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Establishing normative pinch and grip strengths across adult age groups in Singapore

Ananda Sidarta[1*], Li Jing Soh[1], Eloise Lie[1], Wai Hang Patrick Kwong[1,2], I-Ling Yeh[3], Phyllis Liang[1] and Wei Tech Ang[1,4]

Abstract

Background Pinch and grip strengths are vital indicators of upper limb function, musculoskeletal health, and general health. While most research has focused on older individuals, it is crucial to build normative data for younger populations. This cross-sectional study was conducted to determine the normative values for lateral pinch strength (LPS) and hand grip strength (HGS) in healthy adult Singaporeans.

Methods The study recruited 500 healthy individuals without any serious general illnesses and upper limb pain, aged 21–80 years. LPS and HGS were measured using a standardized JAMAR hand dynamometer. Age, gender, hand dominance, and participant demographics were recorded. Normative values were then established for different age groups and hand dominance. A machine learning approach was employed to determine the most relevant variables for dominant LPS and HGS in our data, respectively.

Results Our data showed that HGS and LPS peaked between 40–44 years of age in women. In men, average HGS peaked between 35–39 years and LPS peaked between 50–54 years. Compared to the non-dominant side, dominant HGS was 6.86% and 6.23% higher in women and men, respectively. The difference between dominant and non-dominant LPS in men and women was 6.96% and 9.18%, respectively. Age was strongly associated with hand strength for older participants, but not for younger ones. Height, weight, and age were important for predicting dominant HGS and LPS, and gait speed for HGS only.

Conclusions Our data align with past results, but the normative values are comparatively lower than the consolidated Western norms. Compared to the non-dominant hand, the strength of the dominant hand is significantly higher. No statistical difference between the right- and left-handed participants in terms of dominant HGS and dominant LPS. The results can be valuable for researchers and healthcare providers working with young and older adults.

Keywords Lateral pinch strength, Hand grip strength, Reference values, Hand injuries, Muscle strength

Introduction

In recent years, there has been a growing interest in physical strength and movement as valuable indicators of an individual's performance, functional capacity, and overall health. In particular, lateral pinch strength (LPS) and hand grip strength (HGS) have emerged as reliable measures that can be assessed easily in clinical settings [1, 2]. Earlier studies have demonstrated strong associations between low grip strength and adverse health outcomes, e.g. disability, cardiovascular events, and overall morbidity [3, 4]. HGS is a reliable predictor of functional

*Correspondence:
Ananda Sidarta
ananda.sidarta@ntu.edu.sg
[1] Rehabilitation Research Institute of Singapore, Lee Kong Chian School of Medicine, Nanyang Technological University, Singapore, Singapore
[2] Department of Rehabilitation Sciences, The Hong Kong Polytechnic University, Hong Kong SAR, China
[3] Health and Social Sciences Cluster, Singapore Institute of Technology, Singapore, Singapore
[4] School of Mechanical and Aerospace Engineering, Nanyang Technological University, Singapore, Singapore

decline in the elderly [5–7]. LPS and HGS assessments are equally important in sports because they provide insights into overall muscle function, upper limb strength, and physical health, all of which are critical for athletic performance [8]. Grip strength has been studied in sports that demand upper body power, such as rock climbing [9], gymnastics [10], and rowing [11].

Upper limb injuries, such as fractures and repetitive strain injuries, often result in reduced strength and limited engagement in activities of daily living (ADLs). In Singapore alone, hand fractures are notably prevalent among younger individuals, particularly those working in the construction and manufacturing industries [12, 13]. Poor ergonomics, repetitive use, and overuse of the wrist and hand can lead to carpal tunnel syndrome, which damages the peripheral nerve fibres and even introduces maladaptive reorganization in the central nervous system [14, 15]. Grip strength assessment is typically used following hand surgery or injuries to examine both functional recovery and clinical outcomes [16], or to monitor shoulder rotator cuff function [17].

Complimentary to HGS measurement is the assessment of pinch strength, which emphasizes distal function and fine motor control [18]. Together with grasping, the ability to pinch is often assessed in stroke populations as part of upper limb assessments, for example, in the Action Research Arm Test (ARAT) [19]. Reduced hand strength in stroke patients, including pinch strength, has been found to impact upper extremity functions and the ability to perform daily activities [20]. Moreover, studies have assessed the impact of surgical treatments on LPS, such as ligament reconstruction for carpal tunnel syndrome [21] and trapeziectomy for thumb basal joint arthritis [22]. Thus, HGS and LPS assessments not only aid in identifying functional limitations to inform interventions but are also essential in monitoring post-surgery recovery.

Grip strength assessments have long been utilized in clinical and rehabilitation settings to evaluate upper limb function in individuals with medical conditions, such as stroke and hand injuries. However, the interpretation of these assessments relies on appropriate reference values derived from healthy individuals [23]. Establishing normative datasets for grip and pinch strength is essential to differentiate pathological weakness from expected age-related decline, facilitating early detection of impairments and guiding rehabilitation strategies. The current study established a normative dataset of HGS and LPS in a multi-ethnic Singaporean adult population. In each measure, the impact of hand dominance and the effect of different age and gender strata were investigated. Contributions of demographic factors to the strength of the dominant hand were further examined using data-driven techniques, as the hand is essential in many ADLs and fine motor control. To date, there is no report of LPS in healthy adults across all age groups, and no report of HGS in younger Singaporean adults below 50 years old. The most recent study conducted locally by Pua and colleagues [24] provides the normative range of older adults above 50 years old. Our results offer a normative benchmark for evaluating upper limb strength and functional capacity of older adults in Singapore, as well as younger adults with prior relevant injuries. Additionally, we compare our findings with existing normative datasets from other Asian and Western populations to contextualize regional differences in hand strength.

Materials and methods

Study design

The data reported here are part of the 'Ability Data' project, a recent initiative to build an Asian-centric movement database of basic ADLs [25]. The data provide a valuable reference for detecting movement deviation and measuring general human physical performance. The study was approved by the Nanyang Technological University Institutional Review Board (IRB- 2018–04–014). All recruited participants provided written informed consent prior to the data collection.

A trained researcher measured the weight and height of each participant using a scale with a stadiometer, accurate to the nearest 0.1 points. Body mass index (BMI) was calculated by dividing the weight (in kilograms) by the square of height (in meters), i.e. weight scaled to height as a reliable indicator of body fatness. Additional information, such as education level, employment status, and race, was also collected. Participants then performed a series of activities of daily living (ADLs) tasks while being recorded by a high-definition motion capture system (Qualisys AB, Sweden). The ADL tasks included walking, stepping up and down, picking up objects, putting objects on a shelf, simulated feeding and turning a key. Pinch and grip strength were measured after the ADL tasks. Only the grip and pinch strengths, and gait speed from the 10-m walk were used and reported in this research. Gait speed was generated from the motion analysis using Visual3D (C-Motion, Inc).

Grip and pinch strength measurement

Jamar Plus + Digital Hand Dynamometer and Jamar Digital Pinch Gauge (Sammons Preston, Bolingbrook, IL, USA) were used to assess the maximum hand grip strength (HGS) and lateral pinch strength (LPS) respectively. Grip strength measures the muscle force exerted by the hand and forearm while squeezing the dynamometer. Pinch strength, on the other hand, follows the lateral key pinch measurement where a pinch gauge is placed between the thumb pulp and the lateral aspect of the middle phalanx of the index finger [26]. Both tests evaluate resistive strength where a participant exerts maximum voluntary contraction with the hand.

The procedures in the data collection followed closely the recommendation by the American Society of Hand Therapists [27]. Before the measurement, a study team member explained the procedure to each participant. Participants were asked to sit on a chair comfortably with both feet on the ground, the shoulder in a neutral position, and the elbow at a 90-degree angle. They were then instructed to squeeze each device as hard as they could for 3 s [28]. The grip strength of the dominant and non-dominant hands was measured first, followed by the pinch strength in a similar manner after a short break. Each measurement was done thrice consecutively with a 10-s break in between. The average of the three values was taken as the participant's nominal performance.

Participants

Five hundred healthy volunteers of Asian ethnicity who are residing in Singapore, aged 21 to 80 years old, enrolled and completed the trials for the movement database initiative. They were excluded if they had (1) prior neurological conditions, musculoskeletal issues, or surgeries and other medical conditions that require active treatment or therapy within the previous three months; (2) depression or mental health conditions that interfere with daily task performance; (3) visual problems that recently resulted in an accident, fall, or near-fall; (4) skin lesions or known skin allergies that would interfere with marker placement; and (5) inability to engage in daily activities normally. Of the 500 participants, 495 of them were included in the analytical sample. Four persons with missing HGS and LPS data and one with incorrect data registration were excluded. Hand dominance was determined based on a self-reported answer. Responses in the analytical sample were either (1) right hand (90%); (2) left hand (8%); or (3) ambidextrous (1%). For the ambidextrous participants, the hand with the higher HGS value was considered dominant.

Statistical analysis and feature selection

All statistical analyses were performed using R environment (v4.1.2; R Core Team 2021). Normative values of each HGS and LPS were presented as descriptive statistics, separated by gender, hand dominance, and age strata. The normality assumption and the assumption of the homogeneity of group variances were checked using the Shapiro–Wilk's test and Levene's Test, respectively. If the assumption of normality was violated, the Wilcoxon signed-rank test was used. Differences in HGS and in LPS for the dominant and non-dominant hands were compared in men and women separately. Bivariate Spearman's correlation analyses were conducted to better understand the relation between the predictor variables and HGS or LPS, respectively. Statistical significance was evaluated at $a = 0.05$. An accompanying web-based application was developed using the *Shiny* library in R to let users explore the normative hand strengths from our data (https://ansidarta.shinyapps.io/shiny/).

To contextualize our findings, we compared the normative values obtained in this study with previously published datasets from regional and international studies. Data sources were selected based on their methodological rigour and population relevance. For consistency, we extracted the mean values for each age and gender group from individual studies where available.

Sample characteristics and demographics (Table 1) that influence the grip and pinch of the dominant hand were further examined. Information such as gender, age, height, weight, gait speed, educational background, marital status, employment status, and living status were selected as predictors. HGS and LPS were the dependent variables to be predicted. To identify the most informative predictors of hand strength, a 'feature selection' process was conducted using the Recursive Feature Elimination (RFE) technique. RFE is advantageous because it can efficiently handle correlated predictors and does not require a strictly linear relationship between variables [29, 30]. This technique builds predictive models and iteratively removes the least important features or predictor variables from the data until a certain level of model performance is achieved. The commonly used metric to quantify model performance includes the prediction accuracy, i.e. mean absolute error (MAE) between the real grip strength and the predicted one by the model, and R-squared (or R^2) which returns a value between 0 and 1. R-squared provides a measure of how much variation in the actual data is explained by the model. A value of 0 indicates a bad prediction model with no explanatory power, while a value of 1 denotes a perfect model that explains all variability in the HGS or LPS. All factors being equal, the smaller the MAE and the larger the R-squared, the better the model performance. All analyses were conducted for dominant HGS and dominant LPS separately, using the *Caret* library in R [31].

Ordinal variables, such as education, were first converted into numbers (primary education and university/postgraduate being lowest and highest, respectively). Employment, living status, and marital status were converted into numerical values through a one-hot encoding [32]. The dataset was used to train the RFE model using available functions in Caret, including 'random forests,' 'linear regression,' 'k-nearest neighbours,' and 'bagged trees.' [33]. RFE with random forests was implemented

Table 1 Sample characteristics by gender

Categories	Total (*n* = 495)	Women (*n* = 271)	Men (*n* = 224)
Age (years)			
Mean (SD)	44.8 (± 16.3)	45.4 (± 16.1)	44.1 (± 16.5)
Age Stratum (years)			
20–24	89 (18%)	50 (18%)	39 (17%)
25–29	49 (10%)	19 (7%)	30 (13%)
30–34	31 (6%)	17 (6%)	14 (6%)
35–39	28 (6%)	17 (6%)	11 (5%)
40–44	35 (7%)	16 (6%)	19 (8%)
45–49	40 (8%)	22 (8%)	18 (8%)
50–54	52 (11%)	31 (11%)	21 (9%)
55–59	57 (12%)	39 (14%)	18 (8%)
60–64	52 (11%)	29 (11%)	23 (10%)
65–69	41 (8%)	22 (8%)	19 (8%)
> 70	21 (4%)	9 (3%)	12 (5%)
Hand Dominance			
Left	45 (9%)	19 (7%)	26 (12%)
Right	450 (91%)	252 (93%)	198 (88%)
Race			
Chinese	452 (91%)	251 (93%)	201 (90%)
Indian	25 (5%)	11 (4%)	14 (6%)
Malay	15 (3%)	6 (2%)	9 (4%)
Other	3 (1%)	3 (1%)	0 (0%)
Education Level			
Mean (SD)	3.35 (± 0.759)	3.26 (± 0.803)	3.46 (± 0.688)
Employment Status			
Employee	182 (37%)	103 (38%)	79 (35%)
Homemaker	26 (5%)	25 (9%)	1 (0%)
Retired	82 (17%)	40 (15%)	42 (19%)
Self-employed	64 (13%)	26 (10%)	38 (17%)
Semi-retired	8 (2%)	5 (2%)	3 (1%)
Student	93 (19%)	46 (17%)	47 (21%)
Unemployed	40 (8%)	26 (10%)	14 (6%)
Marital Status			
Divorced/Seperated	26 (5%)	13 (5%)	13 (6%)
Married	204 (41%)	106 (39%)	98 (44%)
Single	253 (51%)	142 (52%)	111 (50%)
Widowed	12 (2%)	10 (4%)	2 (1%)
Living Status			
Living alone	67 (14%)	43 (16%)	24 (11%)
Not living alone	428 (86%)	228 (84%)	200 (89%)
BMI Group (kg/m2)			
Underweight	36 (7%)	23 (8%)	13 (6%)
Normal	344 (69%)	194 (72%)	150 (67%)
Overweight	85 (17%)	37 (14%)	48 (21%)
Obesity	30 (6%)	17 (6%)	13 (6%)
Weight (kg)			
Mean (SD)	62.7 (± 13.6)	56.5 (± 11.3)	70.1 (± 12.3)
Height (cm)			
Mean (SD)	164 (± 9.22)	158 (± 6.15)	172 (± 6.85)

SD standard deviation

as it can handle correlated and complex data with several encoded categorical variables. To optimize model performance and reduce overfitting, we employed the tenfold cross-validation with 5 repeats [34]. Here, the sample was divided randomly into 10 parts, nine of which were for training and one for testing (validating) the model. We performed the procedure 10 times, each reserving a different tenth for testing. This cross-validation process was repeated 5 times to further refine the prediction accuracy during training, each time with a new random partitioning of the data. The model performance (MAE and R-squared) was averaged across all iterations to provide robust estimates of model performance. Finally, feature importance scores derived from the final model were computed and the top 5 variables, if any, were subsequently presented.

Results

Characteristics of study participants

Table 1 describes participant characteristics. Participants'age on average was 44.10 years for men and 45.40 years for women, ranging from 21 to 78 years. Almost half of the participants completed a university education from an institute of higher learning. Most participants were employed and lived with others. The average gait speed in men was 1.63 m/sec and in women was 1.50 m/sec.

Normative values of HGS and LPS

Tables 2 and 3 present the normative values of HGS and LPS individually, separated by 5-year age stratum, gender, and hand dominance strata. Each table provides detailed point estimates, including mean, standard deviation, median, minimum, and maximum values. Figure 1 depicts the relationship between age and HGS or LPS, which exhibits a curvilinear pattern. Our data indicate that grip and pinch strength in women peak between ages 40–44, while in men, average grip strength peaks at 35–39 years and pinch strength at 50–54 years. The standard deviation, representing variability in the sample, is notably higher for HGS than LPS in both genders.

In terms of the effect of hand dominance on HGS and LPS, as expected, the dominant hand had significantly higher strength than the non-dominant one for both HGS [Wilcoxon signed-rank tests, V = 20,921, $p < 0.0001$] and LPS [V = 21,576, $p < 0.0001$]. The average HGS was 29.31 kg and 27.52 kg for the dominant and non-dominant hands, with a mean difference of 1.79 kg. In contrast, the average LPS was 6.68 kg and 6.19 kg for the dominant and non-dominant hands, with a mean difference of 0.49 kg. No statistical difference in the dominant HGS [Wilcoxon rank sum test, W = 8776, p = 0.14], and in the dominant LPS [W = 9577.5, $p = 0.55$], between the right-handed and left-handed participants.

Table 2 Descriptive statistics for HGS and LPS in women by different age strata

Women	Hand Grip Strength		Lateral Pinch Strength	
Age Stratum	Dominant (kg)	Non-dominant (kg)	Dominant (kg)	Non-dominant (kg)
20–24 (n = 50)	23.0 (4.38) | 22.6 [10.8, 31.7]	21.6 (4.26) | 21.5 [9.60, 31.9]	5.45 (0.964) | 5.30 [3.70, 7.57]	5.12 (0.932) | 4.98 [3.40, 7.30]
25–29 (n = 19)	24.6 (3.75) | 23.9 [19.0, 33.4]	23.2 (4.05) | 22.9 [16.1, 32.1]	5.72 (0.894) | 5.80 [4.30, 7.40]	5.16 (1.23) | 5.03 [3.37, 7.30]
30–34 (n = 17)	25.3 (5.52) | 26.3 [14.6, 37.4]	23.8 (5.23) | 24.6 [13.0, 35.7]	6.14 (1.12) | 6.03 [4.27, 8.90]	5.70 (1.06) | 5.43 [4.30, 8.40]
35–39 (n = 17)	23.9 (4.97) | 22.9 [16.2, 32.4]	22.8 (4.72) | 22.3 [12.9, 30.8]	5.68 (0.648) | 5.60 [4.40, 6.53]	5.22 (1.26) | 5.20 [2.23, 6.70]
40–44 (n = 16)	27.3 (6.96) | 27.7 [11.8, 39.3]	25.0 (6.99) | 24.9 [10.4, 36.6]	6.28 (1.03) | 6.50 [3.30, 7.77]	5.69 (1.03) | 5.94 [3.40, 7.00]
45–49 (n = 22)	23.8 (3.68) | 24.1 [17.3, 31.2]	21.6 (3.93) | 21.1 [15.5, 30.7]	5.72 (0.864) | 5.45 [4.30, 7.40]	5.05 (1.02) | 4.84 [3.17, 6.80]
50–54 (n = 31)	24.3 (3.98) | 23.6 [16.8, 32.1]	23.2 (4.14) | 22.8 [14.7, 31.0]	5.91 (0.999) | 6.00 [3.72, 8.83]	5.32 (0.862) | 5.27 [3.90, 7.00]
55–59 (n = 39)	22.8 (4.06) | 23.7 [10.6, 29.3]	21.6 (4.34) | 21.5 [12.1, 31.6]	5.29 (1.00) | 5.50 [3.57, 7.40]	5.00 (0.975) | 5.10 [3.30, 7.16]
60–64 (n = 29)	22.8 (4.48) | 22.2 [15.6, 33.0]	20.9 (3.98) | 20.2 [14.5, 30.7]	5.51 (0.822) | 5.73 [3.90, 7.00]	4.90 (0.739) | 4.77 [3.60, 6.60]
65–69 (n = 22)	21.9 (4.38) | 22.1 [11.7, 30.1]	20.2 (4.61) | 20.0 [10.6, 27.4]	5.36 (1.01) | 5.45 [3.37, 7.30]	4.85 (1.13) | 5.02 [2.40, 6.50]
> 70 (n = 9)	19.2 (2.26) | 18.5 [16.9, 23.2]	18.4 (1.83) | 17.5 [15.8, 20.9]	4.31 (0.413) | 4.37 [3.70, 5.10]	4.13 (0.461) | 3.96 [3.80, 5.30]
Overall (n = 271)	23.5 (4.63) | 23.2 [10.6, 39.3]	22.0 (4.60) | 21.8 [9.60, 36.6]	5.59 (0.991) | 5.60 [3.30, 8.90]	5.12 (1.02) | 5.10 [2.23, 8.40]

Mean (SD) | Median [Min, Max]

Table 3 Descriptive statistics for HGS and LPS in men by different age strata

Men	Hand Grip Strength		Lateral Pinch Strength	
Age Stratum	Dominant (kg)	Non-dominant (kg)	Dominant (kg)	Non-dominant (kg)
20–24 (n = 50)	37.5 (8.23) | 36.5 [22.6, 52.6]	35.2 (8.04) | 34.3 [22.0, 51.3]	8.16 (1.82) | 7.90 [5.70, 16.1]	7.43 (1.80) | 7.26 [4.80, 15.5]
25–29 (n = 19)	36.7 (8.03) | 35.3 [20.4, 53.7]	35.8 (8.10) | 36.4 [19.0, 55.1]	8.06 (1.19) | 8.15 [5.80, 10.7]	7.74 (1.26) | 7.85 [5.60, 9.70]
30–34 (n = 17)	32.6 (8.63) | 31.9 [11.6, 50.6]	31.4 (8.70) | 31.2 [10.8, 43.9]	7.11 (1.97) | 7.60 [3.03, 10.0]	6.81 (1.74) | 7.30 [2.67, 9.33]
35–39 (n = 17)	40.4 (9.42) | 38.5 [27.2, 60.0]	35.8 (8.60) | 36.0 [22.3, 50.7]	8.52 (2.04) | 8.20 [5.57, 11.7]	8.08 (2.12) | 8.80 [4.93, 11.0]
40–44 (n = 16)	37.3 (6.53) | 38.6 [25.4, 49.9]	34.4 (6.52) | 36.6 [23.5, 47.0]	8.16 (1.55) | 7.80 [4.60, 11.6]	7.73 (1.49) | 7.70 [4.50, 11.6]
45–49 (n = 22)	34.5 (7.15) | 35.8 [19.8, 49.7]	33.6 (6.67) | 35.2 [20.8, 48.0]	7.66 (1.93) | 7.59 [4.10, 13.4]	7.19 (1.44) | 7.40 [4.73, 10.8]
50–54 (n = 31)	37.7 (8.69) | 37.6 [23.0, 54.8]	36.3 (7.90) | 34.3 [24.1, 51.2]	8.67 (1.48) | 8.57 [5.40, 12.1]	8.17 (1.49) | 7.90 [5.97, 11.4]
55–59 (n = 39)	36.4 (5.54) | 35.8 [28.0, 46.3]	33.5 (4.79) | 33.9 [26.0, 43.0]	8.35 (1.20) | 8.75 [5.50, 9.77]	7.72 (1.08) | 7.75 [5.37, 9.90]
60–64 (n = 29)	37.1 (6.66) | 38.4 [16.3, 49.0]	34.4 (5.81) | 33.9 [17.5, 43.4]	8.12 (1.52) | 8.30 [3.90, 10.4]	7.58 (1.63) | 7.60 [3.75, 9.90]
65–69 (n = 22)	36.0 (5.18) | 35.7 [28.2, 45.6]	33.6 (4.50) | 34.0 [25.5, 40.3]	7.49 (1.37) | 7.03 [5.40, 9.30]	7.04 (1.55) | 7.13 [4.40, 10.3]
> 70 (n = 9)	29.8 (5.56) | 27.0 [23.7, 38.9]	27.3 (6.11) | 28.5 [16.9, 35.6]	7.15 (1.26) | 7.20 [5.40, 9.80]	6.33 (1.75) | 5.95 [2.50, 9.10]
Overall (n = 271)	36.3 (7.59) | 36.3 [11.6, 60.0]	34.2 (7.24) | 34.1 [10.8, 55.1]	8.01 (1.61) | 7.94 [3.03, 16.1]	7.49 (1.61) | 7.50 [2.50, 15.5]

Mean (SD) | Median [Min, Max]

The mean dominant and non-dominant HGS in men were 36.26 kg and 34.12 kg, respectively [paired t-test, t(222) = 8.29, $p < 0.0001$]. In women, the mean dominant and non-dominant HGS were 23.51 kg and 22.00 kg, respectively [t(270) = 10.92, $p < 0.0001$]. Computing the mean difference resulted in 2.14 kg in men (dominant HGS is 6.23% greater than non-dominant) and 1.51 kg in women (dominant HGS is 6.86% greater than non-dominant). When taking right-handed participants only, the dominant HGS was 6.36% stronger than the non-dominant one. Similar characteristics were found in LPS. The mean dominant and non-dominant LPS in men were 7.97 kg and 7.45 kg [t(222) = 7.37, $p < 0.0001$]. In women, the mean dominant and non-dominant LPS were 5.59 kg and 5.12 kg [t(270) = 10.72, $p < 0.0001$]. The average difference was 0.52 kg in men (dominant LPS is 6.96% greater than non-dominant) and 0.47 kg in women (dominant LPS is 9.18% greater than non-dominant).

Table 4 shows the bivariate relationship between sample characteristics (age, weight, height, BMI, gait speed, and education level) and hand strengths of the dominant and non-dominant hands, stratified by gender. In women, higher HGS and LPS of the dominant hand were significantly correlated with younger age ($r = -0.14$ to -0.16), taller ($r = 0.18$ to 0.36), and heavier body build ($r = 0.27$ to 0.36), faster gait speed ($r = 0.16$ to 0.24), and higher

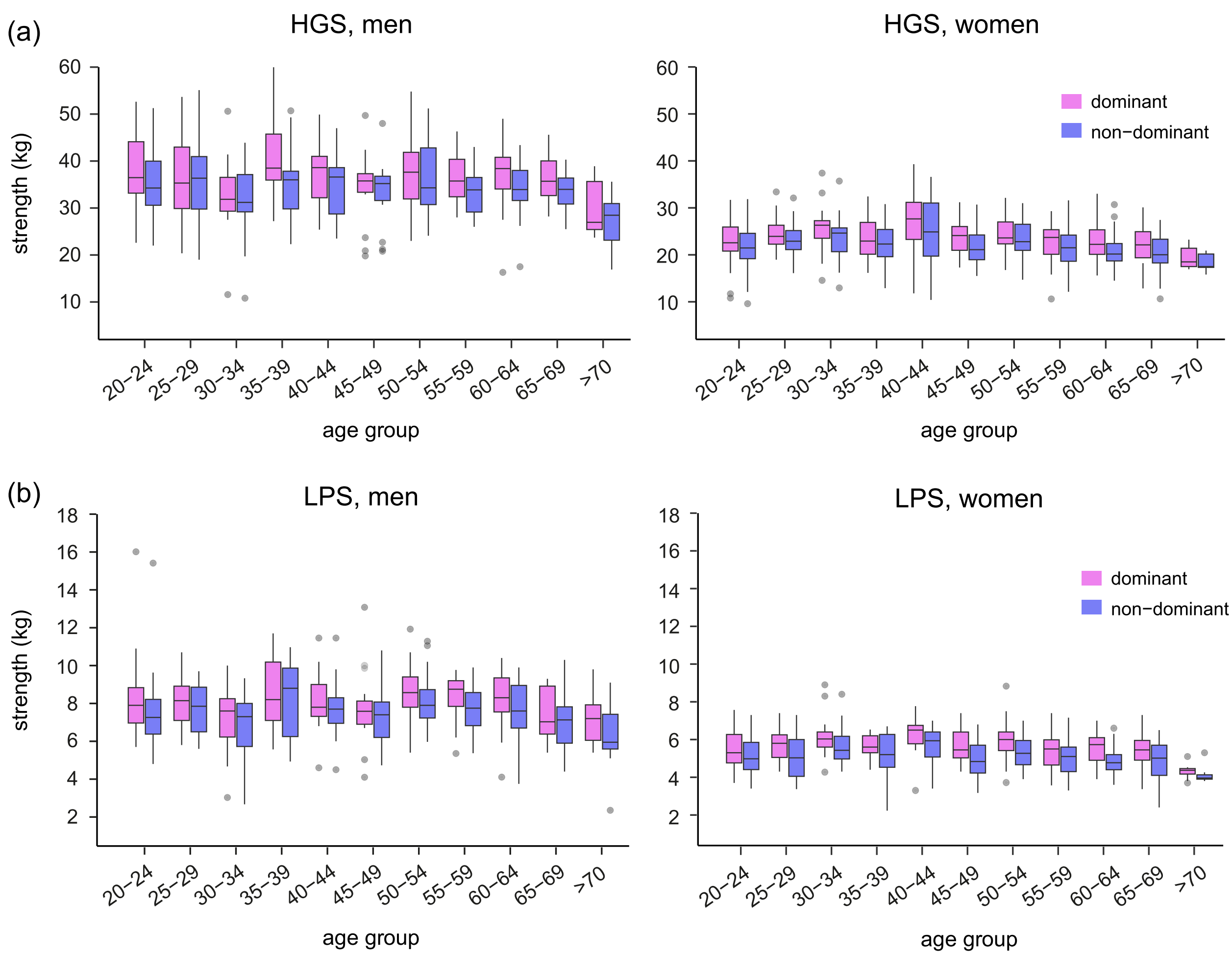

Fig. 1 Normative values of hand grip strength (HGS) and lateral pinch strength (LPS) from the current study; **a** Top Panel: Boxplots of HGS across 11 successive age groups from 21 to over 70 years. The edges of the boxplot represent the 25 th and 75 th percentiles, while the whiskers indicate the range of variation beyond the interquartile range. **b** Bottom Panel: Boxplots of LPS across the same 11 age groups

education level ($r = 0.19$ to 0.27). In contrast, higher HGS and LPS in men were found to be related only to taller ($r = 0.17$ to 0.33) and heavier body build ($r = 0.31$ to 0.35). A strong positive correlation was found between HGS and LPS values ($r = 0.62$ to 0.68) regardless of hand dominance and gender. Readers are invited to explore bivariate correlations for a specific age stratum using the web-based application stated earlier.

To further test the relationship between age and hand strength, a sub-group analysis was conducted to separate younger and older adults above a cutoff age of 50, following a recent study locally [24]. It was found that age was not strongly associated with LPS and HGS for adults younger than 50 years old. Most bivariate relationships remained like the one shown in Table 4 for the younger adult men. For younger women, only weight and BMI were strongly correlated with LPS. In contrast, age was found to be strongly associated with both HGS and LPS for older adults from 50 years old and above, regardless of hand dominance, having a range of reliable negative correlation coefficients (ρ) between − 0.36 and − 0.26 ($p < 0.001$). The negative relationships indicate that the older the person, the weaker the strength is.

Comparison with other asian norms

Figures 2 and 3 illustrate comparisons between our normative values and previously published normative values for dominant HGS and LPS, respectively. When comparing our findings with other studies that include similar age groups, differences in sample size in each age group shall be noted. This is taken into consideration in the figures by the point size of the respective plot, except for the Western reference dataset by Bohannon and colleagues (Fig. 2), which reflects the consolidated norms from 12 past studies with more than 3000 participants in the United States, Australia, Canada, and Europe.

Table 4 Strength in bivariate relationship (Spearman's correlation) between the hand strength of the dominant (Dom.) and non-dominant (Non Dom.) hand with each of the predictor variable of interest. Top and bottom panels describe the correlation for men and women respectively

Women				
	HGS		**LPS**	
	Dom.	Non Dom.	Dom.	Non Dom.
Age	− 0.14*	− 0.14*	− 0.14*	− 0.16**
Weight	0.28***	0.27***	0.36***	0.30***
Height	0.36***	0.32***	0.24***	0.18**
BMI	0.15*	0.16**	0.29***	0.24***
Gait speed	0.21***	0.24***	0.16*	0.12
Education level	0.27***	0.21**	0.245***	0.19**
Men				
	HGS		**LPS**	
	Dom.	Non Dom.	Dom.	Non Dom.
Age	− 0.10	− 0.13	− 0.05	− 0.07
Weight	0.33***	0.35***	0.31***	0.31***
Height	0.33***	0.30***	0.18**	0.17*
BMI	0.19**	0.24***	0.25***	0.27***
Gait speed	0.06	0.06	0.06	0.02
Education level	0.04	0.09	0.02	0.02

The stars represent the degree of statistical significance, where ***, **, and * represent $p < 0.001$, $p < 0.01$, and $p < 0.05$, respectively

Two studies of HGS with Singapore's older populations were included [35, 36]. Additionally, data from representative Asian countries such as Malaysia [37], Taiwan [38], Hong Kong [39], and South Korea [40], were also shown. Finally, we included consolidated normative values derived from a meta-analysis of Western populations [41]. Fewer studies have been conducted for LPS in Asia, however. Figure 3 illustrates the normative LPS values from Malaysia [37], South Korea [42], and Turkey [43]. For comparison, we presented Western normative values from America, which is one of the articles included in the consolidated norms reported by Bohannon and colleagues in 2006. In all studies, the average values by age and gender strata are shown for HGS and LPS, respectively. Data from the two articles (Yu et al. in Fig. 2, and Shim et al. in Fig. 3) are depicted with a different age range, that is, 10 years instead of 5.

The mean normative values of the current analytical sample were relatively comparable with those in other Asian studies but slightly lower than the reference values reported in the South Korean study. Lower HGS values than the consolidated norms were seen in all Asian studies included. In contrast, our mean LPS values were lower than those reported in other studies. Similar to HGS, Western populations (Americans) showed the highest LPS compared to Asians. Interestingly, young Singaporeans (20–30 years) have relatively stronger grip and pinch strengths than the corresponding young Indian population (average HGS in men: 33.67 kg and women: 19.51 kg; average LPS in men: 6.97 kg and women: 4.85 kg), measured at the same arm posture [44]. It is good to note that our normative data combined participants who are 70 years and older into the same group.

Feature importance

Figure 4 shows variables or features that influence HGS and LPS of the dominant hand using the RFE technique with random forests. The horizontal axis represents the variable importance score, with a higher value means the more informative a particular variable is in determining the hand strength. With the training data, model performance after the cross-validation reached MAE (and R-squared) of 5.61 (0.14) and 3.63 (0.15) for HGS in men and women, and MAE of 1.16 (0.11) and 0.71 (0.17) for LPS in men and women. It was found that weight, height, and age were important in determining the HGS and LPS of both genders. Interestingly, gait speed and education level appeared as important in the data for predicting HGS, but not so much for predicting LPS.

Discussion

This current work established the normative values for HGS and LPS in the adult population in Singapore, including individuals under 50. Previous studies have provided normative HGS data for older Singaporeans. For example, Malhotra and colleagues [35] reported the normative HGS values based on 2,500 older adults from 60 to 89 years old, making it the largest elderly population to date. Other local studies include the works by Ong and colleagues [36, 45] with older dementia group and, one latest study by Pua and colleagues (2023) who investigated HGS in community-dwelling ambulant older adults, including persons over 50 years old. Compared with existing local datasets, this is the first study with a large normative dataset studying HGS across both younger and older adults; and is also the first to report LPS norms. Earlier literature informs us of the need to establish local normative values and some Asian countries have produced their own normative range. This is because international data contain information on sociodemographic and anthropometric profiles that are different from Singaporeans, potentially reducing their clinical applicability locally [45].

In our subgroup analysis of adults aged 20 to 50 years, age was not significantly correlated with HGS and LPS. After controlling for gender, it was found that body height sufficiently predicts HGS values well, while LPS is more associated with height and weight.

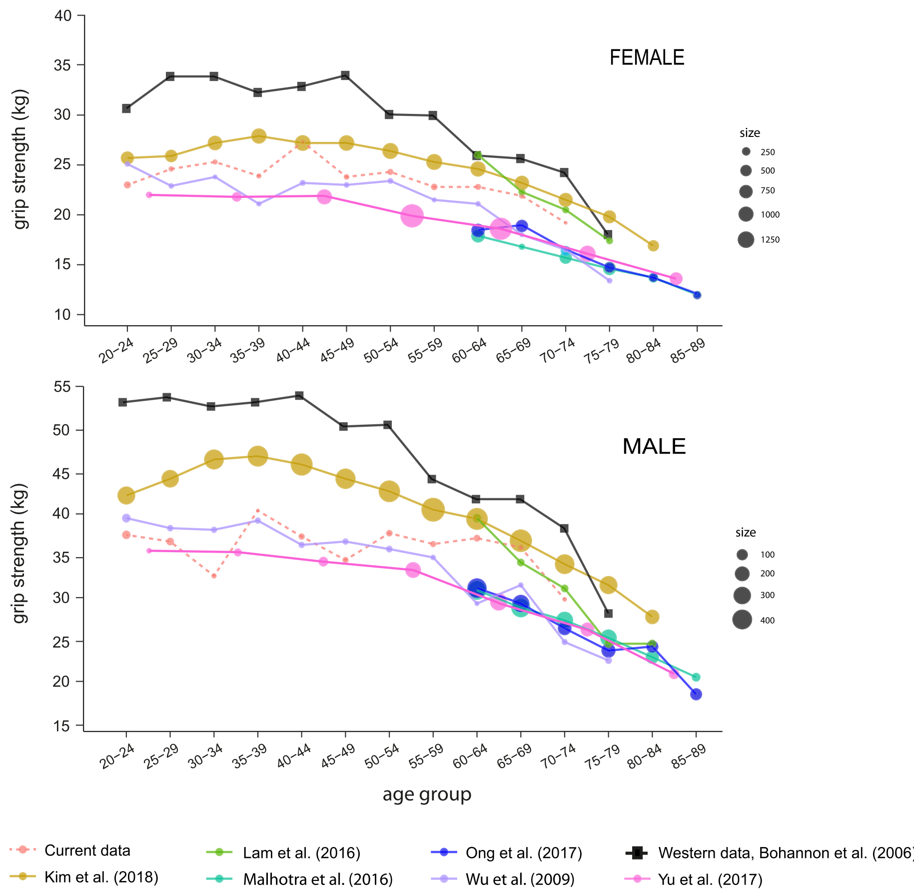

Fig. 2 Mean normative values for dominant HGS in Asian populations and consolidated Western populations extracted from past studies. In the plot, the size of each point is proportional to the sample size of the corresponding age group within each study. The plot in black depicts the combined reference values from the Western cohorts, which is comparatively higher than the rest of the Asian datasets

Understanding the relationship between HGS or LPS strength and health outcomes could be particularly relevant clinically for hand therapy in sports and rehabilitation medicine. Best practice clinical guidelines recommend interpreting one's HGS and LPS results against the norms with key mediators such as age, gender, and body size (height and/or weight) [46]. Normative data, however, can vary widely across countries and even within large countries due to cultural and social differences [38, 47]. This further supports the clinical value of a local normative dataset comprising the adult population of all age strata, for increased accuracy when interpreting baseline and follow-up assessment results to track changes over time.

Our data showed that HGS of the dominant hand was found to be 6—7% higher than in the non-dominant hand of both men and women. In a similar vein, LPS in the dominant hand was 7% and 9% higher than the non-dominant hand. Literature from Western populations suggests that the strength of the dominant hand is 10% greater than the strength of the non-dominant hand, but only for right-handed participants [48, 49]. This so-called '10% Rule' does not seem to be applicable to our data. One possible explanation is the diet and eating habits, as prior work has indicated that HGS is strongly related to nutritional status [1, 50]. Another reason could be the occupation of the local participants who were mainly office-bound workers, students, or retirees, instead of manual workers who are more likely to use the dominant hand regularly.

Several studies have found that grip strengths peak in early adult life, stabilize and decline with ageing as early as early as the fifth decade of life [51]. Typically, there are notable decline observed between grip strength and age across various studies. Although reliable correlations between HGS or LPS with age were lacking in our sample, the subgroup analysis for older adults (50 years and above) observed that age was negatively correlated with HGS and LPS. This is consistent with previous findings both locally and internationally [6, 35, 36, 52].

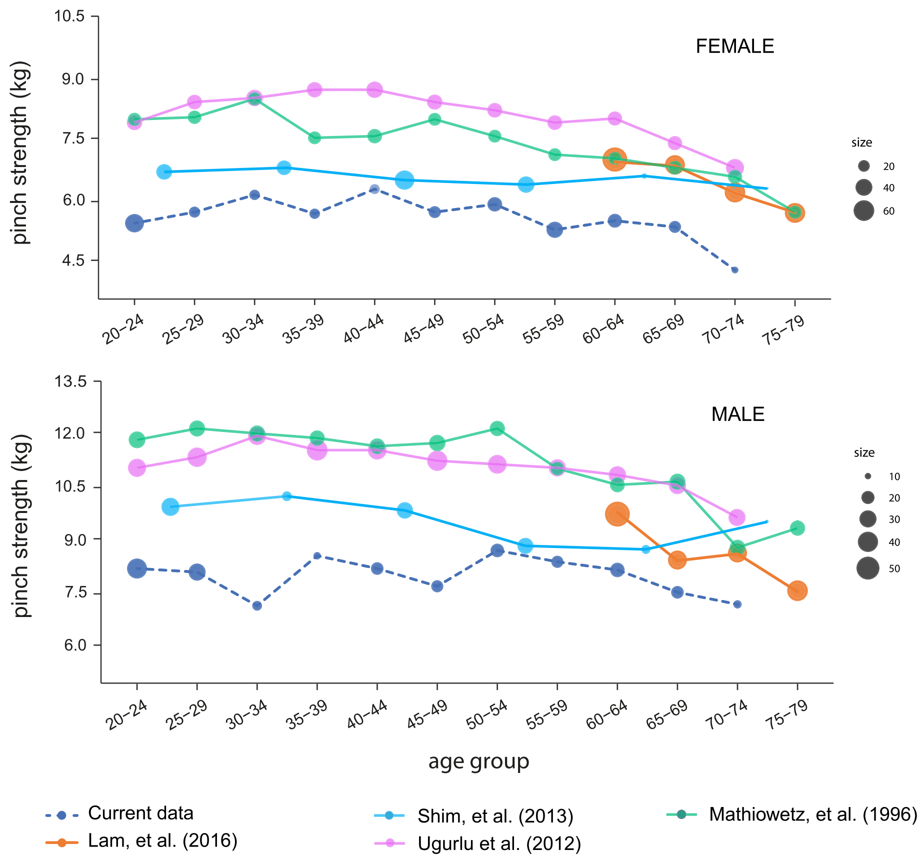

Fig. 3 Mean normative values for dominant LPS in Asian populations and consolidated Western populations extracted from past studies. In the plot, the size of each point is proportional to the sample size of the corresponding age group within each study

This study employed machine learning approaches to identify which variables are more informative in predicting the dominant HGS and LPS. Unlike correlation analyses, which only assess the relationship between two variables (e.g., pinch strength and weight), feature importance from the RFE algorithm tells us the degree of influence a list of predictors has on the dominant hand's strength. This data-driven algorithm is in contrast with past studies that used other methods with prior assumptions of linearity and normality of the data, such as multiple linear regression. Figure 4 shows the predictive value of gait speed in determining HGS, which is aligned with recent studies that link gait speed and HGS in ageing populations [53–55], where lower gait speed is associated with lower HGS. Gait speed and grip strength are also biomarkers of cognitive decline and dementia [56]. In contrast, the relationship between LPS and gait speed in the literature is unclear or less studied, if not none. Additionally, the appearance of education (Fig. 4) makes us speculate that health-conscious behavior is often associated with higher education levels [57, 58], thus, potentially influencing HGS.

Limitation and conclusion

The current study has some limitations. Primarily, the participants were not equally represented across age groups and ethnicities, as the number of older adults aged over 70 and individuals from minority groups was relatively small. However, the impact may be less significant given the availability of prior local studies that focused extensively on geriatric populations. The lack of information on participants' level of sports involvement may also pose a challenge, potentially limiting the ability to match certain participants based on comparable athletic backgrounds. Lastly, it is important to note that muscle mass was not included in our analysis. Given its potential variability among individuals, muscle mass could be a contributing factor influencing hand grip strength and should be considered in future studies. In summary, this study presents normative values for hand grip and pinch grip strengths in young and older populations in Singapore. Dominant hands are stronger than the non-dominant ones, but no statistical difference between the right- and left-handed participants in terms of dominant HGS and dominant LPS. The average values are found to be relatively lower

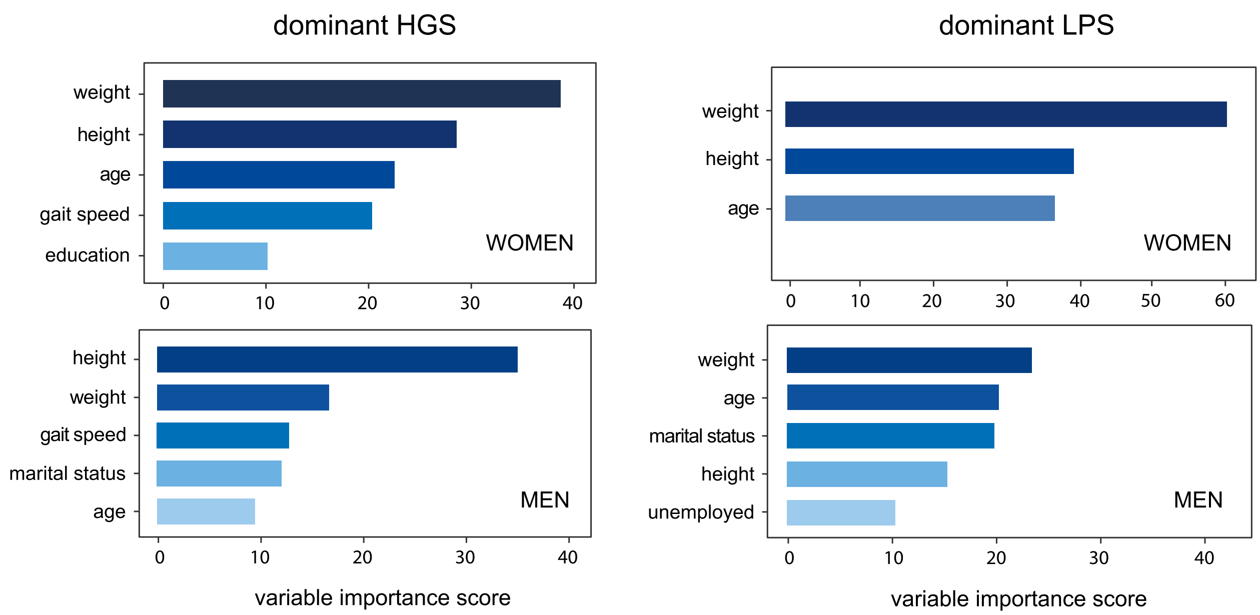

Fig. 4 Variables identified as essential predictors for HGS (left panel) and LPS (right panel) of the dominant hand using the Recursive Feature Elimination (RFE) algorithm with random forests. The horizontal axis in all plots represents the relative importance scores, indicating each variable's contribution to the predictive model, where the higher the value means the more important the variable is. The vertical axis shows the name of the variables sorted by the order of importance

than the consolidated Western norms, consistent with findings from previous local studies. The data can provide a valuable reference for researchers and healthcare practitioners to assess physical strength and monitor treatment progress, while also serving as a general health marker that can offer insights into fitness and fatigue levels.

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Authors' contributions
AS, WHPK, and EL were involved in the experiments and data curation; SLJ and AS performed formal analysis, software coding, and visualization; AS, EL, ILY, and WHPK were involved in writing the original draft, reviewing, and editing. PL and WTA did study conceptualization and project administration; WTA was the Principal Investigator, in charge of supervision and funding acquisition. All authors contributed to reviewing and approving the final manuscript. All authors declared no conflict of interest.

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Data availability
Data are provided within the manuscript can be accessed through a user-friendly online interface: https://ansidarta.shinyapps.io/shiny/.

Declarations

Ethics approval and consent to participate
The study was in accordance with the principles outlined in the Declaration of Helsinki. The study was approved by the Institutional Review Board, Nanyang Technological University (IRB- 2018–04 -01), and was conducted with the participants' informed and written consent.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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