and position	Testing leg	Instruction	Sampling rate of equipment
Crozara (2016)	Yes, a 5-min walk on a treadmill to warm up & familiarization trials	The participants trunk and lower limbs were stabilized using adjustable belts 1) Isometric knee flexion/extension: the hip was positioned at 90° of flexion and the lateral epicondyle was aligned with the dynamometer's axis of rotation. The participants had to move the knee from 90° to 30° and from 30° to 90° 2) Isometric ankle dorsiflexion/plantarflexion: the hip was positioned at 70° of flexion, the knee was positioned at 45° of flexion, and the tip of the lateral malleolus was aligned with the dynamometer's axis of rotation. Move the ankle from 40° of plantarflexion to 10° of dorsiflexion and vice-versa	Dominant leg	As fast and hard as possible	2000 Hz
Dietzel (2015)	Not specified	1) Jumping 2) Sit-to-stand test: stand up from a bench of 45 cm height to full extend, and sit down five times without break and without using the arms	Two-leg	1) Jump as high as possible 2) Stand up at maximum speed	800 Hz
Ejupi (2017)	Not specified	Sit-to-stand test: Wear the pendant device at the height of their chest and under their clothes. Stand up from a chair (height: 45 cm), walk 10 m, and sit down on a second chair at the normal comfortable speed	Two-leg	Stand up at comfortable speed	50 Hz
Hsieh (2023)	Not specified	Leg press: participants sat in a chair and pressed a foot lever attached to a flywheel	Each of two legs	As fast and hard as possible	Not specified
Kamo (2019)	Yes, a familiarization trial	Isometric knee extension: seated on a chair without arm and back support and the hips and knees flexed to 90°. Participants were allowed to lean backward, but not to rise from the seat	Dominant leg	Push with maximal effort	1000 Hz
Kemoun (2002)	Not specified	Walking test: barefoot	One leg	Walk at comfortable speed	50 Hz
Laroche (2010)	Yes, familiarization trials	1) Isometric knee flexion/extension: in a seated position with a hip of 90° and knee of 75° (full knee extension equal to 0°) 2) Isometric ankle dorsiflexion/plantarflexion: in a prone position 90° at the ankle. The participants' torso and active leg were restrained using nylon straps to prevent changes in joint angle that would influence the length of the tested muscle and subsequently joint torque. This restraint also served to limit the biarticular muscles to the desired joint action	Dominant leg	As quickly as possible and maintain for 2 s	1000 Hz
Parsons (2020)	Not specified	Jumping: Bend the knees, swing arms, and jump once	Two-leg	Jump as high as possible	800 Hz

First author (Year)	Warm-up or familiarization trials	Testing task and position	Testing leg	Instruction	Sampling rate of equipment
Porto (2022)	Yes, 5 min of warm-up on a bicycle	Isometric hip adduction/abduction: in the lateral decubitus position, with the limb to be tested upward at 15° of hip abduction. The trunk and contralateral lower limb were secured with straps. The mechanical axis of the dynamometer was aligned with the point corresponding to the intersection of a line drawn from the posterior superior iliac spine in a longitudinal direction and another drawn from the greater trochanter of the femur in a transverse direction. The lever of the dynamometer was positioned 5 cm above the upper edge of the patella. To avoid muscle compensation during the test, participants were requested to keep the toes of the feet forward and not flex the knee of the limb being tested Isometric hip flexion/extension: in the supine position, with the pelvis and contralateral lower limb secured with straps. The mechanical axis of the dynamometer was positioned on the hip joint axis (region of the greater trochanter of the femur) and the lever of the dynamometer was positioned 5 cm above the upper edge of the patella. The dominant limb to be tested was positioned at 60° of hip flexion Isometric knee flexion/extension: seated with hip flexion of 90° and the trunk, pelvis and contralateral lower limb secured by straps. The mechanical axis of the dynamometer was aligned with the lateral epicondyle of the femur and the lever of the dynamometer was positioned above the upper edge of the lateral malleolus. The limb to be tested was positioned at 60° of knee flexion Isometric ankle dorsiflexion/plantarflexion: seated with the hip of the limb to be tested flexed at 70° and the knee at 45°. The pelvis and contralateral lower limb were secured with straps. The mechanical axis of the dynamometer was aligned with the inner edge of the lateral malleolus and the ankle was positioned in neutral for plantarflexion and dorsiflexion	Dominant leg	As quickly as possible (with constant verbal encouragement) and maintain for 5 s	2000 Hz
Ribeiro (2012)	Yes, 8 to 12 repetitions with minimum load for familiarization	Concentric knee extension: in sitting position and hold the lateral handles of the extension machine for obtaining more comfort	Dominant leg	As quickly as possible with a load corresponding to 70% of 1 RM (repetition maximum)	Not specified

Appendix C3

Lower-limb power, RTD, or RFD values of older adults ($N=20$, mean ± SD).

First author (Year)	Group	Sample size	Single muscle group								Entire unilateral/bilateral lower limb(s)	Unit
			Hip				Knee		Ankle			
			Flex	Ext	Abd	Add	Flex	Ext	Plantar	Dorsi		
Atrsaei (2021)[a]	NF	350									sit-to-stand peak power: 189.7 (131.5, 279.1); minimum power: − 222.6 (− 320.4, 144.1); average power: 2.63 (− 0.08, 5.35); normalized peak power: 6.68 (4.71, 9.26) stand-to-sit peak power: 148.2 (102.9, 216.2); minimum power: − 151.8 (− 211.9, − 106.3); average power: − 1.49 (− 3.90, 0.80); normalized peak power: 5.50 (3.67, 6.95)	W & unitless
	F	108									sit-to-stand peak power: 157.2 (108.9, 206.2); minimum power: − 180.6 (− 232.2, 126.0); average power: 2.09 (0.17, 5.29); normalized peak power: 5.44 (3.96, 7.78) stand-to-sit peak power: 125.2 (82.1, 178.8); minimum power: − 136.5 (− 177.3, − 92.8); average power: − 1.10 (− 3.54, 0.68); normalized peak power: 4.70 (3.08, 6.46)	
Bento (2010)	NF	13	0.76 ± 0.54	1.57 ± 0.97	1.04 ± 0.62	0.87 ± 0.54	0.43 ± 0.30	0.71 ± 0.47	0.23 ± 0.20	0.12 ± 0.11		Nm/s
	SF	8	0.72 ± 0.19	1.21 ± 0.75	0.82 ± 0.58	0.78 ± 0.26	0.25 ± 0.07	0.60 ± 0.19	0.23 ± 0.10	0.14 ± 0.03		
	RF	10	0.76 ± 0.58	1.49 ± 1.09	0.85 ± 0.62	0.72 ± 0.58	0.23 ± 0.12	0.49 ± 0.34	0.20 ± 0.18	0.09 ± 0.09		
Chan (2007)	NF	5995									average leg-press power (non-reported raw data)	W
	F										average leg-press power (non-reported raw data)	
Cheng (2014)	NF	35									5.50 ± 2.02	W/kg
	F	35									3.66 ± 1.45	

First author (Year)	Group	Sample size	Single muscle group								Entire unilateral/bilateral lower limb(s)	Unit
			Hip				Knee		Ankle			
			Flex	Ext	Abd	Add	Flex	Ext	Plantar	Dorsi		
Crozara (2013)	NF	22					1.24 ± 0.56	2.94 ± 1.02	1.30 ± 0.48	0.85 ± 0.37		Nm/(s·kg)
	F	21					0.92 ± 0.50	2.53 ± 1.20	1.17 ± 0.69	0.83 ± 0.36		
Crozara (2016)	NF	23					90°/s: 0.80 ± 0.17; 120°/s: 0.98 ± 0.18	90°/s: 0.80 ± 0.17; 120°/s: 0.98 ± 0.18	90°/s: 0.80 ± 0.17; 120°/s: 0.98 ± 0.18	90°/s: 0.80 ± 0.17; 120°/s: 0.98 ± 0.18		W/kg
	F	22					90°/s: 0.64 ± 0.21; 120°/s: 0.86 ± 0.24	90°/s: 0.64 ± 0.21; 120°/s: 0.86 ± 0.24	90°/s: 0.64 ± 0.21; 120°/s: 0.86 ± 0.24	90°/s: 0.64 ± 0.21; 120°/s: 0.86 ± 0.24		
Dietzel (2015)	NF	246									jumping: Male 30.5 ± 6.9; Female 25.7 ± 5.1 sit-to-stand: Male 10.8 ± 2.5; Female 9.2 ± 1.9	W/kg
	F	47									jumping: Male 29.9 ± 6.7; Female 22.6 ± 7.1 sit-to-stand: Male 11.1 ± 2.6; Female 8.2 ± 2.6	
Ejupi (2017)	NF	60									594.4 ± 292.9	W
	F	34									464.1 ± 225.3	
Hsieh (2023)	NF	63									1.45 ± 0.50	W/kg
	F	61									1.43 ± 0.46	
Kamo (2019)	NF	88						5.8 ± 2.7				Nm/(s·kg)
	SF	24						6.5 ± 3.6				
	RF	10						3.5 ± 2.0				
Kemoun (2002)[a]	NF	38	generation: 1.23 (0.89, 1.34)				absorption: 1.35 (1.25, 1.48)		generation: 3.12 (2.53, 3.65)			W/kg
	F	16	generation: 0.93 (0.69, 0.94)				absorption: 0.81 (0.70, 0.95)		generation: 2.53 (2.42, 2.82)			
Kera (2020)	NF	433									239.9 ± 84.4; normalized: 4.2 ± 1.2	kgf/s & kgf/(s · kg)
	F	23									228.6 ± 82.5; normalized: 3.8 ± 1.1	
LaRoche (2010)	NF	12					4.50 ± 2.67	6.90 ± 3.86	4.12 ± 1.89	1.93 ± 0.55		Nm/(s·kg)
	F	11					4.02 ± 2.17	6.97 ± 2.90	3.18 ± 1.14	1.57 ± 0.36		
Palmer (2015)	NF	9		0-50 ms: 80.86 ± 48.12; 0-50 ms normalized: 127.07 ± 33.25 100-200 ms: 34.28 ± 18.56; 100–200 ms normalized: 56.19 ± 23.42								Nm/s & %MVC/s

First author (Year)	Group	Sample size	Single muscle group								Entire unilateral/ bilateral lower limb(s)	Unit
			Hip				Knee		Ankle			
			Flex	Ext	Abd	Add	Flex	Ext	Plantar	Dorsi		
	F	6		0-50 ms: 37.43 ± 23.95; 0-50 ms normalized: 78.21 ± 27.21 100-200 ms: 28.73 ± 17.70; 100–200 ms normalized: 64.56 ± 31.72								
Parsons (2020)	NF	129									24.0 ± 5.8	W/kg
	F	40									21.4 ± 4.3	
Perry (2007)[b]	NF	44									150.7 ± 9.6	W
	F	34									120.3 ± 13.1	
Porto (2022)	NF	72	30-80 ms: 1.08 ± 0.90; 200-250 ms: 0.94 ± 0.64	30-80 ms: 1.30 ± 1.07; 200-250 ms: 0.80 ± 0.65	30-80 ms: 0.94 ± 0.60; 200-250 ms: 1.13 ± 0.69	30-80 ms: 0.90 ± 0.60; 200-250 ms: 0.66 ± 0.50	30-80 ms: 1.07 ± 0.75; 200-250 ms: 1.03 ± 0.60	30-80 ms: 2.15 ± 1.69; 200-250 ms: 1.87 ± 1.11	30-80 ms: 0.61 ± 0.45; 200-250 ms: 0.56 ± 0.26	30-80 ms: 0.84 ± 0.61; 200-250 ms: 0.72 ± 0.46		Nm/(s·kg)
	F	28	30-80 ms: 0.88 ± 0.98; 200-250 ms: 0.86 ± 0.50	30-80 ms: 0.98 ± 0.69; 200-250 ms: 0.65 ± 0.33	30-80 ms: 0.80 ± 0.50; 200-250 ms: 0.98 ± 0.66	30-80 ms: 0.75 ± 0.55; 200-250 ms: 0.88 ± 0.57	30-80 ms: 0.78 ± 0.49; 200-250 ms: 0.88 ± 0.57	30-80 ms: 1.84 ± 1.24; 200-250 ms: 1.66 ± 0.87	30-80 ms: 0.57 ± 0.44; 200-250 ms: 0.48 ± 0.32	30-80 ms: 0.65 ± 0.35; 200-250 ms: 0.59 ± 0.32		
Ribeiro (2012)	NF	15						129.41 ± 28.83				W
	F	11						134.43 ± 46.18				
Skelton (2002)	NF	15									average of two legs: 107.8 ± 38.5; normalized 1.70 ± 0.6 weakest leg: 104.2 ± 37.2; normalized 1.64 ± 0.6	W/kg
	F	20									average of two legs: 90.3 ± 36.3; normalized 1.35 ± 0.5 weakest leg: 83.1 ± 36.6; normalized 1.24 ± 0.5	
Winger (2023)	NF	3088									2.59 ± 0.70	W/kg
	F	2090									2.47 ± 0.68	

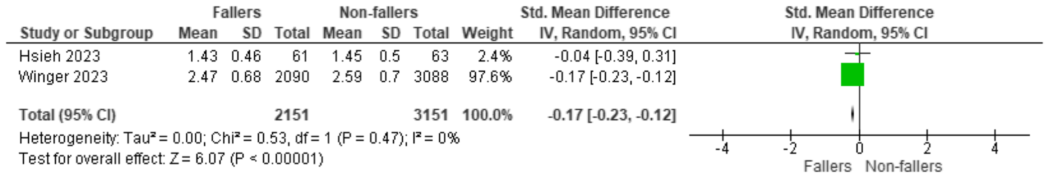
SD Standard deviation, *F* Fallers, *NF* Non-fallers, *SF* Single fallers, *RF* Recurrent fallers. *Flex.* Flexors, *Ext.* Extensors, *Abd.* Abductors, *Add.* Adductors, *Plantar.* Plantarflexors, *Dorsi.* Dorsiflexors. *MVIC* Maximal voluntary isometric contraction. *RTD* Rate of torque development. *RFD* Rate of ground reaction force development

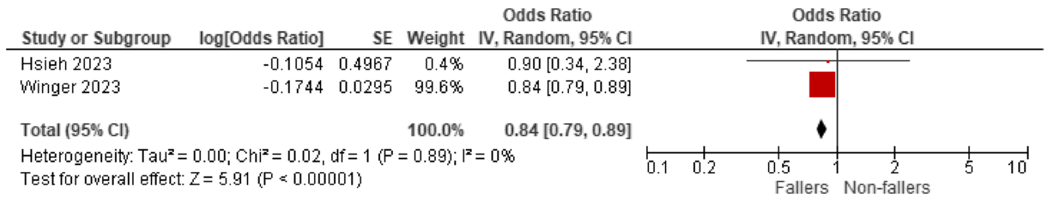
[a] Represents the strength value documented in median and interquartile range

[b] Represents the strength value documented in mean and standard error

Appendix D1

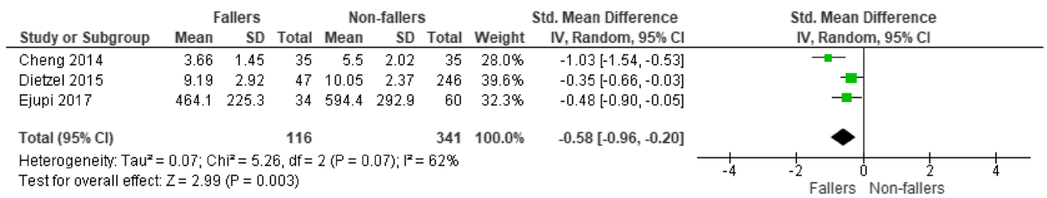
Average leg-press power in fallers vs non-fallers (prospective cohort studies).





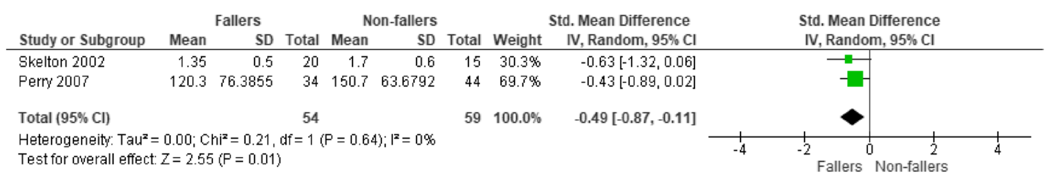
Appendix D2

Peak sit-to-stand power in fallers vs non-fallers (cross-sectional studies).



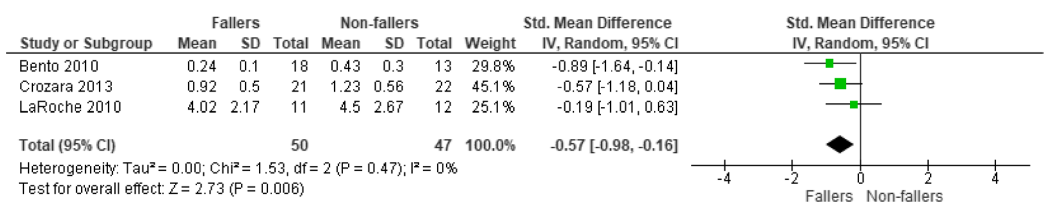
Appendix D3

Average leg-press power in fallers vs non-fallers (cross-sectional studies).



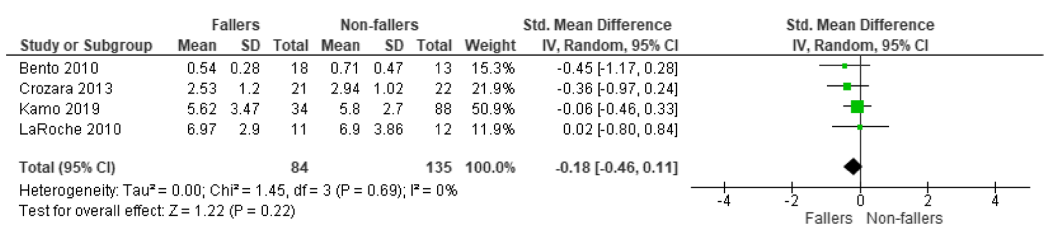
Appendix D4

RTD of knee flexors during the MVIC task in fallers vs non-fallers (cross-sectional studies).



Appendix D5

RTD of knee extensors during the MVIC task in fallers vs non-fallers (cross-sectional studies).

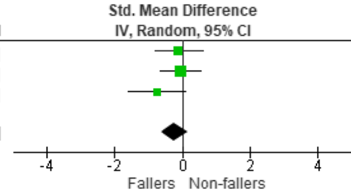


Appendix D6

RTD of ankle dorsiflexors during the MVIC task in fallers vs non-fallers (cross-sectional studies).

	Fallers			Non-fallers				Std. Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
Bento 2010	0.11	0.07	18	0.12	0.11	13	32.0%	-0.11 [-0.82, 0.60]
Crozara 2013	0.83	0.36	21	0.85	0.37	22	45.6%	-0.05 [-0.65, 0.54]
LaRoche 2010	1.57	0.36	11	1.93	0.55	12	22.5%	-0.74 [-1.59, 0.11]
Total (95% CI)			**50**			**47**	**100.0%**	**-0.23 [-0.63, 0.18]**

Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 1.82$, df = 2 (P = 0.40); $I^2 = 0\%$
Test for overall effect: Z = 1.10 (P = 0.27)

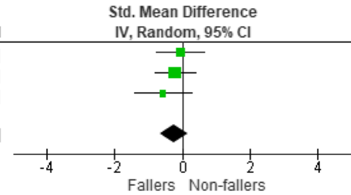


Appendix D7

RTD of ankle plantarflexors during the MVIC task in fallers vs non-fallers (cross-sectional studies).

	Fallers			Non-fallers				Std. Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
Bento 2010	0.22	0.14	18	0.23	0.2	13	31.9%	-0.06 [-0.77, 0.66]
Crozara 2013	1.17	0.69	21	1.3	0.48	22	45.1%	-0.22 [-0.82, 0.38]
LaRoche 2010	3.18	1.14	11	4.12	1.89	12	23.1%	-0.57 [-1.41, 0.26]
Total (95% CI)			**50**			**47**	**100.0%**	**-0.25 [-0.65, 0.15]**

Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 0.86$, df = 2 (P = 0.65); $I^2 = 0\%$
Test for overall effect: Z = 1.21 (P = 0.23)

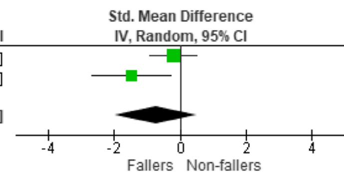


Appendix D8

RTD of hip extensors during the MVIC task in fallers vs non-fallers (cross-sectional studies).

	Fallers			Non-fallers				Std. Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
Bento 2010	1.37	0.94	18	1.57	0.97	13	57.5%	-0.20 [-0.92, 0.51]
Palmer 2015	78.21	27.21	6	127.07	33.25	9	42.5%	-1.48 [-2.68, -0.28]
Total (95% CI)			**24**			**22**	**100.0%**	**-0.75 [-1.98, 0.49]**

Heterogeneity: $Tau^2 = 0.56$; $Chi^2 = 3.19$, df = 1 (P = 0.07); $I^2 = 69\%$
Test for overall effect: Z = 1.18 (P = 0.24)

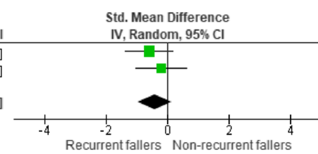


Appendix D9

RTD of knee flexors during the MVIC task in recurrent fallers vs non-recurrent fallers (cross-sectional studies).

	Recurrent fallers			Non-recurrent fallers				Std. Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
Bento 2010 (knee flex. isometric)	0.23	0.12	10	0.36	0.25	21	53.2%	-0.58 [-1.35, 0.19]
LaRoche 2010 (knee flex. isometric)	4.02	2.17	11	4.5	2.67	12	46.8%	-0.19 [-1.01, 0.63]
Total (95% CI)			**21**			**33**	**100.0%**	**-0.40 [-0.96, 0.16]**

Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 0.47$, df = 1 (P = 0.50); $I^2 = 0\%$
Test for overall effect: Z = 1.39 (P = 0.16)

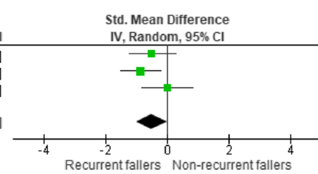


Appendix D10

RTD of knee extensors during the MVIC task in recurrent fallers vs non-recurrent fallers (cross-sectional studies).

	Recurrent fallers			Non-recurrent fallers				Std. Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
Bento 2010 (knee ext. isometric)	0.49	0.34	10	0.67	0.38	21	31.8%	-0.48 [-1.24, 0.29]
Kamo 2019	3.5	2	10	5.95	2.91	112	39.7%	-0.85 [-1.51, -0.20]
LaRoche 2010 (knee ext. isometric)	6.97	2.9	11	6.9	3.86	12	28.6%	0.02 [-0.80, 0.84]
Total (95% CI)			**31**			**145**	**100.0%**	**-0.48 [-0.98, 0.01]**

Heterogeneity: $Tau^2 = 0.05$; $Chi^2 = 2.67$, df = 2 (P = 0.26); $I^2 = 25\%$
Test for overall effect: Z = 1.92 (P = 0.05)

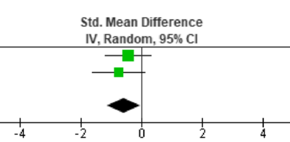


Appendix D11

RTD of ankle dorsiflexors during the MVIC task in recurrent fallers vs non-recurrent fallers (cross-sectional studies).

	Recurrent fallers			Non-recurrent fallers				Std. Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
Bento 2010 (ankle dorsi. isometric)	0.09	0.09	10	0.13	0.09	21	55.5%	-0.43 [-1.19, 0.33]
LaRoche 2010 (ankle dorsi. isometric)	1.57	0.36	11	1.93	0.55	12	44.5%	-0.74 [-1.59, 0.11]
Total (95% CI)			**21**			**33**	**100.0%**	**-0.57 [-1.14, -0.00]**

Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 0.28$, df = 1 (P = 0.60); $I^2 = 0\%$
Test for overall effect: Z = 1.97 (P = 0.05)

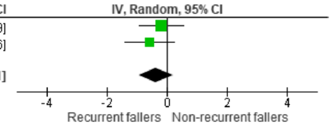


Appendix D12

RTD of ankle plantarflexors during the MVIC task in recurrent fallers vs non-recurrent fallers (cross-sectional studies).

	Recurrent fallers			Non-recurrent fallers				Std. Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
Bento 2010 (ankle plantar. isometric)	0.2	0.18	10	0.23	0.17	21	55.2%	-0.17 [-0.92, 0.59]
LaRoche 2010 (ankle plantar. isometric)	3.18	1.14	11	4.12	1.89	12	44.8%	-0.57 [-1.41, 0.26]
Total (95% CI)			**21**			**33**	**100.0%**	**-0.35 [-0.91, 0.21]**
Heterogeneity: Tau² = 0.00; Chi² = 0.50, df = 1 (P = 0.48); I² = 0%								
Test for overall effect: Z = 1.22 (P = 0.22)								

Std. Mean Difference IV, Random, 95% CI

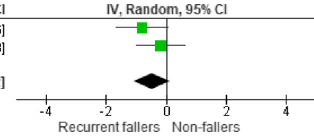


Appendix D13

RTD of knee flexors during the MVIC task in recurrent fallers vs non-fallers (cross-sectional studies).

	Recurrent fallers			Non-fallers				Std. Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
Bento 2010 (knee flex. isometric)	0.23	0.12	10	0.43	0.3	13	47.5%	-0.80 [-1.67, 0.06]
LaRoche 2010 (knee flex. isometric)	4.02	2.17	11	4.5	2.67	12	52.5%	-0.19 [-1.01, 0.63]
Total (95% CI)			**21**			**25**	**100.0%**	**-0.48 [-1.08, 0.12]**
Heterogeneity: Tau² = 0.00; Chi² = 1.02, df = 1 (P = 0.31); I² = 2%								
Test for overall effect: Z = 1.57 (P = 0.12)								

Std. Mean Difference IV, Random, 95% CI

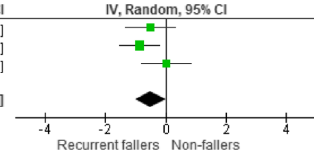


Appendix D14

RTD of knee extensors during the MVIC task in recurrent fallers vs non-fallers (cross-sectional studies).

	Recurrent fallers			Non-fallers				Std. Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
Bento 2010 (knee ext. isometric)	0.49	0.34	10	0.71	0.47	13	29.0%	-0.51 [-1.35, 0.33]
Kamo 2019	3.5	2	10	5.8	2.7	88	40.8%	-0.86 [-1.53, -0.20]
LaRoche 2010 (knee ext. isometric)	6.97	2.9	11	6.9	3.86	12	30.2%	0.02 [-0.80, 0.84]
Total (95% CI)			**31**			**113**	**100.0%**	**-0.49 [-1.01, 0.02]**
Heterogeneity: Tau² = 0.05; Chi² = 2.69, df = 2 (P = 0.26); I² = 26%								
Test for overall effect: Z = 1.88 (P = 0.06)								

Std. Mean Difference IV, Random, 95% CI

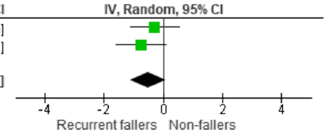


Appendix D15

RTD of ankle dorsiflexors during the MVIC task in recurrent fallers vs non-fallers (cross-sectional studies).

	Recurrent fallers			Non-fallers				Std. Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
Bento 2010 (ankle dorsi. isometric)	0.09	0.09	10	0.12	0.11	13	51.3%	-0.28 [-1.11, 0.55]
LaRoche 2010 (ankle dorsi. isometric)	1.57	0.36	11	1.93	0.55	12	48.7%	-0.74 [-1.59, 0.11]
Total (95% CI)			**21**			**25**	**100.0%**	**-0.51 [-1.10, 0.09]**
Heterogeneity: Tau² = 0.00; Chi² = 0.57, df = 1 (P = 0.45); I² = 0%								
Test for overall effect: Z = 1.67 (P = 0.10)								

Std. Mean Difference IV, Random, 95% CI

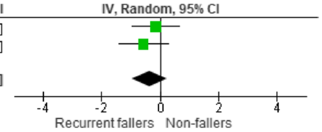


Appendix D16

RTD of ankle plantarflexors during the MVIC task in recurrent fallers vs non-fallers (cross-sectional studies).

	Recurrent fallers			Non-fallers				Std. Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
Bento 2010 (ankle plantar. isometric)	0.2	0.18	10	0.23	0.2	13	50.7%	-0.15 [-0.98, 0.67]
LaRoche 2010 (ankle plantar. isometric)	3.18	1.14	11	4.12	1.89	12	49.3%	-0.57 [-1.41, 0.26]
Total (95% CI)			**21**			**25**	**100.0%**	**-0.36 [-0.95, 0.23]**
Heterogeneity: Tau² = 0.00; Chi² = 0.50, df = 1 (P = 0.48); I² = 0%								
Test for overall effect: Z = 1.20 (P = 0.23)								

Std. Mean Difference IV, Random, 95% CI

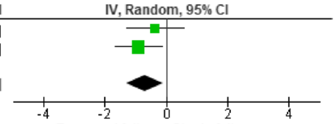


Appendix D17

RTD of knee extensors during the MVIC task in recurrent fallers vs single fallers (cross-sectional studies).

	Recurrent fallers			Single fallers				Std. Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
Bento 2010 (knee ext. isometric)	0.49	0.34	10	0.6	0.19	8	40.3%	-0.37 [-1.31, 0.57]
Kamo 2019	3.5	2	10	6.5	3.6	24	59.7%	-0.91 [-1.68, -0.13]
Total (95% CI)			**20**			**32**	**100.0%**	**-0.69 [-1.29, -0.09]**
Heterogeneity: Tau² = 0.00; Chi² = 0.75, df = 1 (P = 0.39); I² = 0%								
Test for overall effect: Z = 2.26 (P = 0.02)								

Std. Mean Difference IV, Random, 95% CI

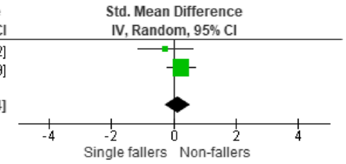


Appendix D18

RTD of knee extensors during the MVIC task in single fallers vs non-fallers (cross-sectional studies).

Study or Subgroup	Single fallers Mean	SD	Total	Non-fallers Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
Bento 2010 (knee ext. isometric)	0.6	0.19	8	0.71	0.47	13	20.9%	-0.27 [-1.16, 0.62]
Kamo 2019	6.5	3.6	24	5.8	2.7	88	79.1%	0.24 [-0.21, 0.69]
Total (95% CI)			**32**			**101**	**100.0%**	**0.13 [-0.27, 0.54]**

Heterogeneity: Tau² = 0.00; Chi² = 1.01, df = 1 (P = 0.32); I² = 1%
Test for overall effect: Z = 0.64 (P = 0.52)



Abbreviations

BBS	Berg Balance Scale
CI	Confidence interval
GRADE	Grading of Recommendations, Assessment, Development and Evaluation
MVIC	Maximal voluntary isometric contraction
OR	Odds ratio
PRISMA	Preferred Reporting Items for Systematic Review and Meta-Analyses
RFD	Rate of force development
RR	Risk ratio
RTD	Rate of torque development
SMD	Standardized mean difference
TUG	Timed Up and Go

Supplementary Information

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Additional file 1

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Authors' contributions

Ringo Tang-Long Zhu: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Data Curation, Writing- Original Draft, Visualization; Jenny Jing-Jing Zuo: Methodology, Investigation, Writing- Review & Editing; Ke-Jing Li: Software, Investigation, Validation, Writing- Review & Editing; Freddy Lam: Writing- Review & Editing; Arnold Yu Lok Wong: Writing- Review & Editing; Lin Yang: Writing- Review & Editing; Xue Bai: Writing- Review & Editing; Man Sau Wong: Writing- Review & Editing; Timothy Kwok: Writing- Review & Editing; Yong-Ping Zheng: Resources, Writing- Review & Editing; Christina Zong-Hao Ma: Methodology, Resources, Writing- Review & Editing, Supervision, Project administration, Funding acquisition.

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Data availability

Data is provided within the manuscript or supplementary information files.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

Author details

[1]Department of Biomedical Engineering, The Hong Kong Polytechnic University, Hong Kong SAR, China. [2]Research Institute for Smart Ageing, The Hong Kong Polytechnic University, Hong Kong SAR, China. [3]Department of Rehabilitation Sciences, The Hong Kong Polytechnic University, Hong Kong SAR, China. [4]School of Nursing, The Hong Kong Polytechnic University, Hong Kong SAR, China. [5]Department of Applied Social Sciences, The Hong Kong Polytechnic University, Hong Kong SAR, China. [6]Department of Applied Biology and Chemical Technology, The Hong Kong Polytechnic University, Hong Kong SAR, China. [7]Department of Medicine & Therapeutics, The Chinese University of Hong Kong, Hong Kong SAR, China.

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