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An Ultrasound Study of the Mobility of the Median Nerve during Composite Finger Movement in the Healthy Young Wrist

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Abstract

Introduction/Aims: There is a lack of consensus regarding median nerve movement in the carpal tunnel during composite finger flexion in healthy individuals. This study aimed to examine the amount and direction of median nerve movement and differentiate nerve mobility between dominant and non-dominant sides in a large healthy young adult cohort.

Methods: Sonographic videos of the median nerve during composite finger motion from extension to full flexion were analyzed in 197 participants without median nerve pathology. Displacement of the nerve's centroid was calculated based on a change in the relative location of the nerve. Longitudinal nerve sliding was categorized as none, independently from the tendons, or with the tendons.

Results: In short axis, median nerves moved within 1 mm vertically and 3 mm horizontally; no direction was predominant. About half of the nerves (52.5%) slid independently while 26.9% slid with the tendons; 21.3% did not slide at all. On the non-dominant side, median nerves that slid with the tendons had a larger absolute vertical displacement than nerves that slid independently or did not slide at all ($p<0.01$). Nerves on the dominant side moved in a radial direction more frequently than on the non-dominant side ($p=0.02$).

Discussion: Transverse nerve movement during composite finger flexion in healthy individuals varies widely with no clear pattern in the direction of transverse movement or amount of longitudinal sliding. These data provide a foundation for future research to better understand the biomechanical contribution of nerve movement to median nerve pathologies.

Keywords

sonography; median nerve; displacement; movement

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Introduction

Repetitive movements of the hands, wrists, and fingers have been identified as key contributing factors in the development of median nerve pathologies.[1,2] Specifically, constant or repeated, fast-paced, and heavy-force finger or hand movements introduce compression, strain, and shear stress on the median nerve and may contribute to pathological processes of demyelination, fibrosis, and ischemic injury.[3] Dynamic ultrasound imaging has been used to investigate the impact of finger movement on the median nerve with a focus on nerve compression,[4,5] mobility of the nerve within the carpal tunnel,[6,7] and gliding or sliding of the nerve relative to the flexor tendons.[8–10] In patients with carpal tunnel syndrome, the median nerve tended to have more limited movements during finger movements than in healthy controls, with more restricted mobility as symptoms increased or the condition became more chronic.[3,11]

To interpret nerve mobility findings among clinical populations and to be able to evaluate effects of functional hand use on pathological changes of the median nerve, it is essential to illustrate and understand the dynamic biomechanics of the normal anatomical structures in the carpal tunnel in healthy people. While reliability has been established for evaluating nerve excursion in a longitudinal plane using sonography, studies measuring median nerve movement in a cross-sectional plane have conflicting results.[6,9,11–15] For example, in fifteen healthy individuals, Yoshii et al.[6] found that the median nerve moved to the volar-ulnar side during a four-finger flexion motion. In contrast, using data from a different sample of fifteen asymptomatic people, Van Doesburg et al.[14] found that the nerve moved to the radial-dorsal side during finger movements.

In addition to lack of consensus regarding the direction of nerve motion, there is limited research describing the amount of movement that is typical in healthy individuals. Most previous studies examining nerve mobility in healthy individuals have had small sample sizes, and rarely accounted for or compared movement differences in the dominant and non-dominant sides. Given these limitations, the aims of this study were to describe median nerve movement during composite finger flexion and extension and to examine any effects of laterality between the dominant and non-dominant sides in a young healthy population.

Methods

Participants and procedures

A cross-sectional, observational study was conducted with students recruited from two universities between June 2015 and September 2018. The institutional review boards at both universities approved the study protocol, and informed consent was obtained from all research subjects prior to participation. Participants were excluded if they had a history of carpal tunnel release surgery or a known diagnosis of median nerve pathology. Once enrolled, nerve conduction studies were performed to verify that no median nerve pathology existed, and participants were excluded if a bifid median nerve was identified in sonographic analysis.

Demographic data (age, gender, ethnicity/race, and hand dominance) and any history of diabetes, arthritis, multiple sclerosis, spinal cord injury, traumatic brain injury, stroke/ cerebrovascular accident, or hypertension were self-reported by the participants. External wrist width and depth were measured at the distal wrist crease using a digital caliper. Sonography was performed by one of two sonographers, each with more than 10 years of experience, using a Logiq-e (GE Healthcare, Milwaukee, WI) ultrasound machine and a 12-MHz linear array transducer. The participant was seated facing the sonographer with the shoulder adducted, forearm fully supinated and resting on the table, and elbow comfortably extended (e.g., approximately 120 degrees). Transverse images of the median nerve were obtained at the level of the pisiform and longitudinal images of the nerve were obtained centered over the radial-carpal joint (Supplemental figure 1). In both views, participants slowly moved the fingers from a relaxed, open position to a closed fist without any forceful squeezing. This full fist position was held for two seconds before slowly extending the fingers back to a relaxed, open position. Videos of the composite finger movement were obtained at least twice in each plane to ensure high-quality images were available for analysis.

Image Processing

All ultrasound data were imported into ViewPoint 6 (GE Healthcare) and screened to identify bifid median nerves; these participants were excluded. Cross-sectional videos were reviewed to identify one clip per participant with the best optimization of the nerve. To minimize measurement error caused by transducer movement, any clips where the pisiform was observed to move within the frame were excluded. Two still frames were identified within each included video for measurement of transverse displacement. First, a relaxed position image with the clearest resolution of the median nerve was selected from the frames prior to the initiation of any movement. Second, a full fist position image was selected from the middle of the clip once all motion had paused. Longitudinal videos were screened in a similar manner to identify one clip per participant that was stable, had high image clarity, and showed the entire length of the nerve throughout the composite finger movement. Prior to displacement analyses, the carpal tunnel width, depth, and cross-sectional area were measured in the transverse carpal tunnel images for all participants. Linear measures were obtained at the furthest distance from the inner border of the pisiform to the scaphoid bone (width) and from the carpal ligament to the lunate or triquetrum (depth). Area was measured around the inner border of the four bones and the carpal ligament.

Transverse Displacement Analysis

Transverse displacement of the median nerve within the carpal tunnel was evaluated using the two still images of relaxed position and full fist position by establishing coordinate points for the nerve’s centroid on each image (Supplemental figure 2). The centroid of the nerve area was determined as the common intersection of two sets of approximately orthogonal lines after each of the four lines was drawn to bisect the area of the nerve. A vertical line and a horizontal line were placed over the image at a 90° angle with the vertex of the lines positioned directly over the nerve’s centroid. By tracing over the vertical line, a vertical coordinate point was identified as the distance from the top edge of the sonographic image (i.e., skin surface) to the centroid of the nerve area. The horizontal coordinate point was identified as the distance along the horizontal line from the ulnar edge of the image to the centroid of the nerve area.

This measurement process was repeated three times on every image. Average values were calculated for each vertical and horizontal distance to establish an average coordinate point for the location of the nerve in both the relaxed position and full fist position images. Vertical and horizontal displacement were calculated by subtracting the respective coordinate value at relaxed position from the value at full fist position in paired images from each video. Endpoint displacement was calculated using the formula: $\sqrt{a^2 + b^2}$ where a and b represent each of the displacement values. Endpoint displacements of the median nerve were categorized into four groups based on their movement directions: Volar-Radial, Volar-Ulnar, Dorsal-Ulnar, and Dorsal-Radial.

Transverse displacement measurements were performed by three raters. Prior to conducting measures, each rater conducted the displacement analysis process three times for each of 10 cases, completing one round of measurements per day over three days. All intraclass correlation coefficients (ICCs) were excellent for intra-rater (0.981 to 0.999) and inter-rater (0.955 to 0.994) reliability. The three trained raters then coded all cases independently, with only one rater coding each frame. The calculated values for vertical, horizontal, and endpoint displacement represented both the distance and direction of movement. An absolute value for each measure was used to represent the distance of movement regardless of direction.

Longitudinal Sliding Analysis

A registered musculoskeletal sonographer (RMSKS) with more than 10 years of experience and the three raters developed a system for classifying longitudinal sliding of the median nerve relative to the tendons in videos. *No sliding* was determined when the there was no visible proximal or distal movement of the median nerve (Supplemental video 1). *Sliding independently from the tendons* occurred when median nerve movement was noticeable but was slower than or asynchronous to the movement of the tendons in the far field (Supplemental video 2). *Sliding with the tendons* was indicated when the nerve and tendons moved at approximately the same speed and by the same distance during finger movement (Supplemental video 3). Before independently coding images, multiple rounds of 5 to 10 randomly selected cases were coded by all three raters. Pairwise agreement for subjective categorization of nerve movement was > 0.75. The final coding process was completed by the three raters independently; only one rater coded each of the images.

Statistical Analysis

Descriptive analyses for normally distributed continuous results are expressed as mean ± standard deviation (SD) and non-normal distributions as median and interquartile range (IQR). Correlations between external wrist and internal carpal tunnel measures with transverse nerve displacements were tested using Pearson correlation coefficient to determine if any within-person weighting or adjustments were necessary. All correlations were exceptionally weak ($r < 0.13$), therefore no adjustments were completed. Furthermore, because our dataset included both dominant and non-dominant wrists from all participants, all comparative analyses examining differences between the dominant and non-dominant hands were conducted to evaluate within-subject differences rather than general overall differences. Paired t-tests were conducted to compare differences in the amount of vertical and horizontal displacement; Wilcoxon signed rank tests were used to examine differences in the amount of vertical absolute movement, horizontal absolute movement, and endpoint absolute movement; McNemar's chi-squared test was used to examine differences in the direction of movement. A two-dimension kernel distribution was charted to visually interrogate the combined distance and direction for all endpoint displacements across the sample. Differences between sides in type of longitudinal sliding were examined using a non-linear mixed model (SAS: PROC GENMOD, DIST=MULT) that accounted for within-subject correlation of hand dominance. The amount of transverse displacement by side was compared across the three longitudinal sliding groups using analysis of variance and Kruskal-Wallis tests.

Given the study sample size, for 80% power, an alpha level of 0.05, and assuming a standard deviation of the difference of 1, the minimal detectable effect size is 0.20 for paired t-test analyses and 0.21 for Wilcoxon signed rank tests, ensuring that our study was powered to detect small effect sizes. Additionally, the sample size allowed for a minimal detectable proportion difference of 15% for comparing proportion differences. Data were analyzed using Stata 15.1 (StataCorp, College Station, TX) and SAS 9.4 (SAS Institute Inc., Cary, NC), and a $p < .05$ was considered statistically significant.

Results

A total of 229 students were recruited, 30 (13.1%) of whom had at least one bifid median nerve and two had missing data. Demographics of the remaining 197 included participants are presented in Table 1, and none of these participants reported any history of the medical conditions noted in the Methods. The mean or median transverse displacement during composite finger movement for dominant and non-dominant hands are reported in Table 2. There was a statistically significant but weak difference (Cohen's d = 0.33) in horizontal displacement between the dominant hand and the non-dominant hand; however, there was no statistically significant difference between sides in the absolute horizontal movement. No statistically significant differences in vertical or endpoint displacement were observed between the dominant and non-dominant sides.

Endpoint displacements were distributed across all four quadrants of movement as demonstrated by the frequency distribution in Table 3 and the two-dimension kernel distribution in Figure 1. Horizontal displacement favored a radial direction, with the fewest nerves moving into the volar-ulnar quadrant. The percentage differences in nerve displacement direction were small between dominant and non-dominant hands, ranging from 3.1% to 7.7% and not statistically significant. There was no difference in the direction of vertical movement between sides, but nerves on the dominant side moved in a radial direction (124 (62.9%)) more frequently than did nerves on the non-dominant side (103 (52.3%), p=0.02). Of 197 subjects, 84 subjects had the same nerve displacement direction for both hands, and 113 had different directions between two sides.

The distribution of longitudinal sliding of the median nerves is shown in Table 4. Approximately half of the median nerves slid independently with regard to the surrounding tendons, whereas the other half slid equally with the surrounding tendons as one or did not slide longitudinally during composite finger movement. Of 197 subjects, 113 had the same sliding pattern for both hands, and 84 subjects had different sliding patterns of the median nerve in their hands. The percentage differences in nerve sliding between dominant and non-dominant side across three categories were small, ranging from 0% to 5.1%, and statistically not significant. In the non-dominant hand, the distribution of absolute vertical movement values for median nerves that slid together with surrounding tendons was larger when compared to the distribution of values for nerves that had no sliding or that slid independently from the surrounding tendons ($p<0.01$). In the dominant hand, the distribution of absolute horizontal movement values was smaller in those individuals when the nerve slid independently than when sliding together with the tendon ($p<0.01$). Although the distributions are statistically different, clinical relevance is unclear given the lack of significance in the opposing side and the generally small differences across median values and IQR (figure 2).

Discussion

This study demonstrated that most median nerves in our participants moved within the range of 1 mm vertically and 3 mm horizontally. Although there was no predominant direction of movement across the entire group of participants, within-participant examination found that the dominant side median nerve moved more frequently in a radial direction than did the nerves on the non-dominant side. Longitudinal sliding of the nerve in a proximal and distal direction occurred independently of the tendons in about half of the participants, while a quarter of the nerves were observed to move in unison with the flexor tendons of the fingers during composite finger movement. There is suggestive evidence that nerves which slide together with the surrounding tendons may have increased transverse displacement than other nerves.

Our findings indicate wide variability and no clear pattern of nerve movement during composite finger flexion in healthy individuals. This finding is in contrast to previous studies that have had more definitive statements and contradictory conclusions regarding nerve displacement. Yoshii et al.[6] found that the median nerve moved to the ulnar-volar side during a four-finger flex motion, while Van Doesburg et al.[14] concluded that nerves move in a radial-dorsal direction during an index finger movement. Each of these studies had only fifteen healthy participants, whereas the median nerves in our large cohort moved in all four directions (radial-dorsal, ulnar-dorsal, radial-palmar, ulnar-palmar), favoring radial and dorsal movement. Movement of individual fingers may have a different effect than composite flexion. In Van Doesburg's study,[14] index finger flexion led to radial movement while thumb flexion resulted in ulnar movement. As such, during gripping activities or composite flexion, differential actions of the flexor pollicis longus tendon to move the thumb could result in altered movements of the nerve.

Although our data suggested no predominant direction of nerve displacement, they do show endpoint displacement of the nerve of approximately 1.30 mm between rest and full flexion of the fingers. Similar studies of endpoint displacement during hand and finger movement in healthy participants reported higher average values than our study, ranging between 1.55 mm and 2.10 mmm.[6,9,13,16] As with the direction of nerve movement, the samples sizes in these previous studies were small (i.e., N < 29), which may have led to an overestimate of the amount of movement as compared to the findings in our larger sample. Despite being smaller than previous studies, the average endpoint displacement in our sample is still larger than the displacements reported for carpal tunnel syndrome patients in a previous study that associated reduced nerve movement in the transverse plane with a diagnosis of carpal tunnel syndrome.[9] It is remains unknown if decreased nerve movement in patients with carpal tunnel syndrome occurs first and leads to pathology, or if the pathological process causes fibrosis or adhesions of the nerve to the surrounding tissues thereby restricting movement.[11]

In this study, we found some difference in nerve movement by side. At the same time, we noted moderate within-subject association between sides (ICCs = 0.20 to 0.30) in our analyses. We currently have limited understanding of biological and physical exposure effects on lateralized differences in median nerve morphology, which creates complexity in research design and analysis for median nerve studies in both healthy and clinical populations. It remains unclear how much weight should be given to an assumption of symmetrical anthropometry or systemic biological contributions to lateralized tissues as opposed to accounting for independence of the structures in the hands and wrists due to heterogeneity in physical exposures.[17] Unfortunately, a noticeable amount of median nerve research either indiscriminately blends information from the two sides or does not account for potential within-subject dependency, which could possibly lead to unreliable variances and erroneous conclusions.

While our pairwise analysis has accounted for these within-subject associations, our work has some limitations. First, because we recruited a healthy, young adult population the findings might be very different from individuals with comorbidities (e.g., diabetes), history of physical work exposures, or other median nerve diagnoses, particularly carpal tunnel syndrome. Furthermore, given that the average age in this study’s sample was approximately 24 years old, these data may not be able to serve as reference values for clinical studies of individuals who are older. However, because the data were obtained in a young, healthy population, they provide a foundational understanding of the degree of nerve mobility that would be expected prior to the onset of ageing or pathologic processes. Additionally, we examined composite finger flexion and did not evaluate nerve changes with the application of additional resistive force that would commonly occur during functional gripping. Future studies are needed to describe nerve movement when such resistances are applied.

In addition to limitations in scope, there are several possible sources of measurement errors in our study. First, we were limited to the best resolution possible given a 12 MHz transducer, which has poor sensitivity for measuring differences of less than 0.1 mm. Second, we did not stabilize the participant’s wrist, nor did we use a mounting device to ensure the transducer was held stationary with minimal pressure during composite finger movement. To reduce measurement error as much as possible, efforts were made by the sonographer to maintain minimal contact pressure and only store videos when noting that both the participant and transducer remained stable. All videos were closely evaluated for stability prior to any measurements. Finally, we analyzed endpoint displacement using only two still frames, which does not capture the total amount of nerve movement and likely underestimates the furthest distance of displacement due to the assumption of direct linear movement rather than the typical curve-shaped displacement pattern.[18]

Further research is needed to determine if endpoint displacement, total movement, or more complex analyses to capture the entire path of movement may be useful for differentiating high-risk populations, early detection of pathologic progression, or as a diagnostic measure in clinical care. Such research might consider more robust automated analysis techniques such as pixel tracking algorithms. In addition, further investigation is needed to determine if the amount or direction of nerve movement during functional hand use may be a predisposing or contributing factor in the development of pathologies. If so, ultrasound imaging could be used to differentiate high-risk populations to target preventive interventions. Alternatively, longitudinal studies may be useful to determine if and how movements of the median nerve become altered due to pathophysiologic processes associated with nerve pathology. Knowledge of these pathophysiologic indicators could enable the use of ultrasound as a tool for early detection, diagnosis, or precision approaches to preventive or other clinical interventions.

This study indicates that, in young healthy individuals, there is no clear pattern of transverse displacement of the median nerve during composite flexion of the fingers, but that median nerves on the dominant side tend to move in a radial direction more-so than nerves on the non-dominant side. Similar variability exists within a healthy population relative to the amount of longitudinal nerve sliding. These data provide a foundation for future research interested in understanding the biomechanical contribution of nerve movement to median nerve pathologies.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Abbreviations

ICCs	intraclass correlation coefficients
SD	standard deviation
IQR	interquartile range

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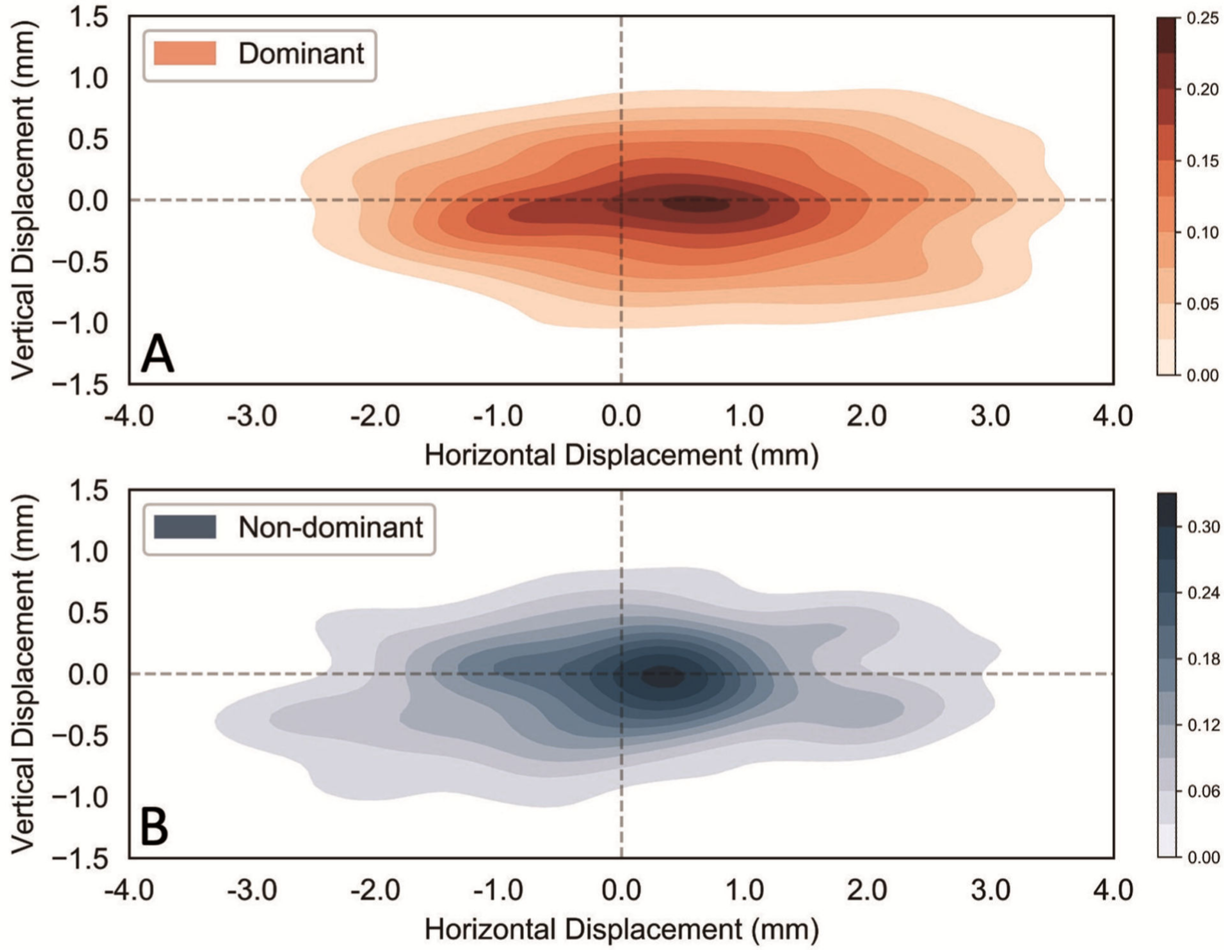

Figure 1.

Two-dimension kernel density plots demonstrating distribution of endpoint displacement of the median nerves from rest to composite finger flexion for dominant (A) and non-dominant (B) hands. The (0,0) coordinate represents the location of the nerve at rest, and the colors represent the location of the nerve during composite finger movement based on the distribution across the two planes of motion and color intensity representing the density of individuals within a region across the sample (i.e., percentage). The direction and distance of nerve movement were fairly normally distributed around the group mode in the dominant side, whereas nerves on the non-dominant side had increased variability with an increased tendency for nerves to move in an ulnar direction.

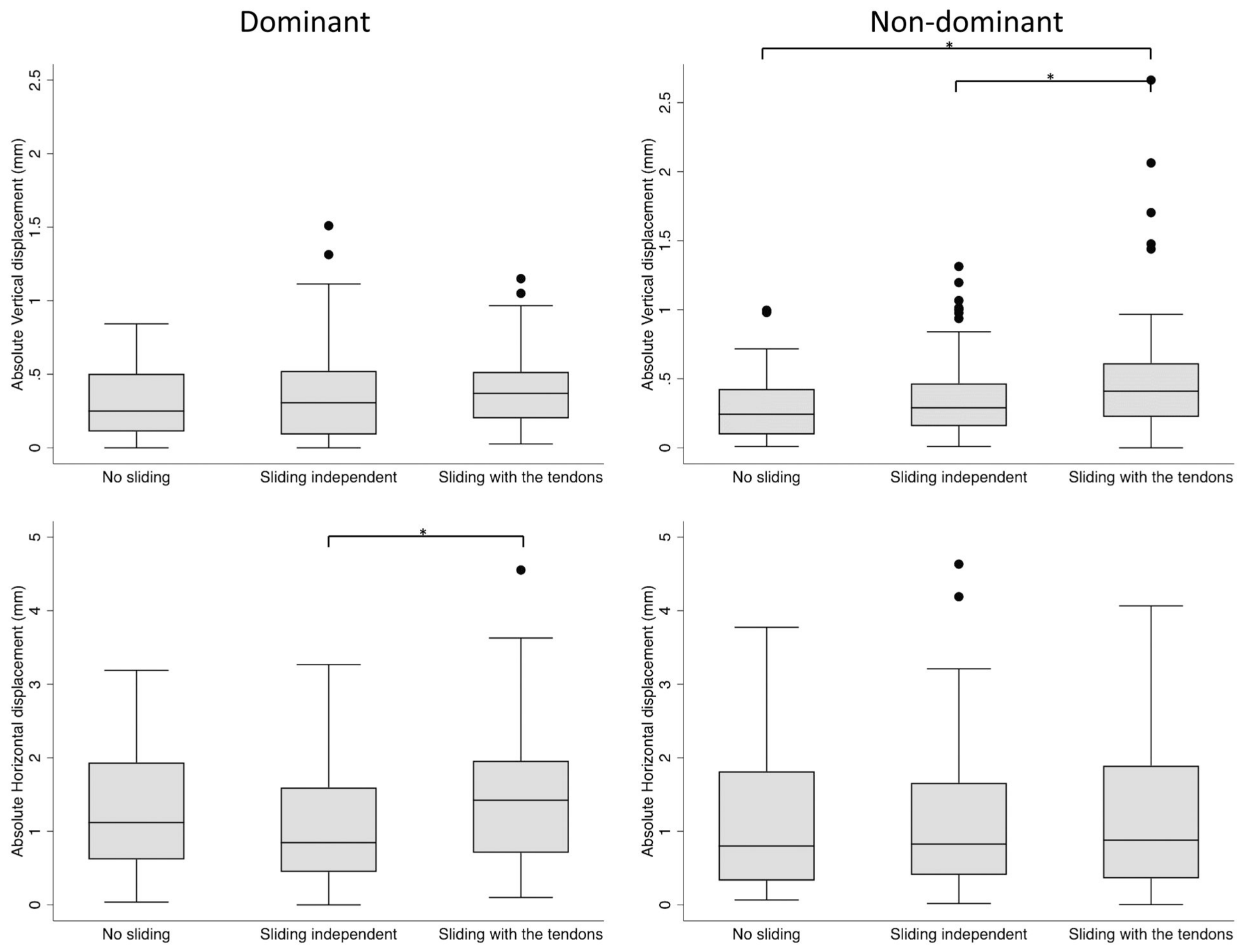

Figure 2.

The absolute vertical and horizontal displacement for median nerves with no sliding, sliding independently from the tendons, and sliding with the tendons. The median is represented by the line subdividing the box, and the length of the box thus represents the interquartile range (IQR). *Post-hoc pairwise comparisons with p-value < 0.01.

Table 1.

Demographic data across participants enrolled in the study (n=197)

	Mean (SD) / Frequency (%)
Age, years	24.6 (3.1)
Gender, male	27 (13.7)
Race	
American Indian/Alaska Native	2 (1.0)
Asian	84 (42.6)
Native Hawaiian or other Pacific Islander	1 (0.5)
Black	3 (1.5)
White	84 (42.6)
Other	23 (11.7)
Ethnicity, Hispanic	37 (18.8)
Handedness, right-handed	181 (91.9)

Table 2.

Comparison of transverse displacement of median nerve during composite finger movement between the dominant and non-dominant hands (n=197).

	Dominant hand	Non-dominant hand	*p*
Vertical absolute movement *	0.31 (0.38), [0–1.51]	0.30 (0.35), [0, 2.66]	0.58
Vertical displacement †	0.07 (0.45), [−0.84–1.51]	0.09 (0.52), [−2.06–2.66]	0.63
Horizontal absolute movement *	1.02 (1.19), [0–4.55]	0.83 (1.38), [0–4.63]	0.48
Horizontal displacement †	0.46 (1.44), [−4.55–3.63]	−0.04 (1.47), [−4.63, 4.19]	< 0.001
Endpoint displacement †	1.34 (0.83), [0.11–4.56]	1.27 (0.90), [0.07–4.82]	0.43

*Values are reported as median (IQR), [min-max]

†Values are reported as mean (SD), [min-max]

Table 3.

Frequency (percentage) of each direction of endpoint displacement of the median nerve during composite finger movement.

	Dominant*	Non-dominant*	Total
Dorsal-Radial	66 (33.5)	53 (26.9)	119 (30.2)
Dorsal-Ulnar	44 (22.3)	59 (30.0)	103 (26.1)
Volar-Ulnar	29 (14.7)	35 (17.8)	64 (16.2)
Volar-Radial	58 (29.4)	50 (25.4)	108 (27.4)

*Chi-square test was not significant for any differences between dominant and non-dominant (p = .19)

Table 4.

Comparison of longitudinal sliding of median nerve between dominant and non-dominant hands.

	Dominant (n=197)*	Non-dominant (n=197)*
Sliding with the tendons	37 (18.8%)	47 (23.9%)
Sliding independently	107 (54.3%)	97 (49.2%)
No sliding	53 (26.9%)	53 (26.9%)

*In a non-linear mixed effect model, the fixed effect of hand dominance was not statistically significant (p = .38).