

Functional correlates of mobility across three regional samples of community-dwelling older adults

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Article

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Abstract

Community mobility screening combines measures that represent different functional tasks, yet their correlates may not be interchangeable across regional field samples. We harmonised cross-sectional assessments from 848 candidates in Beijing, Taiyuan/Shanxi and Zhengzhou; 769 community-dwelling adults aged at least 60 years entered analysis. Outcome-specific, site-adjusted linear models used standardised coefficients, HC3 standard errors and Benjamini–Hochberg correction. Older age was associated with slower gait speed ($\beta = -0.30$), lower cadence ($\beta = -0.27$), longer Timed Up and Go duration ($\beta = 0.43$) and a lower single-leg balance index ($\beta = -0.22$). Higher body mass index was associated with greater plantar contact area ($\beta = 0.24$; all preceding $q \leq 4.73e - 06$). In the 459-participant two-site handgrip subcohort, greater strength was associated with faster gait and higher cadence. It was also associated with shorter Timed Up and Go duration and a higher balance index (absolute $\beta = 0.19-0.31$; all $q \leq 0.006$). Ankle-flexion range of motion showed no consistent independent association, while the age–Timed Up and Go association varied by site and was nonlinear. The results support outcome-specific interpretation but not causal inference or national generalisation.

Introduction

Mobility screening in later life is useful only when its component tests are interpreted according to the tasks they represent. Preserving locomotor capacity is central to person-centred assessment [1], while falls remain a substantial and geographically heterogeneous burden among older adults in China [2]. In a recent Chinese longitudinal cohort, slower gait speed and longer Timed Up and Go (TUG) duration were prospectively associated with falls [3]. Short gait-speed tests are generally reliable, but their validity and responsiveness depend on the construct and protocol [4]. Usual gait speed has prognostic value, and spatial or wearable-derived gait features have been associated with falls and functional decline [5–7]. TUG adds standing, turning and sitting to straight-line walking [8–9]. Its distributions and outcome thresholds vary by age and population, and its stand-alone fall-prediction value remains context dependent [10–11]. Gait-speed distributions also vary by age and sex, while supervised, laboratory and daily-life estimates are not interchangeable [12–15].

A single screening visit therefore samples related, but non-equivalent, functional domains. Trunk-acceleration harmonic ratios depend on speed, axis and analytic definition, and age-related changes in dynamic balance are direction and construct specific [16–19]. Walking velocity and sex influence plantar-pressure variables [20], while BMI is related to foot posture [21]. Contact-area and loading patterns across BMI categories can be nonlinear, and obesity spans several musculoskeletal and mobility domains [22–24]. At the distal limb, ageing redistributes joint work, whereas ankle-foot power and dynamic range of motion remain task dependent [25–27]. Neural control strategies and postural sway also change with age [28–29]. Recent cross-domain evidence further indicates that balance, mobility and strength do not change uniformly with age [30], alongside broader losses of muscle mass and function [31].

Handgrip strength offers a complementary, low-burden marker of strength reserve and is associated with adverse health outcomes [32]. It is also a standard muscle-strength measure in Asian consensus assessment, although the present study did not diagnose sarcopenia [33]. More broadly, the psychometric properties of TUG and gait-speed tests depend on the intended construct and context [34]. Grip strength has been associated with several domains of intrinsic capacity [35] and with physical fitness and 8-foot up-and-go performance in active community-dwelling older adults [36]. Cohort and field-sensor studies also link stronger grip with faster walking, although their age ranges, settings and sex distributions differ [37–39]. Longitudinal evidence from rural China supports a temporal association between baseline grip strength and subsequent gait speed, without establishing the present effect size [40]. Strength, gait and cognitive status have also been examined jointly, while wearable gait and sway patterns have been studied in relation to fall history [41–42]. Together, these studies support a complementary-marker hypothesis, not substitution of one functional test for another.

Regional field datasets rarely contain every measure at every site. Restricting all analyses to one universal complete-case sample can discard valid observations. Conversely, pooling a site-limited variable can create a geographic claim that the data cannot support. We therefore harmonised three regional community samples in China and estimated outcome-specific, site-adjusted associations for measures shared across all sites. Handgrip strength was analysed only in the two sites where it was collected. We hypothesised that age would align most consistently with dynamic mobility, body mass index (BMI) with plantar contact area, and handgrip strength with functional performance in the measured subcohort. Ankle-flexion range of motion (ROM) was treated as a candidate correlate rather than presumed to have an independent association.

Results

Cohort construction retained 769 records while preserving structural missingness

The harmonised source contained 848 candidate records. Eighteen were removed because age was missing or below 60 years, and 61 additional records failed at least one prespecified plausibility rule. The analysis dataset contained 769 participants: 266 from Beijing, 290 from Taiyuan/Shanxi and 213 from Zhengzhou (Fig. 1a). The strict complete set across all shared variables comprised 658 participants. Handgrip strength was not collected in Beijing; 459 participants in Taiyuan/Shanxi and Zhengzhou had the covariate set required for handgrip models before outcome-specific deletion (Fig. 1b,c; Table 1).

Table 1
Participant characteristics after cleaning

Characteristic	Overall	Beijing	Taiyuan/Shanxi	Zhengzhou
Participants, n	769	266	290	213
Women, n (%)	411 (53.4%)	143 (53.8%)	152 (52.4%)	116 (54.5%)
Age, years	71.0 (66.0–77.0)	72.0 (67.0–78.0)	71.0 (66.0–76.0)	70.0 (65.0–75.0)
BMI, kg/m ²	24.1 (22.1–26.2)	21.9 (18.8–23.4)	25.9 (24.7–27.5)	24.3 (22.7–26.3)
Gait speed, m/s	0.98 (0.82–1.14)	0.98 (0.80–1.15)	0.96 (0.84–1.09)	1.02 (0.81–1.21)
Cadence, steps/min	115.4 (105.9–123.5)	117.2 (106.9–125.5)	114.0 (105.1–122.7)	113.4 (105.7–122.1)
Harmonic ratio, device units	0.54 (0.36–1.06)	0.52 (0.34–0.99)	0.58 (0.33–1.09)	0.60 (0.39–1.09)
TUG duration, s	11.74 (10.36–13.16)	10.86 (9.53–12.37)	12.39 (11.47–13.92)	11.43 (10.01–12.77)
Plantar contact area, mm ²	11012 (9898–11907)	10918 (9742–11880)	11031 (10039–11818)	11226 (9870–11992)
Single-leg balance index, device units	0.07 (0.04–0.11)	0.07 (0.05–0.12)	0.06 (0.04–0.08)	0.07 (0.05–0.14)
Ankle-flexion ROM, °	11.0 (7.0–16.0)	10.0 (6.1–14.0)	10.5 (7.0–14.5)	14.5 (8.0–19.0)
Handgrip strength, kg	19.7 (15.3–26.1)		19.2 (14.4–25.8)	19.9 (16.4–26.5)
Values are median (interquartile range) unless otherwise stated. Handgrip strength was not collected in Beijing.				

Table 2
Prespecified focal associations

Analysis	Outcome	Predictor	n	Standardised β (95% CI)	P	BH q
Three-site pooled	Gait speed	Age	713	-0.30 (-0.37, -0.22)	1.74e-13	1.39e-12
Three-site pooled	TUG duration	Age	719	0.43 (0.35, 0.52)	1.18e-22	2.82e-21
Three-site pooled	Plantar contact area	BMI	702	0.24 (0.15, 0.32)	6.95e-08	3.34e-07
Three-site pooled	Gait speed	Ankle-flexion ROM	713	0.06 (-0.01, 0.12)	0.085	0.176
Two-site grip subcohort	Gait speed	Handgrip strength	434	0.23 (0.10, 0.35)	3.46e-04	0.001
Two-site grip subcohort	Cadence	Handgrip strength	436	0.19 (0.07, 0.32)	0.002	0.006
Two-site grip subcohort	TUG duration	Handgrip strength	431	-0.31 (-0.43, -0.19)	5.92e-07	5.92e-06
Two-site grip subcohort	Single-leg balance index	Handgrip strength	419	0.22 (0.10, 0.34)	3.11e-04	0.001
β values are standardised. P values are two-sided HC3 results. BH q values control the false discovery rate within each model family.						

Measurement availability and distributions differed across regional samples

All three samples contributed gait, TUG, plantar-contact, balance and ankle-flexion observations, but completeness, source-table structure and distributions varied by site (Figs. 1b and 2; Supplementary Table S9). Outcome-specific sample sizes ranged from 702 to 727 in pooled models and from 419 to 436 in the handgrip subcohort. Every pooled model therefore included site indicators. The resulting coefficients are adjusted average associations; they do not establish identical regional distributions, measurement error or slopes.

Age aligned with dynamic mobility, whereas BMI aligned with plantar contact area

In the pooled models, older age was associated with slower gait speed ($\beta = -0.30$, 95% CI -0.37 to -0.22, $P = 1.74e-13$, $q = 1.39e-12$) and lower cadence ($\beta = -0.27$, 95% CI -0.35 to -0.20, $P = 5.43e-12$, $q = 3.26e-11$). It was also associated with longer TUG duration ($\beta = 0.43$, 95% CI 0.35 to 0.52, $P = 1.18e-$

22, $q = 2.82e - 21$) and a lower single-leg balance index ($\beta = -0.22$, 95% CI -0.30 to -0.13, $P = 1.18e - 06$, $q = 4.73e - 06$; Fig. 3a and Supplementary Table S2). Higher BMI was associated with greater plantar contact area ($\beta = 0.24$, 95% CI 0.15 to 0.32, $P = 6.95e - 08$, $q = 3.34e - 07$). These were standardised partial coefficients from outcome-specific complete-case samples, adjusted for the other covariates and site.

Ankle-flexion ROM showed no consistent independent association

Ankle-flexion ROM was not associated with gait speed after adjustment ($\beta = 0.06$, 95% CI -0.01 to 0.12, $P = 0.085$, $q = 0.176$). None of its six pooled outcome coefficients survived FDR correction (Fig. 3a and Supplementary Table S2). Magnitudes remained small in most site-deletion and influence-point analyses, although nominal significance changed under one threshold variant. The data therefore show no consistent independent association for this summary ROM measure; they do not show that ankle function is irrelevant to mobility.

Handgrip strength tracked four outcomes in the measured subcohort

Within Taiyuan/Shanxi and Zhengzhou, greater handgrip strength was associated with faster gait speed ($\beta = 0.23$, 95% CI 0.10 to 0.35, $P = 3.46e - 04$, $q = 0.001$) and higher cadence ($\beta = 0.19$, 95% CI 0.07 to 0.32, $P = 0.002$, $q = 0.006$). It was also associated with shorter TUG duration ($\beta = -0.31$, 95% CI -0.43 to -0.19, $P = 5.92e - 07$, $q = 5.92e - 06$) and a higher device-derived single-leg balance index ($\beta = 0.22$, 95% CI 0.10 to 0.34, $P = 3.11e - 04$, $q = 0.001$; Fig. 3b). Associations with harmonic ratio and plantar contact area did not survive FDR correction. Grip-by-site interactions for gait speed and TUG were nominally significant ($P = 0.0317$ and 0.0346) but not after correction (both $q = 0.104$). The two-site estimates were therefore retained as adjusted averages with an explicit geographic boundary.

Sensitivity analyses preserved the central directions but exposed limits to transportability

All 72 coefficients from the archived analysis were reproduced to numerical precision. The central directions persisted after leave-one-site-out refitting, exclusion of observations with Cook's distance above $4/n$ and seven alternative screening or tail-handling scenarios (Supplementary Tables S4–S8). The maximum variance-inflation factor was 2.14. Age-by-site tests survived FDR correction for TUG ($P = 1.04e - 04$, $q = 0.00188$) and harmonic ratio ($P = 0.00824$, $q = 0.0494$). The BMI-by-site test also survived for gait speed ($P = 0.00282$, $q = 0.0254$). Site-specific slopes from these interaction models are reported in Supplementary Table S10 to show the direction and magnitude underlying each joint test. A quadratic age term was retained for TUG in sensitivity analysis ($q = 0.00550$). Heteroscedasticity was detected in 10 of 12 models, residual non-normality in all 12 and functional-form evidence in 6. HC3 inference and log-TUG analyses preserved the focal directions, but the diagnostics preclude a universal linear or mechanistic interpretation.

Discussion

Three regional samples revealed a coherent but non-uniform pattern. Age aligned most consistently with dynamic mobility, BMI with plantar contact area, and handgrip strength with four functional outcomes in the two sites that measured it. Ankle-flexion ROM did not provide a stable independent signal. The principal contribution lies in showing, within one harmonised and reproducible analysis, that these correlates separate by functional domain and that several pooled slopes conceal regional heterogeneity. Each coefficient must therefore retain the boundaries of its task, analytic sample and regional composition.

The age pattern crossed speed, rhythm, transitional mobility and balance, but its magnitude was not constant. Associations with slower gait and longer TUG are consistent with the integrative nature of these tasks [5, 8–9, 12]. Age-related differences across balance, mobility and strength domains are also known to be non-uniform [19, 30]. Muscle function, postural control and joint-work redistribution provide plausible context [25, 28–29, 31], but none was tested as a mediator here. The age-by-site interaction and quadratic term for TUG sharpen this boundary. They indicate that the pooled coefficient averages regional and age-related variation rather than estimating a universal annual decline. Differences between supervised and habitual gait further argue against transporting a single estimate across settings [14–15].

BMI followed a narrower pattern: plantar contact area was its clearest independent correlate. This result is compatible with evidence linking body size, foot posture and loading conditions to plantar measures [20–21, 23]. Pedobarographic patterns across BMI categories can be nonlinear, while obesity can affect several musculoskeletal and mobility domains [22, 24]. The present linear coefficient is therefore a sample-specific summary, not a universal dose-response relation. Contact area should not be interpreted as another expression of gait speed or TUG. A larger value also cannot be labelled beneficial or harmful because regional pressure distribution, pain, footwear, deformity and foot morphology were unavailable.

Handgrip strength showed a broader functional profile within its measured subcohort. Grip is an upper-limb measure, but it is used as a practical marker of strength reserve and is embedded in Asian geriatric assessment [32–33, 35]. Its association with gait speed is consistent with cohort, field-sensor and longitudinal evidence [37–40]. Community evidence also links grip with 8-foot up-and-go performance, although that task is not interchangeable with the present TUG protocol [36]. The present cadence, TUG and balance-index estimates extend that pattern within two sites, but do not identify a lower-limb mechanism. The balance index is device derived, and Beijing contributed no grip data. Thus, the evidence supports adjusted two-site associations, not a three-region prevalence claim, diagnostic threshold or replacement for direct mobility testing.

The ankle finding is informative precisely because it remained null under the same framework. Age and task speed can alter ankle-foot power, and frailty-related differences occur in ankle motion during gait [26–27]. However, a bilateral field ROM summary is not equivalent to weight-bearing dorsiflexion, ankle strength or propulsion. Pain, footwear, task demand and the prevalence of clinically restricted motion

may further modify any relationship. The small, threshold-sensitive coefficients observed here support a more specific prospective experiment, not a conclusion that ankle function is irrelevant.

Two design choices strengthen interpretation: outcome-specific models preserve usable data, and all focal estimates are accompanied by site adjustment, heterogeneity tests, multiplicity control and reproducible sensitivity analyses. Transparent reporting is particularly important when missingness is structured by site [43]. The protocol matrix in Supplementary Table S9 makes residual comparability limits explicit rather than assuming that common variable names imply identical measurement error. These safeguards do not remove the study's limitations. Cross-sectional associations cannot establish temporal or causal direction [44]. The regional field samples were not probability samples and do not represent all older adults in China. Record-wide screening removed some records that retained other usable values, so the primary cohort may be selected partly on measurements outside a given outcome model. Valued screening preserved the focal directions, but neither that analysis nor complete-case modelling proves that selection was ignorable. Site indicators controlled mean differences but did not eliminate slope heterogeneity. Harmonic-ratio interpretation remains dependent on speed, axis and testing condition [16–18]. The device-specific balance index lacks external validation for the present use, and osteoporosis-sample wearable evidence cannot supply that validation [42]. Finally, heteroscedastic, non-normal and partly nonlinear residual structures mean that robust coefficients remain descriptive summaries rather than biological laws.

Within these limits, the study supports outcome-specific interpretation of multiregional mobility screening. Gait, transitional mobility, plantar contact, joint motion and strength are related but non-equivalent domains. Shared measures should be analysed across all contributing sites, site-limited measures should remain in named subcohorts, and null and positive findings should be reported under the same multiplicity framework.

Methods

Study design and participants

This cross-sectional observational analysis combined community health-screening assessments from Beijing, Taiyuan/Shanxi and Zhengzhou, China. Eligible participants were at least 60 years old, lived in the community, could complete walking and chair-rise tasks independently, could follow test instructions and provided written informed consent. Exclusion criteria were acute lower-limb injury, recent lower-limb surgery, movement-limiting impairment, unstable medical, neurological or orthopaedic disease that made testing unsafe, and severe cognitive impairment that prevented cooperation. All available eligible records were considered; no prospective sample-size calculation was performed for this secondary harmonised analysis. Precision is therefore conveyed through outcome-specific sample sizes and 95% confidence intervals rather than a post hoc power claim. Reporting was guided by STROBE [45].

Ethics

The study protocol and all three regional datasets were covered by the Science and Technology Ethics Committee of Jimei University (approval no. 20260629001; approved 29 June 2026). All procedures followed relevant institutional regulations and the 2024 revision of the Declaration of Helsinki [46]. Every participant provided written informed consent before testing.

Instrumentation and field protocol

Plantar pressure was recorded with an iGAIT platform at 400 Hz. Trunk inertial data were recorded with a Baibot system at 200 Hz, with the sensor positioned over L4–L5. TUG testing used a chair approximately 46 cm high and a 3 m walkway. After a 5–10 min warm-up, participants completed barefoot quiet-standing plantar assessment, usual-speed straight-line walking, TUG and quiet single-leg standing. Ankle flexion was measured bilaterally. Zhengzhou recorded three handgrip trials per hand, Taiyuan/Shanxi recorded two per hand and Beijing did not collect handgrip strength.

Outcome definitions and harmonisation

Gait speed, cadence and a device-derived harmonic ratio were taken from the inertial-system export. TUG duration covered rising from the chair, walking 3 m, turning, returning and sitting. For Beijing and Taiyuan/Shanxi, bilateral plantar contact areas and single-leg balance indices were averaged when both sides were available; the supplied Zhengzhou workbook contained the corresponding bilateral summary values. Ankle-flexion ROM was the mean of available left and right measurements. Handgrip strength was the mean of all valid recorded trials at each measured site. Site-specific records were linked through de-identified site–participant identifiers, and duplicate identifiers were audited before concatenation. The site-by-site source, aggregation and structural-missingness matrix is reported in Supplementary Table S9; harmonisation establishes a common analytic definition, not identical measurement error across sites.

Data screening and missing values

Rule-based plausibility screening preceded model fitting. Records were removed when age was missing or below 60 years, height was outside 130–210 cm, or BMI was outside 14–45 kg/m². Gait speed at most 0.2 or above 2.0 m/s and TUG duration at most 1 or above 60 s triggered removal. Handgrip strength at most 0 or above 80 kg also triggered removal. Ankle flexion outside 0–60° and plantar contact area outside 4,000–20,000 mm² were handled in the same way. Missingness alone did not trigger exclusion when a variable had not been measured, whereas any observed value outside a rule removed the record from the primary dataset. Outcomes and covariates were not imputed; each model used outcome-specific complete cases. Sensitivity analyses instead set only offending cells to missing and examined stricter, relaxed and tail-handling alternatives.

Statistical analysis

Continuous variables are reported as median (interquartile range) and categorical variables as number (percentage). Separate linear models were fitted for gait speed, cadence, harmonic ratio, TUG duration, plantar contact area and the single-leg balance index. Continuous outcomes and predictors were

standardised within each model. Pooled three-site models included age, sex, BMI, ankle-flexion ROM and site indicators, with Zhengzhou as the reference. The handgrip models additionally included handgrip strength and were restricted to Taiyuan/Shanxi and Zhengzhou. All tests were two-sided. HC3 standard errors provided heteroscedasticity-robust 95% confidence intervals and P values. Benjamini–Hochberg correction was applied within each model family across the six outcomes and non-site predictors (24 tests in the pooled family and 30 in the handgrip family); $q < 0.05$ defined the discovery threshold. Sensitivity analyses included predictor-by-site interactions, leave-one-site-out refits, log-transformed TUG, quadratic age terms, variance-inflation factors, Cook’s-distance deletion and alternative screening rules. Analyses used Python 3.13.8, pandas 3.0.3, NumPy 2.4.6 and statsmodels 0.14.6. The fixed plotting seed and complete package versions are recorded in the reproducibility files.

Use of generative AI

OpenAI Codex was used for Python code review, figure formatting and English-language editing. It was not treated as an author and did not determine study eligibility, make analytical decisions or formulate scientific conclusions. The named authors reviewed the code, outputs, references and manuscript and accept responsibility for the submitted work.

Data availability

The de-identified analysis dataset, data dictionary, statistical source tables and Python code needed to reproduce the reported results are included with the submission for editorial and peer-review assessment. Because these are human-participant data, dissemination beyond peer review remains subject to the consent, ethics approval and institutional data-governance conditions. Requests for access should be addressed to the corresponding author at linjinbiao139060@163.com and will be evaluated under those conditions.

Declarations

Competing interests

The authors declare no competing interests.

Author Contribution

J.P. curated the data, conducted the investigation, contributed to the statistical analyses, and drafted the original manuscript. J.L. supervised the study, reviewed the methodology, and critically revised the manuscript. Both authors verified the final analyses, reviewed and approved the final manuscript, and accept responsibility for the integrity of the work.

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Data Availability

The de-identified analysis dataset, data dictionary, statistical source tables and Python code required to reproduce the reported results are included with the submission for editorial and peer-review assessment. Because the study involves human-participant data, access and dissemination beyond peer review are subject to the participants' consent, ethics approval and applicable institutional data-governance requirements. Requests for access should be directed to the corresponding author and will be evaluated in accordance with these conditions.

Additional information

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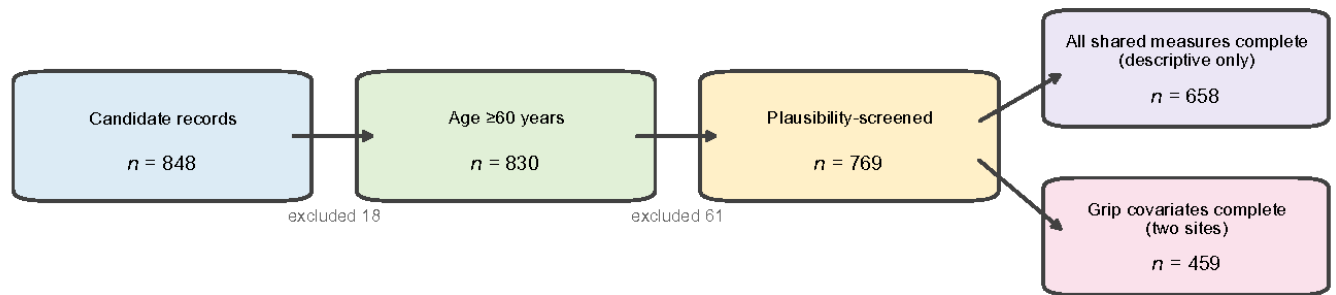
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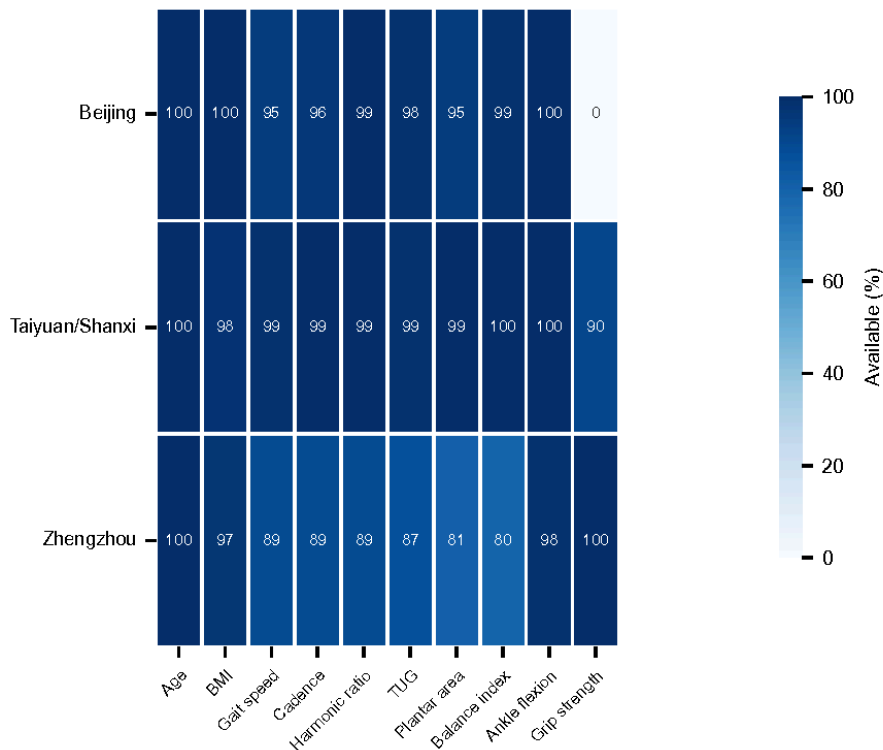
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Figures

a Cohort construction and analysis strata



b Variable availability after cleaning



c Model-specific sample sizes

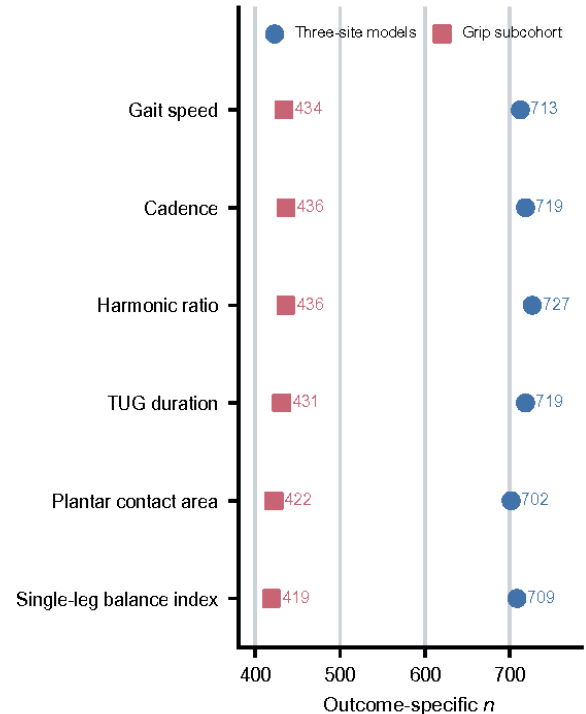


Figure 1

Cohort construction, variable availability and model-specific sample sizes. a, Flow from 848 candidate records through age and plausibility screening to the descriptive complete set and the two-site handgrip-analysis base. b, Percentage availability of each measurement after cleaning by site. c, Outcome-specific complete-case sample sizes for pooled three-site models and two-site handgrip models. The strict complete set and handgrip base are descriptive strata, not the sample size of every regression. Source data are provided with the submission.

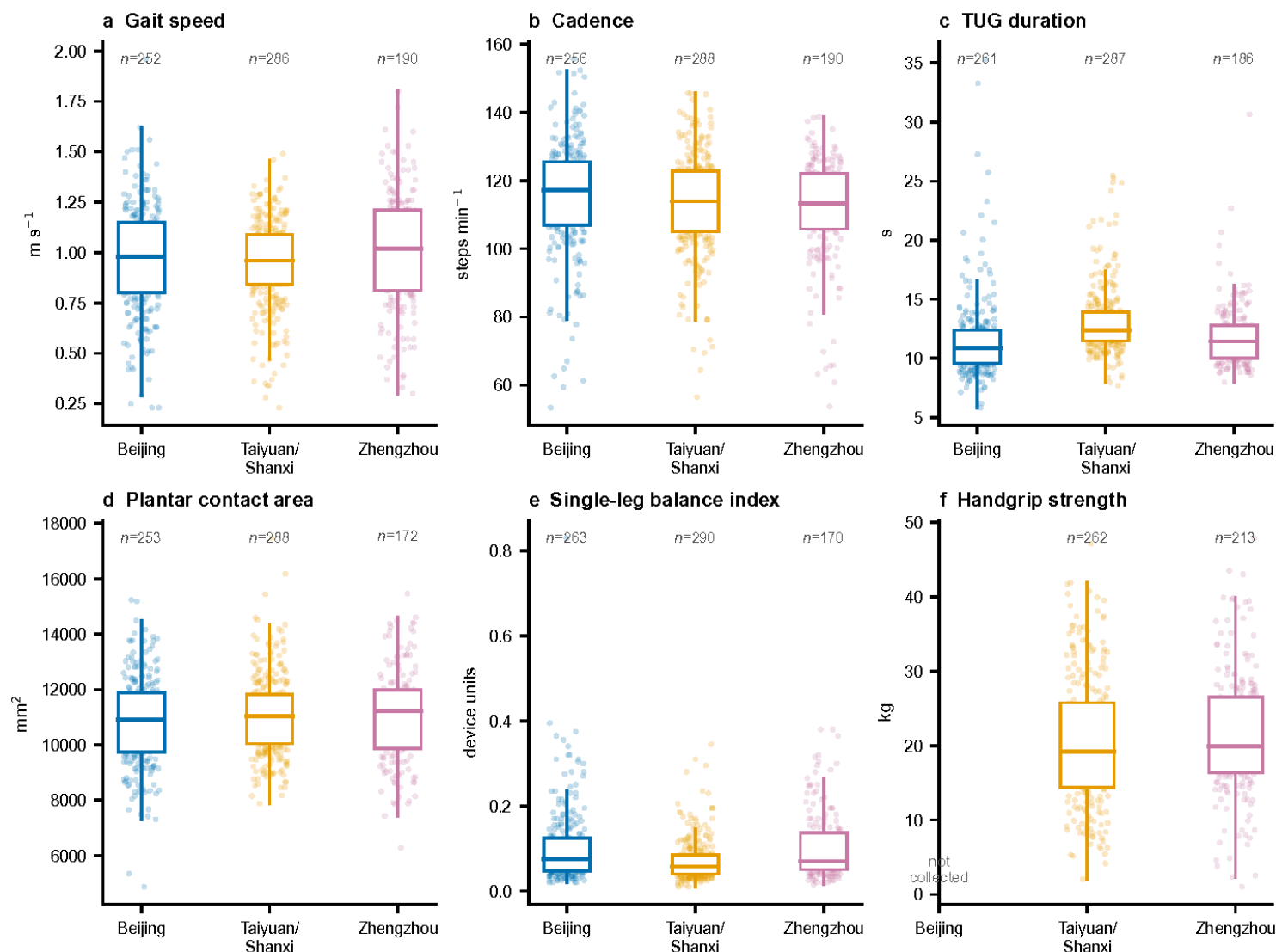


Figure 2

Distributions of key functional measurements across regional samples. Points show individual observations; boxes show the median and interquartile range; whiskers extend to the most extreme observation within 1.5 interquartile ranges. Panel-top n values are non-missing observations after cleaning. Handgrip strength was not collected in Beijing. Regional distributions are descriptive and were not interpreted as causal site effects. Source data are provided with the submission.

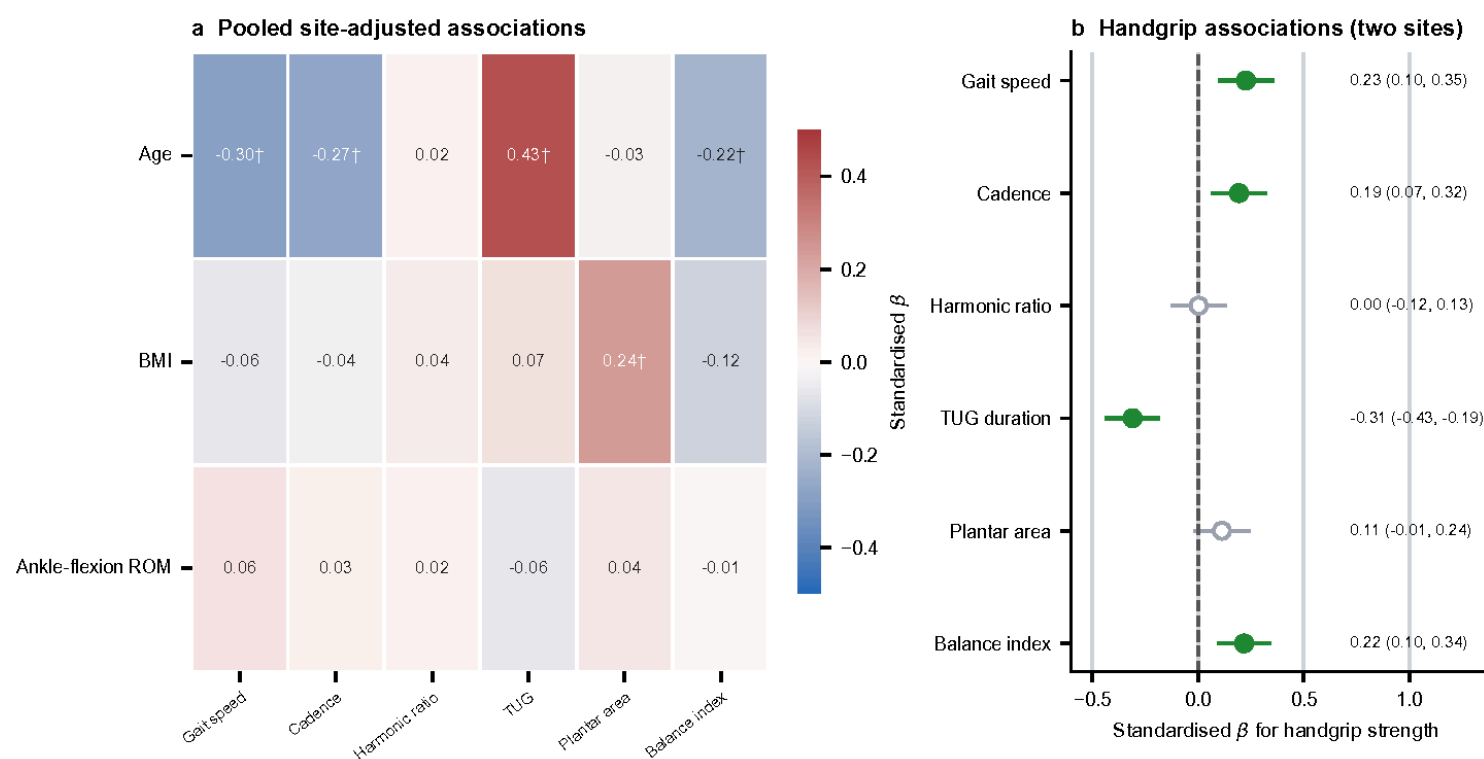


Figure 3

Pooled focal associations and handgrip-strength associations. a, Standardised coefficients from pooled three-site models adjusted for sex and site in addition to the displayed focal predictors. Daggers indicate BH-adjusted $q < 0.05$ across 24 non-site-predictor tests (age, sex, BMI and ankle-flexion ROM across six outcomes); sex was included in the multiplicity family but is not displayed. b, Standardised handgrip-strength coefficients from two-site models adjusted for age, sex, BMI, ankle-flexion ROM and site. Lines are 95% CIs; filled points indicate BH-adjusted $q < 0.05$ across 30 non-site-predictor tests. Exact P and q values and outcome-specific n values are reported in Supplementary Table S2. Source data are provided with the submission.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [06SourceData.xlsx](#)
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