

# Becoming A Two-Handed Surgeon: Comparing Non-Dominant Hand Strength and Dexterity Across Training stages

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## Research Article

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# Abstract

**Objective:** Bimanual skill in the operating room is essential to the maturation of surgical trainees, yet normative data on surgeon grip strength and dexterity are limited. Comparing dominant-non-dominant hand asymmetry and absolute performance across various stages of surgical training allows educators to identify areas for improvement and assess how targeted interventions can enhance surgical performance.

**Methods:** A cross-sectional study was conducted among medical students, surgical residents, and faculty. Hand strength was evaluated using a hydraulic dynamometer and pinch gauge across 4 tasks (hand grip, tip pinch, key-pinch, and palmar pinch). Manual dexterity was evaluated using the Purdue Pegboard across 4 tasks (dominant, non-dominant (ND), both-hand, and assembly). Within-subject asymmetry differences were analyzed using paired t-tests, and between-group comparisons across training stages using one-way ANOVA ( $\alpha=0.05$ ).

**Results:** One hundred and one participants (45 medical students, 39 residents, 17 faculty) were included. For hand strength, asymmetry of palmar pinch differed by training stage ( $p = 0.04$ ), with faculty showing less dominant–ND difference. In faculty 3 out of 4 measures showed symmetry between dominant and ND hands, compared to 1 out of 4 measures in medical students.

For dexterity again faculty had no significant asymmetry between dominant and ND hands ( $p = 0.344$ ) compared to medical students and residents who demonstrated asymmetry between hands ( $p = 0.02$  and  $p = 0.001$  respectively).

Hand strength did not differ among the three groups. Manual dexterity similarly did not differ across stage of surgical training, except for the both-hand task, where medical students outperformed residents and faculty ( $p = 0.02$ ).

**Conclusions:** Faculty showed greater hand symmetry strength and manual dexterity. However, strength and dexterity did not increase with progression through surgical training. These findings establish quantitative baselines for strength and dexterity that can be used to guide future studies evaluating targeted educational interventions to improve bimanual surgical skill rather than overall strength or dexterity.

## Introduction

Bimanual skill in the operating room is essential to the maturation of surgical trainees. Utilizing both hands proficiently during an operation confers technical advantages, which may reduce operative time and minimize complications.<sup>1</sup> Across multiple surgical specialties, individual steps within an operation may show laterality bias and can benefit from effective use of both hands.<sup>2–4</sup>

While true ambidexterity is uncommon, bimanual skill can be fostered through targeted training interventions.<sup>5</sup> These are often in the form of direct, task-specific practice with the non-dominant (ND) hand.<sup>6</sup> Additionally, studies have shown that interventions targeting the ND hand, confers benefits in both hands.<sup>7,8</sup> Despite this, actionable guidance on formal bimanual skills development during surgical training remains limited. One potential factor contributing to this is the lack of normative data on surgeons' grip strength and manual dexterity. Prior studies have largely examined these measures in relation to gender, specialty, or handedness, often emphasizing assumed innate differences rather than describing how levels of strength and dexterity may change throughout surgical training.<sup>9–12</sup> However, studies categorizing baseline strength and dexterity across training stages are limited.

Fitts and Posner's model of motor skill acquisition provides one framework for interpreting these measures: with practice, task performance progresses from cognitively demanding movements toward automatically coordinated execution.<sup>13</sup> Muscle fatigue and weakness are often cited as barriers to surgical skill, with trainees experiencing this to a greater degree than experienced surgeons.<sup>14–16</sup> Similarly, technical dexterity barriers such as instrument handling, time, and motion further comprise areas of improvement for trainees.<sup>17,18</sup> These can be measured through various measures of grip strength and manual dexterity tasks, such as hydraulic dynamometers and the Purdue Pegboard task.<sup>19,20</sup> Understanding baseline measures of surgical trainees allows for tracking over time and can aid in exploring how targeted interventions enhances surgical performance.

Thus, we conducted a cross-sectional study comparing hand strength and dexterity in dominant and ND hands across training stage in medical students, residents, and faculty comparing how dominant-ND asymmetry differed across training stages.

## Methods

### Study Design and Data Collection

This cross-sectional study evaluated hand strength and dexterity among medical students, surgical residents, and surgical faculty in the department of surgery from a single academic center. A convenience sample included medical students undergoing their surgical clerkship and current general surgery residents and faculty during skill simulation activities throughout the year. Before testing, participants completed a self-administered survey reporting age, sex, glove size, writing hand, and training role. The study protocol (Pro00062197) was determined to be exempt by the local Institutional Review Board and informed consent was obtained from all individual participants at the start of data collection.

### Grip Strength Assessment

Grip strength was assessed as a conceptually relevant measure to sustained instrument holding, retraction, or stapling. This was evaluated using the Jamar Hydraulic Hand Dynamometer (Model 63785; Sammons Preston, USA) following standard protocols (Fig. 1a).<sup>20-22</sup> Participants were seated in a chair with feet flat on the floor, elbows flexed to 90°, and wrists in a neutral position. Maximal isometric grip force was recorded to the nearest kilogram. Each hand was tested three times, beginning with the dominant hand. The mean force for each hand was calculated for analysis.

## Pinch Strength Assessment

Pinch strength was assessed in three configurations (key pinch, palmar pinch, and tip pinch) as a conceptually relevant measure to actions in the operating room including direct retraction of tissue, using forceps, and holding retractors. This was evaluated using a Jamar Hydraulic Pinch Gauge (Model 52603; Sammons Preston, USA) (Fig. 1b-d). Participants were seated on a chair with feet flat on the floor, shoulders adducted, elbows flexed at 90 degrees, and forearms and wrists in a neutral position. Each pinch configuration was performed three times per hand, with all measurements recorded. The mean force across trials was calculated for each hand.

## Dexterity Assessment

Hand dexterity was assessed using the Purdue Pegboard Test (Model 32020A; Lafayette Instrument Company, USA) as a standardized measure of fine motor coordination.<sup>19</sup> The pegboard consists of two parallel rows of 24 holes. Participants completed four standardized trials. The first trial instructed participants to place as many metal cylindrical pegs as possible into a single row within 30 seconds using their dominant hand. The second trial assessed the non-dominant hand using the same procedure. The third trial required simultaneous bimanual peg placement for 30 seconds, with both hands working in coordination. The fourth trial assessed bimanual assembly skills relevant to coordinated hand function. In this trial, participants inserted a peg into a pegboard hole with the dominant hand, followed by placing a washer with the non-dominant hand, a collar with the dominant hand, and a second washer with the non-dominant hand. This alternating sequence was repeated for 60 seconds. The total number of peg-collar-washer assembly components was recorded as the primary outcome for this trial.

## Statistical Analysis

Descriptive statistics were reported for categorical (frequency, %) and continuous (mean, SD) variables. Within-subject differences in hand asymmetry were evaluated using paired t-tests to account for repeated measurements within participants. Between-group comparisons across training stages were performed using one-way analysis of variance (ANOVA) to assess differences among groups, followed by post-hoc Tukey tests to adjust for multiple comparisons. Because this exploratory study used a convenience sample, no a priori sample-size or power calculation was performed. Data were inspected for normality and equal variance assumptions prior to analysis. Statistical significance was defined as  $\alpha$

= 0.05, and effect sizes were reported where appropriate to contextualize the magnitude of observed differences. Statistical analyses were performed using R (version 9.0, 2025 The R Foundation for Statistical Computing, Vienna, Austria).

## Results

### Participant Demographics

A total of 101 participants were included: 45 medical students, 39 residents, and 17 faculty. Mean age increased across training stages (medical students 26.2 years, residents 31.8 years, and faculty 46.1 years,  $p < 0.001$ ). Sex distribution, right-hand dominance, and glove-size distribution did not differ detectably among groups ( $p = 0.204$ ,  $p = 0.497$ , and  $p = 0.322$ , respectively). Most participants were self-reported right-hand dominant (85%), with 14% left-handed and 1% ambidextrous. Glove sizes were evenly distributed, with 51%  $\leq 6.5$  and 49%  $> 6.5$  (mean glove size =  $6.8 \pm 0.6$ ). Additional demographic characteristics are shown in Table 1.

Table 1  
Participant Demographics and  
Baseline Characteristics (n =  
101)

| Characteristic        | n (%)    |
|-----------------------|----------|
| <b>Sex</b>            |          |
| Female                | 54 (53%) |
| Male                  | 46 (46%) |
| Prefer not to say     | 1 (1%)   |
| <b>Age</b>            |          |
| 20–29                 | 52 (51%) |
| 30–39                 | 39 (39%) |
| 40–49                 | 4 (4%)   |
| 50–59                 | 4 (4%)   |
| 60–69                 | 2 (2%)   |
| <b>Hand dominance</b> |          |
| Right                 | 86 (85%) |
| Left                  | 14 (14%) |
| Ambidextrous          | 1 (1%)   |
| <b>Glove Size</b>     |          |
| 5-5.5                 | 5 (5%)   |
| 6-6.5                 | 47 (47%) |
| 7-7.5                 | 42 (42%) |
| 8-8.5                 | 7 (7%)   |
| <b>Training Level</b> |          |
| Medical Student       | 45 (45%) |
| Resident              | 39 (39%) |
| Faculty               | 17 (17%) |

## Differences in Hand Strength

Faculty had a significantly stronger palmar pinch than medical students and residents ( $p = 0.04$ ). No other measures showed a difference across training stage. In 3 out of 4 measures of strength there was no difference in dominant and ND hands in faculty. This contrasted with residents and medical students who demonstrated asymmetry between dominant hand and ND hand strength in 3 of 4 measures (medical students hand grip  $p < 0.001$ , tip pinch  $p = 0.007$ , palmar pinch  $p = 0.005$ , residents (hand grip  $p < 0.001$ , key pinch  $p = 0.043$ , palmar pinch  $p = 0.003$ ).

## Differences in Dexterity

Faculty demonstrated no significant asymmetry between dominant and ND hands in performance on the Purdue Pegboard scores. This contrasts with the medical students and residents whose dominant hands showed higher Purdue Pegboard scores than ND hands ( $p = 0.022$  and  $p = 0.001$ , respectively).

## Strength and Dexterity Distribution

Mean and standard deviations (SD) for strength and dexterity stratified by training stage and hand are displayed in Tables 2–3. Hand strength did not differ significantly across training stages for any test in either hand (Table 2). For dexterity, dominant hand, ND hand, and assembly tasks did not significantly differ across training stages. However, both-hand Purdue Pegboard performance differed significantly across groups, with medical students outperforming residents and faculty (mean pegs 13.0 vs. 12.0 and 11.5 respectively,  $p = 0.023$ ) (Table 3).

Table 2  
Hand Strength by Training Level and Hand Dominance

| Group                                                                                                                                                                                                                                                                                                                        | Dominant (mean $\pm$ SD, lbs) | ND (mean $\pm$ SD, lbs) | Difference (Dominant – ND, 95% CI) | p-value           |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------|-------------------------|------------------------------------|-------------------|
| <b>Hand Grip</b>                                                                                                                                                                                                                                                                                                             |                               |                         |                                    |                   |
| Medical Student                                                                                                                                                                                                                                                                                                              | 81.9 $\pm$ 22.6               | 74.5 $\pm$ 23.1         | 7.36 (4.41–10.31)                  | <b>&lt; 0.001</b> |
| Resident                                                                                                                                                                                                                                                                                                                     | 91.8 $\pm$ 26.7               | 84.3 $\pm$ 25.9         | 7.43 (4.41–10.46)                  | <b>&lt; 0.001</b> |
| Faculty                                                                                                                                                                                                                                                                                                                      | 93.8 $\pm$ 26.0               | 89.6 $\pm$ 29.1         | 4.17 (-0.41–8.74)                  | 0.072             |
| Between-group p-value (ANOVA)                                                                                                                                                                                                                                                                                                | 0.109†                        | 0.065‡                  | 0.441§                             | –                 |
| <b>Tip Pinch</b>                                                                                                                                                                                                                                                                                                             |                               |                         |                                    |                   |
| Medical Student                                                                                                                                                                                                                                                                                                              | 10.9 $\pm$ 3.7                | 9.9 $\pm$ 3.1           | 0.99 (0.28–1.70)                   | <b>0.007</b>      |
| Resident                                                                                                                                                                                                                                                                                                                     | 12.3 $\pm$ 4.3                | 11.4 $\pm$ 4.7          | 0.89 (-0.04–1.83)                  | 0.060             |
| Faculty                                                                                                                                                                                                                                                                                                                      | 12.2 $\pm$ 4.0                | 12.4 $\pm$ 4.2          | -0.21 (-0.96–0.55)                 | 0.571             |
| Between-group p-value (ANOVA)                                                                                                                                                                                                                                                                                                | 0.239†                        | 0.060‡                  | 0.210§                             | –                 |
| <b>Key Pinch</b>                                                                                                                                                                                                                                                                                                             |                               |                         |                                    |                   |
| Medical Student                                                                                                                                                                                                                                                                                                              | 18.1 $\pm$ 5.3                | 17.3 $\pm$ 5.6          | 0.82 (-0.02–1.65)                  | 0.054             |
| Resident                                                                                                                                                                                                                                                                                                                     | 20.0 $\pm$ 6.5                | 18.9 $\pm$ 6.2          | 1.04 (0.03–2.04)                   | <b>0.044</b>      |
| Faculty                                                                                                                                                                                                                                                                                                                      | 19.9 $\pm$ 5.8                | 18.3 $\pm$ 5.2          | 1.64 (0.79–2.48)                   | <b>&lt; 0.001</b> |
| Between-group p-value (ANOVA)                                                                                                                                                                                                                                                                                                | 0.312†                        | 0.447‡                  | 0.578§                             | –                 |
| <b>Palmar Pinch</b>                                                                                                                                                                                                                                                                                                          |                               |                         |                                    |                   |
| Medical Student                                                                                                                                                                                                                                                                                                              | 16.5 $\pm$ 3.7                | 15.3 $\pm$ 3.9          | 1.19 (0.38–2.00)                   | <b>0.005</b>      |
| Resident                                                                                                                                                                                                                                                                                                                     | 17.2 $\pm$ 5.0                | 16.0 $\pm$ 4.8          | 1.19 (0.43–1.94)                   | <b>0.003</b>      |
| Faculty                                                                                                                                                                                                                                                                                                                      | 16.5 $\pm$ 4.1                | 17.0 $\pm$ 4.4          | -0.50 (-1.61–0.61)                 | 0.36              |
| Values represent mean $\pm$ SD strength (lbs). Difference represents dominant – non-dominant strength with 95% confidence intervals (CI). Within-group comparisons used paired t-tests; between-group comparisons used ANOVA. <b>ND</b> , non-dominant; <b>CI</b> , confidence interval; <b>ANOVA</b> , analysis of variance |                               |                         |                                    |                   |
| † ANOVA comparing dominant hand strength across training levels.                                                                                                                                                                                                                                                             |                               |                         |                                    |                   |
| ‡ ANOVA comparing non-dominant hand strength across training levels.                                                                                                                                                                                                                                                         |                               |                         |                                    |                   |
| § ANOVA comparing dominant–non-dominant asymmetry across training levels.                                                                                                                                                                                                                                                    |                               |                         |                                    |                   |

| Group                                                                                                                                                                                                                                                                                                                        | Dominant (mean $\pm$ SD, lbs) | ND (mean $\pm$ SD, lbs) | Difference (Dominant – ND, 95% CI) | p-value |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------|-------------------------|------------------------------------|---------|
| <b>Hand Grip</b>                                                                                                                                                                                                                                                                                                             |                               |                         |                                    |         |
| Between-group p-value (ANOVA)                                                                                                                                                                                                                                                                                                | 0.740†                        | 0.385‡                  | <b>0.040§</b>                      | –       |
| Values represent mean $\pm$ SD strength (lbs). Difference represents dominant – non-dominant strength with 95% confidence intervals (CI). Within-group comparisons used paired t-tests; between-group comparisons used ANOVA. <b>ND</b> , non-dominant; <b>CI</b> , confidence interval; <b>ANOVA</b> , analysis of variance |                               |                         |                                    |         |
| † ANOVA comparing dominant hand strength across training levels.                                                                                                                                                                                                                                                             |                               |                         |                                    |         |
| ‡ ANOVA comparing non-dominant hand strength across training levels.                                                                                                                                                                                                                                                         |                               |                         |                                    |         |
| § ANOVA comparing dominant–non-dominant asymmetry across training levels.                                                                                                                                                                                                                                                    |                               |                         |                                    |         |

Table 3  
Purdue Pegboard Dexterity Performance by Training Level

| Group                                                                                                                                                                                                                                                                                                                                                                                                                | Dominant (mean $\pm$ SD) | Non-dominant (mean $\pm$ SD) | Difference (Dominant – ND, 95% CI) | p-value¶     | Both Hands (mean $\pm$ SD) | Assembly (mean $\pm$ SD) |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------|------------------------------|------------------------------------|--------------|----------------------------|--------------------------|
| Medical Student                                                                                                                                                                                                                                                                                                                                                                                                      | 16.9 $\pm$ 2.5           | 15.8 $\pm$ 2.2               | 1.16 (0.18–2.14)                   | <b>0.022</b> | 13.0 $\pm$ 2.2             | 35.3 $\pm$ 6.8           |
| Resident                                                                                                                                                                                                                                                                                                                                                                                                             | 16.3 $\pm$ 2.8           | 15.0 $\pm$ 2.3               | 1.28 (0.55–2.01)                   | <b>0.001</b> | 12.0 $\pm$ 1.9             | 36.3 $\pm$ 8.5           |
| Faculty                                                                                                                                                                                                                                                                                                                                                                                                              | 16.5 $\pm$ 2.4           | 15.7 $\pm$ 2.6               | 0.76 (-0.90–2.43)                  | 0.344        | 11.5 $\pm$ 1.9             | 31.5 $\pm$ 10.4          |
| <b>Between-group p-value (ANOVA)</b>                                                                                                                                                                                                                                                                                                                                                                                 | 0.537†                   | 0.300‡                       | 0.828§                             | –            | <b>0.023</b>               | 0.129                    |
| Values represent mean number of pegs placed for single-hand and both-hand tasks and number of components for the Assembly task. Difference represents dominant – non-dominant performance with 95% confidence interval (CI). Within-group comparisons used paired t-tests; between-group comparisons used one-way analysis of variance (ANOVA). <b>CI</b> , confidence interval; <b>ANOVA</b> , analysis of variance |                          |                              |                                    |              |                            |                          |
| † Dominant hand performance across training levels                                                                                                                                                                                                                                                                                                                                                                   |                          |                              |                                    |              |                            |                          |
| ‡ Non-dominant hand performance across training levels                                                                                                                                                                                                                                                                                                                                                               |                          |                              |                                    |              |                            |                          |
| § Dominant – non-dominant asymmetry across training levels                                                                                                                                                                                                                                                                                                                                                           |                          |                              |                                    |              |                            |                          |
| ¶ p-values correspond to within-group comparisons of dominant vs non-dominant hands using paired t-tests                                                                                                                                                                                                                                                                                                             |                          |                              |                                    |              |                            |                          |

## Discussion

### Summary of Findings

We conducted a cross-sectional study evaluating dominant and ND hand strength and dexterity differences across surgical training stages. Faculty demonstrated greater symmetry between their dominant and ND hands in both hand strength and manual dexterity. Medical students and residents consistently had asymmetry between their hands with their dominant hand being stronger and more dexterous than their ND hand. These suggest that surgical expertise may not be characterized by increases in absolute hand strength or baseline dexterity but rather by more balanced bimanual skill and increased functionality of the ND hand. This interpretation is consistent with studies demonstrating superior bimanual dexterity with specific operative tasks and instrument handling, such as speed of robotic suturing.<sup>23,24</sup>

Absolute strength values and global dexterity did not differ significantly across training stages, suggesting that increasing surgical experience is not associated with greater overall hand strength or global dexterity as measured by our selected instruments. In contrast, medical students outperformed faculty and residents in the both-hand Purdue Pegboard task. These findings are consistent with prior studies in the general population that show strength and dexterity decreases with age.<sup>25</sup>

The improvements in symmetry of hand strength and dexterity among experienced surgeons is likely related to operative practice, where frequent use of the non-dominant hand for retraction, tissue manipulation, and dissection may promote development of more balanced strength and dexterity, even if absolute levels do not increase. For instance, the palmar pinch strength task has a plausible construct relevant relationship to gripping and retracting with forceps. Fitts and Posner's motor learning framework explains this through task-specific practice that builds development of skill expertise.<sup>13</sup> These results support emphasis on bimanual practice as a key component of surgical skill acquisition with feedback focused on deliberate non-dominant hand practice during simulation or operative experience during training.<sup>5-8</sup> Emphasis on bimanual training may also be particularly helpful for left-handed trainees, who are underrepresented and often report barriers to learning, which may discourage these trainees from pursuing a surgical specialty or lead to technical performance issues early in training.<sup>26-28</sup>

### Limitations

This study has several limitations. First, convenience sampling and differing recruitment channels may have introduced selection bias. Second, the sample size of resident and faculty participants limited statistical power for subgroup analyses by specific trainee year or surgical subspecialty. For example, robotic surgeons may have different patterns compared to surgeons who primarily operate laparoscopically or open.<sup>29</sup> Third, this study evaluated baseline motor characteristics rather than real-world surgical performance, and the generalizability of how these measures directly translate to operative proficiency remains to be explored.

Hand size and sex-related differences may also influence strength and dexterity measurements. In this cohort, sex, hand dominance, and glove-size did not differ across training stages. However, prior studies have demonstrated that greater grip strength is associated with larger hand size and male sex, whereas improved Purdue Pegboard performance has been associated with smaller hand size and female sex.<sup>30,31</sup> These anatomical factors may contribute to variability in baseline performance across individuals and variability in performance on these tasks across individuals, with unknown relationships to surgically relevant strength and dexterity.<sup>18,26,27</sup>

## Future Directions

Future work should focus on educational interventions designed to improve non-dominant hand function and bimanual skill in surgical trainees, as prior work has shown that training the ND hand improves dominant hand skills and decreases fatigue of both hands.<sup>7</sup> Simulation-based training modules, structured non-dominant hand practice, and motion-tracking assessments may provide objective ways to evaluate and enhance bilateral motor performance. Finally, studies incorporating larger faculty cohorts and specialty-specific analyses may help clarify how operative practice patterns influence hand symmetry and motor skill development over time.

## Conclusion

Faculty showed more balanced strength and dexterity of their hands, likely reflecting adaptation to operative tasks that require effective non-dominant hand utilization. Surgical expertise does not appear to be characterized by greater absolute hand strength or baseline dexterity. These findings suggest that surgical training should emphasize the development of bimanual coordination and deliberate practice with the non-dominant hand. Establishing normative benchmarks for hand strength and dexterity provides a foundation for future studies evaluating targeted educational interventions to improve bimanual surgical skill.

## Declarations

### Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☒ The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

## Ethics Approval:

The study protocol (Protocol ID: Pro00062197) was determined to have exempt status by the Duke Health Institutional Review Board. Informed consent was obtained from all individual participants

included in the study.

## Conflict of Interest

The authors have no relevant financial or non-financial interests to disclose

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## Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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## Figures

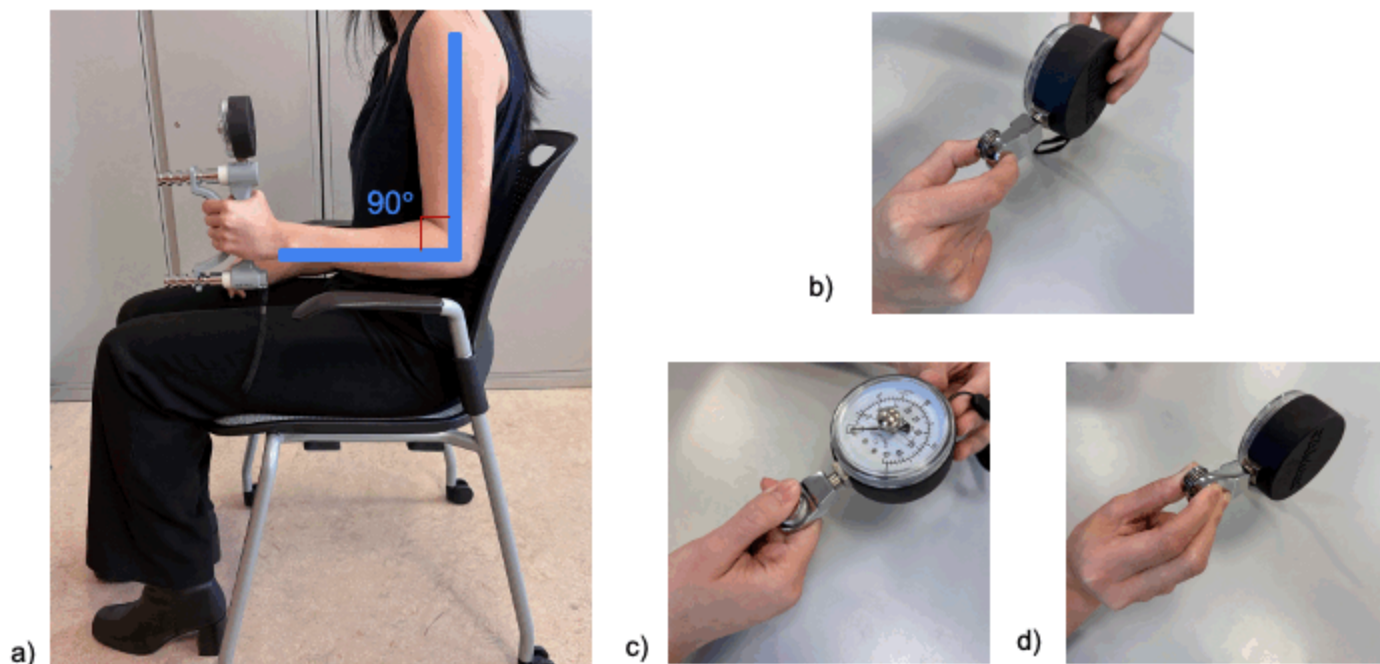


**Figure 1**

**Hand strength assessment protocol.**

**a) Participant positioned seated with arm at side, elbow flexed to 90° using the Jamar hydraulic dynamometer; b) tip pinch measurement, c) key pinch measurement, and d) palmar pinch measurement**