SCIENTIFIC ARTICLE

Evaluation of Load Distributions and Contact Areas in 4 Common Grip Types Used in Daily Living Activities

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Purpose Grip analysis systems, with sensors quantifying load distributions and contact areas applied by the hand while grasping objects, are useful for collecting and recording instant data; these systems are popular in hand assessment. The purpose of this study was to determine the load distribution (LD) and contact area (CA) size of the palmar surface of the hand during 4 common grip types used in activities of daily living (standard, lateral, pinch, and tripod grips).

Methods A convenience sample of 80 right-handed subjects were enrolled in this study. Participants wore special gloves equipped with sensors and grasped a variety of objects. Contact area size and LD were determined for the 4 grip types.

Results The CA and the LD were different for each grip. For standard grip, although the largest CA occurred at the metacarpophalangeal joint level, the largest LD was over the middle finger pulp. For standard grip, index, middle, and ring fingers appear to be loaded with almost the same frequency as the thumb. Although CA on the thumb was maximum in the pinch, lateral and tripod grip types, the LD on the thumb was not.

Conclusions This study shows that the LD and CA patterns differ widely among standard, pinch, lateral, and tripod grips. The percentage of CA occurring on the thumb was maximum in all grip types.

Clinical relevance This information is important to optimize the design of artificial manipulators or assistive devices and to optimize the hand rehabilitation process. In addition, results of the study can be used to guide the design of prostheses and biomedical implants better. *(J Hand Surg Am. 2019;■(■):1.e1-e8. Copyright © 2019 by the American Society for Surgery of the Hand. All rights reserved.)*

Key words Contact area, grasping analysis, load distribution.

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The ability of the human hand to grasp and manipulate objects is unique.[1] Our fingers' capacity for adapting to various object textures, shapes, and sizes is the basis of this ability. Fingers have developed certain adaptations such as creating a larger contact area (CA) for objects of different shape, size, and surface type. Because the skin and tissues of the hand form a structure capable of a wide range of movement, the force applied while grasping an object may be spread over a large CA, resulting in an extremely effective grip. This allows for differences in grip force and CA values in accordance with the physical features of an object. While all these adjustments are taking place, grip function proceeds smoothly.[2]

The load distribution (LD) at the different regions of the hand and the CA between the gripped object and the hand during grasping provide the basis for understanding the normal functioning of the hand during grip. Moreover, this determines the frequency of use of different areas of the hand and may allow for inferences about impairment.[3] The CA between the hand and the object varies according to the grip type and the activity performed. This factor is also considered in the design phase of robotics and electronic prosthetics.[4]

A number of studies concerning the classification of grips exist in the literature. They are based on the relation of grip to the shape of an object, the hand, or the hand's surface. Among these studies, the grip classification described by Kamakura et al[5] has drawn the most interest. They selected objects commonly used in daily life and identified 14 grip patterns in 4 categories. Different grip types have been identified by examining the CAs of the hand being used during varying grip patterns.[6–9]

More recent studies focused more on evaluating LD and CA created during grip instead of the evaluation of grip type.[10–12] With the development of grip mapping systems, researchers have started to use these measurement methods to identify the CA and grip force that occur during grip activity.[13,14]

The CAs in different parts of the hand have been shown and reported in the different grip types in the literature. However, the applied LDs on these CAs is not known for the different grip types. Therefore, the aim of this study was to determine CA and the LD in the 4 common grip types used in daily living activities.

MATERIALS AND METHODS

Subjects and testing sequence

A convenience sample of 80 healthy subjects (37 male and 43 female), mean age 28.7 ± 9.58 years (range, 18–61 years; median, 26.0 years) participated in the study, which was approved by the Human Studies Ethics Committee at the Hacettepe University where the study was conducted.

The sample consisted of students enrolled in the university, their acquaintances, and relatives of patients visiting the occupational therapy department. Inclusion criteria were right-handedness and age between 18 and 65 years. Participants with disorders or previous injuries of the upper extremities or an orthopedic or neurological problem that might affect the functional use pattern of the upper extremities were excluded from the study.

Participants grasped the study objects while wearing a special glove containing sensor areas belonging to the Grip system (Tekscan, Inc, South Boston, MA).[15] The researcher checked full contact of all sensors with the grasped object before each grip activity. Three trials were performed for each grip type and average scores were recorded. The sensors were calibrated before each participant measurement.

Technical setting

With the Grip system, information regarding CA (in square centimeters) and LD (in grams) effected during different grip patterns can be recorded in a reliable and valid manner by manipulating an object on which tactile sensors are added.[16,17] The many separate sensors of the Grip system enable it to record data continuously for contact and force parameters occurring in each phalanx and in different areas of the palm while grasping objects.[16,18] The system consists of 17 sensing regions composed of 349 sensing units, which are connected with a force-sensitive material and a flexible circular plate.[19,20] These sensing regions are located on the anatomic zones of the fingers and palm (Fig. 1). Gaps between the sensing areas allow the joints to move freely and thus do not interfere with grip measurement. Each sensing region has multiple sensing units that enable regional identification of the pressure points in the fingers and palm. Each region density is 6.2 sensing units/cm^2 and the pitch is 4.013 mm.[21] The pitch is the distance between 2 columns or rows in the sensing unit. There are 2 sensing regions in the thumb, 3 in each finger, corresponding to the distal, middle, and proximal phalanges, and 3 in the palm (metacarpophalangeal, thenar, and hypothenar regions). These 17 sensing regions were placed on the glove's volar surfaces corresponding to the palm and fingers, using the joints as reference (Fig. 1).[22]

The Grip system has a soft sensor with a high-resolution tab covering the glove, an edge connector used to connect with the sensor, a 2-port hub, a PC, and system-specific software. Each sensor is sampled. The software allows the researcher to view the collected sensor LD data in real time and record the data across time (Fig. 2).

Calibration

Proper calibration of the sensors is critical to obtain accurate force readings with the system. During

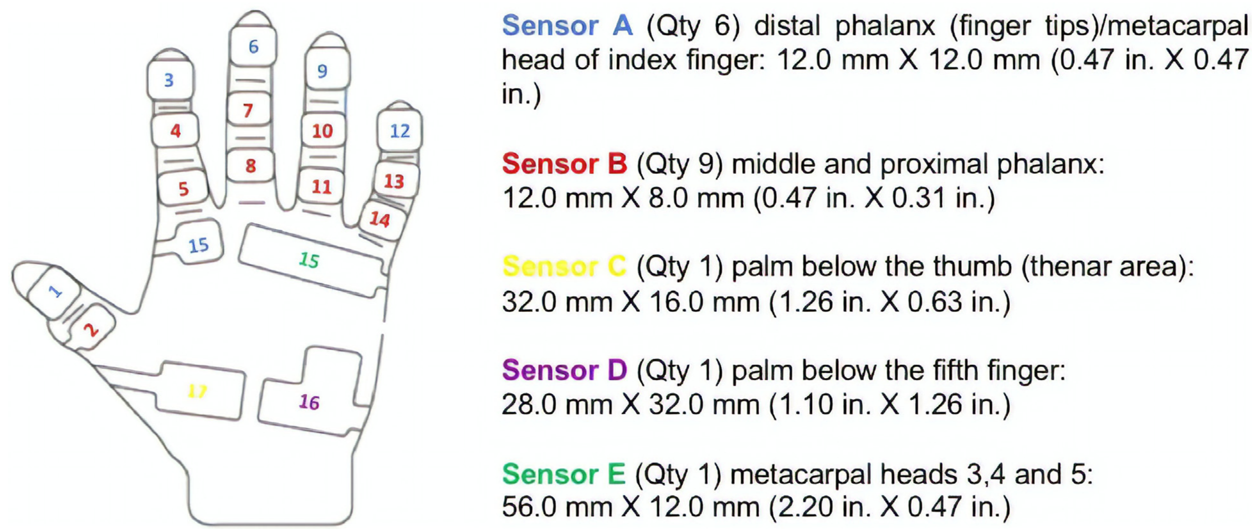

FIGURE 1: Numbers and properties of sensors.[16] Qty, quantity. Adapted with permission from Tekscan Co.

calibration, the raw digital output of the sensor is converted into actual force units such as pounds per square inch or millimeters of mercury. The calibration procedure, in which a known weight of 50 g is placed on the sensors, was conducted before each new participant measurement. Each sensor was individually calibrated to a maximum pressure of 600 kPa with a measurement accuracy of less than 5%.[23] Before each calibration, a method proposed by the tactile sensing device manufacturer was applied to the device to reduce variation between individual sensing elements. This type of equilibration is a method of normalizing the sensor and system so that the output of every sensing element is the same when a uniform pressure is applied.

Grip patterns

Based on the grip classification and sample objects (a glass bottle, screw, key, and metal object) defined by Kamakura et al,[5] we analyzed the 4 grip types commonly used in daily activities: standard grip, pinch grip, lateral grip, and tripod grip.[1,24]

Objects were placed on a standard desk for the assessments. Participants were informed about the study procedure before measurements; they removed clothing that might have inhibited grip activities. Several times before data recording, participants were asked to repeat the different grip activities while wearing the glove, to become acclimated to the equipment. Each grip type measurement was repeated 3 times; the average of these values was calculated. The entire evaluation lasted 20 to 30 minutes for each participant. Only the right hand of each participant was evaluated.

The measurement process was as follows. Each grip type was assessed in the order: standard, pinch, lateral, tripod. For standard grip, grasping was recorded while the participant lifted a completely full glass water bottle (500 mL), held it for 5 seconds, and returned to its original place on the desk. For pinch grip, grasping was recorded while the participant picked up a screw from the desk, held it for 5 seconds, and returned it to its original place on the desk. For lateral grip, grasping was measured while the participant picked up a key lying on the desk, held it for 5 seconds, and returned it to its original place on the desk. For tripod grip, grasping was recorded while the participant lifted a metal object weighing 750 g from the desk, held it for 5 seconds, and returned it to its original place on the desk. Physical properties of objects were: water-filled glass water bottle (242 × 72 × 72 mm, 500 mL, 900 g), screw (5 × 40 mm), metal object (28 × 42 × 63 mm, 250 g), and key (76 × 58 × 8 mm, 14 g).

Data analysis

Data were investigated to explore differences in CAs and LDs in the different regions of the hand and over different surfaces among the 4 different grip types. Average CA and LD of the 3 trials were calculated for each grip type. The percentage of CA and LD in a finger was calculated by multiplying the sum of the values of the sensors on the respective fingers by the total value of all sensors, divided by 100. Descriptive analyses are represented as means and SDs (Fig. 3).

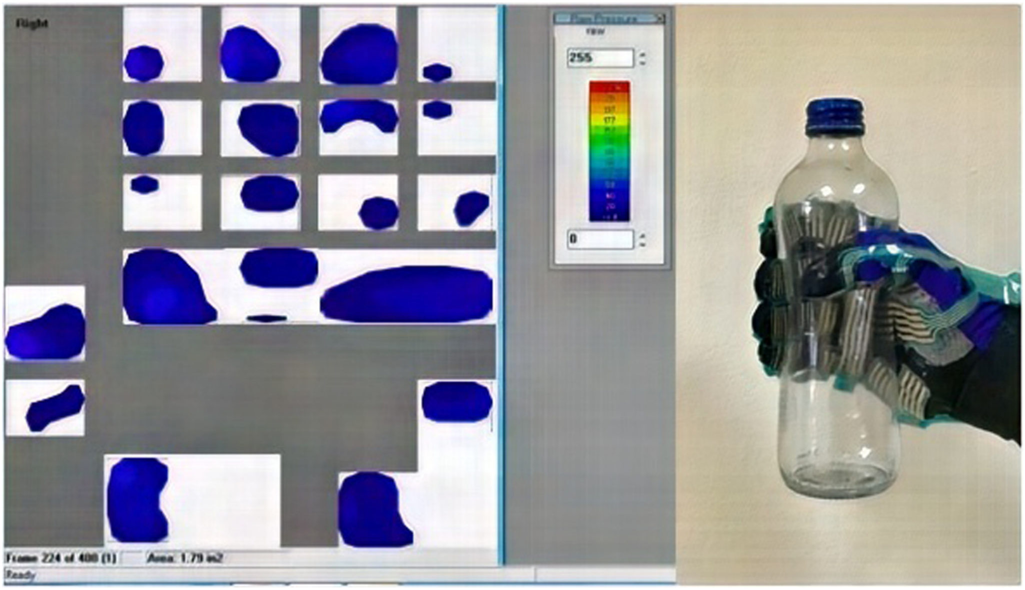

FIGURE 2: Real-time recording of LD and CA data during grasping.

RESULTS

Figure 3 shows the mean CA and LD recorded in each finger during the 4 different grip patterns.

Load distribution and CA by sensors

During standard grip, mean CA was maximum at sensor 15 whereas mean LD was maximum at sensor 6. For pinch grip, mean CA was maximum at sensor 1 whereas LD was maximum at sensor 3. Mean CA and LD during lateral grip were maximum at sensor 1. Mean CA during tripod grip was maximum at sensor 1 whereas mean LD was maximum at sensor 6 (Fig. 3).

Percentages of LD and CA by fingers

Figure 4 displays the variations in frequencies of CA and LD in different grip patterns. The thumb was the most contacted digit. For the LD of the pinch and lateral grip, the index finger was the most maximally loaded. For the standard grip, the index, middle, and ring fingers were loaded with almost the same frequency as the thumb. The palm and little finger were less loaded.

Comparison of CA and LD for index finger and thumb

The CA percentage of the thumb was highest for all grip patterns, whereas the LD percentage of the index finger was maximum for pinch, lateral, and tripod grip patterns. In standard grip, the percentage of LD was almost same for the thumb and index fingers (Fig. 5).

DISCUSSION

We performed grip analyses during a variety of grip types commonly used in daily life (standard, pinch, lateral, and tripod) using the Grip system. This study showed that the LD and CA patterns differed widely among standard, pinch, lateral, and tripod grip patterns. The percentage of CA occurring in the thumb was highest in all grip types. The percentage of LD occurring in the index finger was highest in pinch, lateral, and tripod grip types. For standard grip, the maximum LD occurred at the middle finger.

When objects are grasped, the CA between the hand and the object varies according to grip type, the shape, size, and weight of the object, the structure of the contact surface, and personal factors.[5,25] Therefore, the fingers have a different role in various grip types. We also observed that CA varies according to the physical characteristics of the object being grasped. Contact occurs in all sensors during standard grip, yet the sizes of CA differ. Consistent with the findings of Kamakura et al,[5] our results demonstrated that maximum CA was created by the volar surface of the metacarpophalangeal joint and thumb during standard grip. This clearly indicates the role of the palm for power grip.[26] The literature[1,5] states that the most important characteristic that separates standard grip from other types of grip is the volar contact; the current study supports this. The middle finger had the highest LD in standard grip followed by the thumb and index finger, and little finger had the least. This may result from the mechanical advantage of the

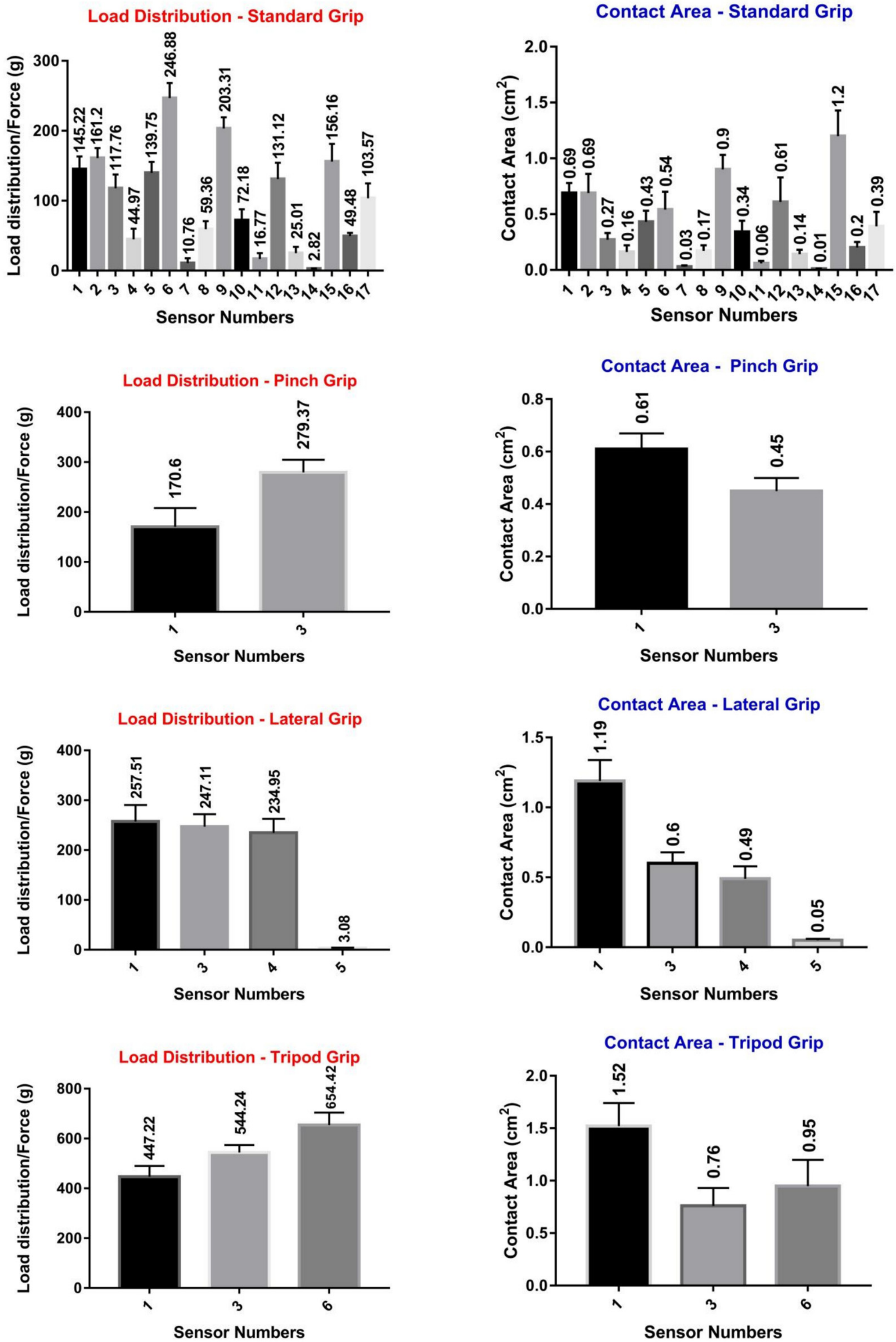

FIGURE 3: Contact area sizes and amount of LD in sensors.

middle finger, whereas the index, ring, and little fingers are shorter than the middle finger and thus generate less power.[26]

The significance of the index finger during pinch and power grips was demonstrated in a number of studies.[27,28] Murray et al[29] demonstrated a nearly 20% decrease in pinch grip, power grip, and supination force after loss of the index finger. For standard and tripod grip types, LD in the middle finger was greater than in the index finger. Park[26] also

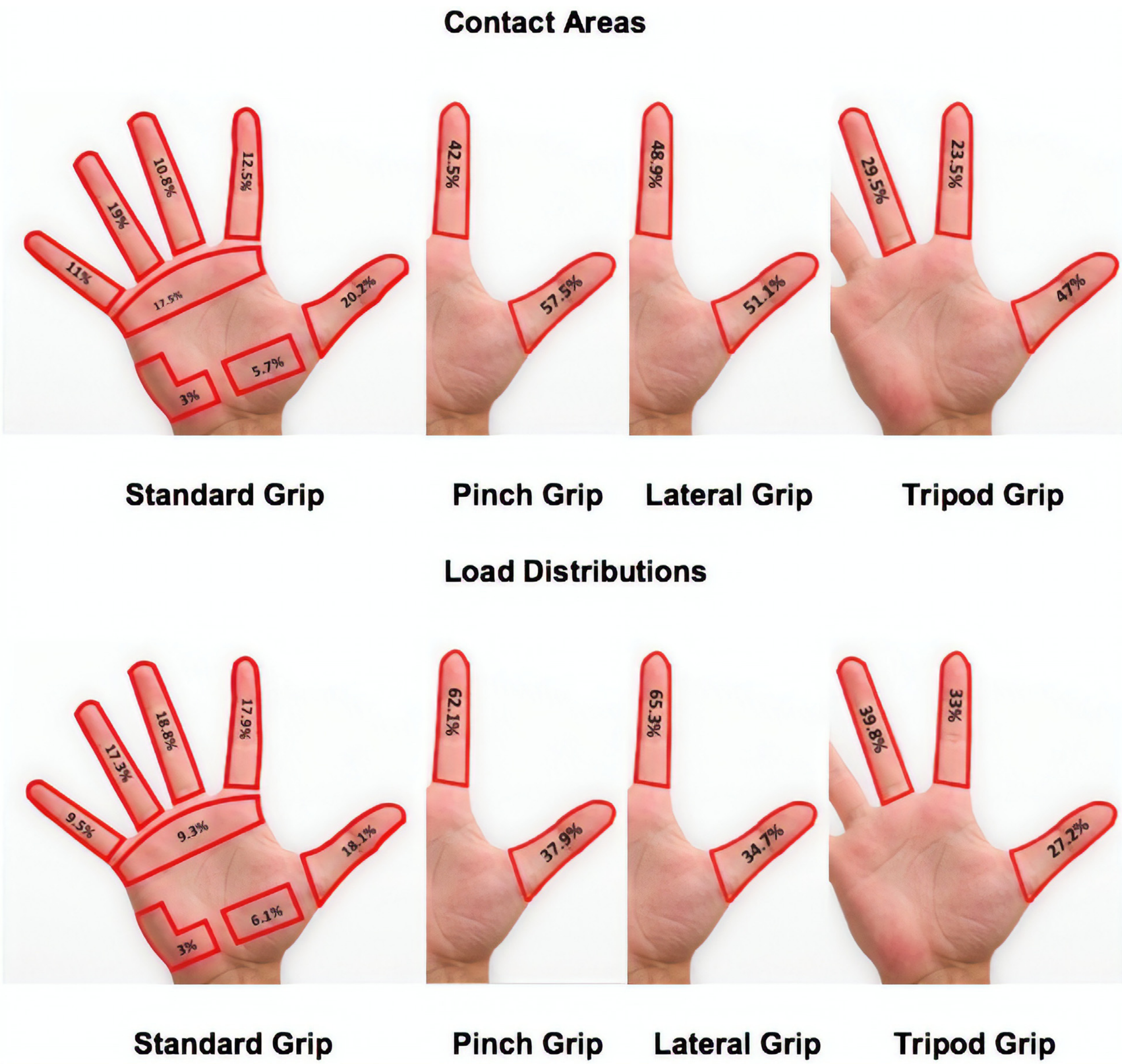

FIGURE 4: Comparing different grip types for the CA and LD of the hand by different anatomic areas.

showed that forces produced by the middle finger were always larger than other in phalanges.

In this study, we evaluated LD and CA using the Grip system. A review of the literature showed that there were few studies in which grip force and CA were evaluated together. The study of Kamakura et al[5] is accepted as the standard for measuring CAs. The ink technique used by Kamakura et al is not practical for application in the clinical setting and does not allow evaluation of temporal changes in LDs and CAs that are currently possible with modern technology. Using the Grip system, LD and CA can be analyzed dynamically and simultaneously, and the values can be recorded. Moreover, in the study of Kamakura et al, it was not possible to observe the continuously changing LD and CA at different time points, whereas the method employed in the current study enabled these values to be plotted against time and monitored visually. In addition to examining the numerical values of grip function parameters such as force, this study presents a different perspective on grip analysis by examining areas in which these values are intensified.

In the study, sensors were fixed on a glove; because the sensors have a sensitive physical structure, it was not possible to fix the sensors on the hand. Several studies in the literature showed the reliability of these sensors, and reports similar to ours also employed the method of fixing the sensors on a glove.[18,22] It was shown that digital anesthesia results in a significant increase in grip force or LD, and that loss of sensation (as in anesthesia) disrupts

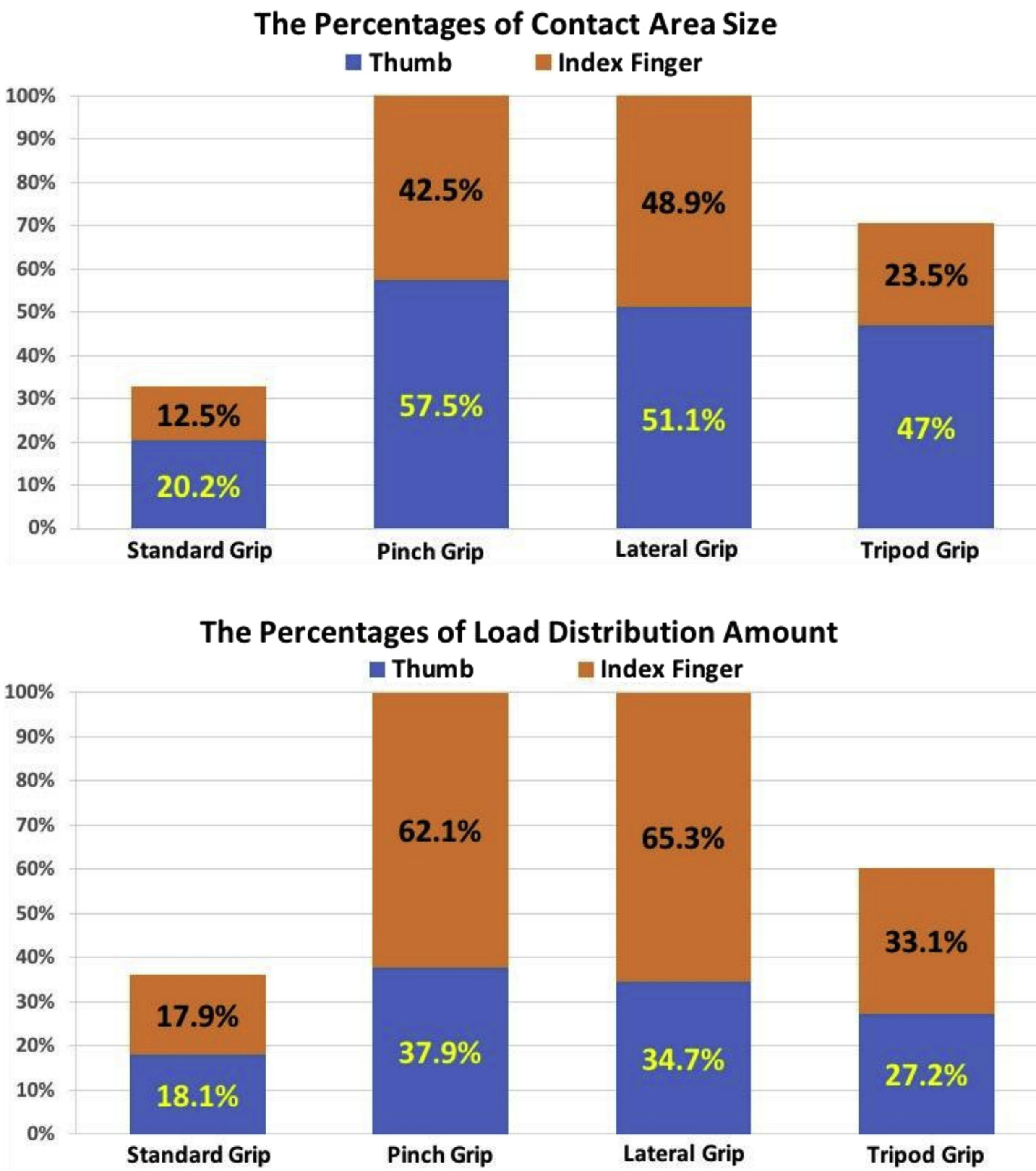

FIGURE 5: Percentages of CA and LD.

coordination between grip and manipulation forces.[30] Using a glove during grip analysis also decreases sensory input. Thus, in light of information provided in the literature, we think that the forces that participants created during gripping in the current study might be greater than normal.[31]

Future studies could focus on analyzing CA and LD occurring during different phases of grip such as reaching, loading, lifting, transition, replacing, and slipping. Although manipulation normally consists of all of these steps, in this study we analyzed only the grasping phase and ignored the other steps of the manipulation.

Sex-based analysis was not the primary aim of our study. However, we believe that the accumulated data will create a basis for future studies. Furthermore, the force applied to the object from each sensor is discussed without discriminating between grip force and manipulation force. Although these points can be considered limitations of the study, we believe that differentiating between grip and manipulation forces is not necessary from a functional point of view.

As another limitation, it is possible that the size of the hand may affect the results. However, the researcher checked full contact of all sensors with the grasped material and the anatomical location of sensors before each grip activity. In addition, all results are given as percentages and ratios.

The process of deciding on a functional object that would be able to be employed during tripod grip was difficult. In daily life, the tripod grip is commonly used during functional activities such as writing. However, considering the distribution of sensors on the Grip system glove, holding a pencil in tripod grip analysis was not preferred because of the lack of sensors on the lateral surfaces of the fingers; therefore, we decided on a large object that would require grasping by the volar surfaces of the fingers.

This study documents differences in LD and CA that occur during various grips. This information is important to optimize the design of artificial manipulators or assistive devices and to optimize the hand rehabilitation process. In addition, results of the study can be used to guide the design of prostheses and biomedical implants better.

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